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

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June 26, 2017

Prepared by
Consolidated Nuclear Security, LLC
Management & Operating Contractor
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APPROVALS

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ABBREVIATIONS

ALARA	as low as reasonably achievable
AM	as-manufactured
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
ASTM	American Society for Testing and Materials
AWS	American Welding Society
CAS	Chemical Abstract Service
Cat 277-4	Thermo Electron Corporation (corporate name changed to Shieldwerx) Catalog No. 277-4™ (or Cat. No. 277-4)
CFR	Code of Federal Regulations
CG	center of gravity
CMTR	certified material test report
CNS	Consolidated Nuclear Security, LLC
CoC	Certificate of Compliance
CSAS	Criticality Safety Analysis Sequence
CSI	criticality safety index
CV	containment vessel
CVA	containment vessel arrangement
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPDM	ethylene propylene diene monomer
ESL	Evaluated Suppliers List
ETP	explicit triangular pack
FEA	finite element analysis
FEP	fluorinated ethylene propylene
GMAW	gas metal arc welding
GTAW	gas tungsten arc welding
HAC	Hypothetical Accident Conditions
HEU	highly enriched uranium
HP	Hewlett Packard
H/X ratio	hydrogen-to-fissile isotope ratio
IAEA	International Atomic Energy Agency
IEU	intermediate enriched uranium
k_{eff}	calculated neutron multiplication factor
LANL	Los Alamos National Laboratory
LEU	low enriched uranium
LOD	loss on drying
LTL	lower tolerance limit
MIT	Massachusetts Institute of Technology
MNOP	maximum normal operating pressure
MOCFR	moisture fraction inside the containment vessel
MOIFR	moisture fraction of the package external to the containment vessel
M.S.	margin of safety
M&TE	measuring and test equipment
NCR	nonconformance report
NCT	Normal Conditions of Transport
NITS	not important to safety
NLF	neutron leakage fraction
NNSA	National Nuclear Security Administration

NRC	U.S. Nuclear Regulatory Commission
NTRC	National Transportation Research Center
OECD	Organization for Economic Cooperation and Development
O	Order
ORNL	Oak Ridge National Laboratory
PBR	pebble bed reactor
PGNAA	prompt gamma-ray neutron activation analysis
ppb	parts per billion
ppm	parts per million
PTE	Packaging and Transportation Engineering
QP&A	Quality Performance & Analysis
QA	quality assurance
QAPP	quality assurance program plan
RCSB	Rackable Can Storage Box
RFID	radio-frequency identification
RFWD	request for waiver or deviation
SAE	Y-12 Safety Analysis Engineering
SARP	safety analysis report for packaging
SCALE	Standardized Computer Analysis for Licensing Evaluation
S/CI	suspect/counterfeit item
SGT	Safeguards Transporter
SNAP	Systems for Nuclear Auxiliary Power
SO	skull oxide
SQA	software quality assurance
SRNL	Savannah River National Laboratory
SS304	Type 304 stainless steel
SSCs	structures, systems, and components
TGA	thermogravimetric analysis
TI	transport index
TID	tamper-indicating device
TRISO	tristructural isotopic
TS	test sample
TSD	Transportation Safety Document
TU	test unit
UNH	uranyl nitrate hexahydrate
UNX	uranyl nitrate crystals
USL	upper subcritical limit
VCO	vacuum coupling O-ring
VF	volume fraction
Y-12	Y-12 National Security Complex

REVISION LOG

Date	Revision No.	Description	Affected Pages
9/25/09	A	Draft for DOE EM review. All revisions to the previous ES-3100 SAR approved by the NRC (Y/LF-717/R3) are shown in red text. Since the revisions to Appendix 3.5.4 and Sects. 7 and 9 were extensive, these sections are shown in black text. Appendices 5.5.2 and 6.9.8 are new, but they are shown in black text.	All
8/12/10	0	Incorporated responses to comments received from DOE EM, Packaging Certification Program SARP Review Team.	All
11/10/10	0 Page Change 1	Incorporated minor revisions to make SARP consistent with Rev. 2 of the CoC.	Cover, title page, iii, v, xxiii, 1-2, 1-12, 1-14, 1-16, 1-17, 1-22, 2-1, 3-37, 6-598, 7-13
2/10/11	0 Page Change 2	• Clarified description of U-Zr oxide in "HEU oxide" category (designated as UO_2-ZrO_2 throughout the SARP) • Added a physical form of oxide under "HEU Oxide" in Sect. 1.2.2 for pellets • In Table 1.3, – Modified "CSI" and "277-4 can spacer" entries for U-Zr in "Research reactor fuel elements and components" category – Added a new content group called "Oxides of U-Zr" under the "Research reactor fuel elements and components" category • Changed the maximum enrichment of TRIGA fuel to ≤70% • Revised CSI entries for air transport in Table 1.3b • Clarified appropriate DOE marking on the drum in Sect. 7.1.2.2 • Editorial corrections as necessary	Cover, title page, iii, v, xxiii, 1-10 through 1-12, 1-15 through 1-17, 2-1, 2-2, 4-3, 6-4, 6-30, 6-33, 6-35, 6-598, 7-11

Date	Revision No.	Description	Affected Pages
6/21/12	0 Page Change 3	• Change the U-233 concentration limit in oxide contents to 0.006 g/gU from 200 ppm • Add bulk HEU oxide as an authorized content for air transport • Add uranium silicide as an authorized content for ground transport • Add Viton GLT-S as an optional O-ring material in addition to EPDM and extend the basis for periodic maintenance from 1 to 2 years for packagings with Viton GLT-S O-rings and temperature monitoring • Revise the spacer can drawing (Drawing M2E801580A043) to make the "vibration absorbing silicone can pad" optional • Increase the amount of U-235 in U-Al reactor fuel • Make allowance for convenience cans with diameters >4.25 in. along with a void volume limit for gas expansion and offgassing materials in the CV • Remove the requirement to place empty convenience cans on top of the loaded cans • Revise the wording regarding convenience can use to allow for contents that cannot fit into a convenience can to be bagged only (no convenience can) • Add the option of applying an RFID system to the ES-3100 • Editorial corrections as necessary	All
1/10/13	0 Page Change 4	Incorporate responses to Q1 comments.	Cover, title page, v, viii, ix, xvii, xxi, xxii, xxiv, 1-11, 1-12, 1-18, 1-19, 1-20, 1-24, 2-39, 2-39a, 2-41, 2-43, 2-44a, 2-56, 2-107, 2-109, 2-110, 3-6, 3-24, 3-54a, 3-54b, 3-80, 3-81, 3-82, 4-7, 4-9, 4-33 through 4-42, 6-30, 6-35, 6-36, 6-598, 6-611 through 6-614, 6-616, 6-629 through 6-633, 7-1, 7-16, 7-26, 7-43, 8-1, 8-31, 9-1, 9-19, 9-20
9/30/13	0 Page Change 5	• Incorporate responses to Q1 comments for shipping HEU metal and alloy turnings, fines, or powder • Clarified the "HEU Metal and Alloy" and "HEU Oxide" shipping configurations including the use of aluminum convenience cans and Teflon bottles • Editorial corrections as necessary	Cover, title page, v, x, xi, xiv, xv, xix, xxiv, 1-2, 1-10, 1-18 through 1-22, 1-24, 1-227, 2-1, 2-5, 2-13, 2-24, 2-25, 2-41, 3-16, 6-1 through 6-688, 7-6
2/27/14	0 Page Change 6	Incorporate responses to Q1 comments for Phase III review documented in RP-801940-0011 with additional editorial changes.	Cover, title page, v, xxiv, 1-10, 1-20, 1-22, 2-28, 2-39a, 2-40, 2-109, 4-6, 4-42, 7-20, 8-9, 9-20

Date	Revision No.	Description	Affected Pages
6/30/15	0 Page Change 7	• Incorporated changes to address the Consolidated Nuclear Security, LLC, (CNS) organization/position titles and procedural requirements • Updated references to the current Quality Assurance Program Plan (QAP-Y-91-273860-1, Rev. 15) • Removed provisions in the SARP that supported the extended periodic maintenance interval for the package including the temperature labels requirements • Updated references to reflect current regulatory and DOE directive requirements	Cover, ii, title page, v, vii, ix, xi, xii, xv, xix, xxi, xxii, xxiv through xxviii, 1-1, 1-6, 1-19, 1-27, 1-29, 1-31, 1-33, 1-125, 1-149, 1-167, 1-213 through 1-232, 2-9, 2-10, 2-31 through 2-33, 2-40, 2-41, 2-105, 2-106, 3-79, 4-41, 5-39, 6-173, 6-193, 6-616, 6-685, 7-2, 7-4, 7-7 through 7-12, 7-14, 7-15, 7-17 through 7-36, 8-4, 8-5, 8-9 through 8-12, 8-19 through 8-29, 8-31, 9-1 through 9-22
9/3/15	1	• Incorporated Page Changes 1–7 and minor editorial changes • Added provisions in the SARP to address the requirements for samples and small quantities (≤ 50 g) of HEU metal or alloy turnings, fines, or powder • Added App. 6.9.10 as the basis for the HEU oxide carbon limit requirements and revised appropriate footnotes in Tables 1.3 and 6.9.8.2	All
9/8/16	2	• Incorporated minor editorial changes • Removed the fluorocarbon elastomer (Viton) O-rings from the SARP • Added provisions in the SARP that supported the extended periodic maintenance interval from one to two years for the EPDM O-rings • Revised the bulk density range for uranium oxide from 2.0–6.54 g/cm^3 to 0.5–6.54 g/cm^3 for ground transport. • Removed the carbon limit for uranium oxide. • Evaluated HEU metal or alloy turnings fines or powder for ground transport at enrichments >80% • Added a uranium oxide loading of 12.323 kg ^{235}U with a CSI of 0.4 • Added a uranium tetrafluoride (UF_4) loading of 24.0 kg UF_4 (18.136 kg ^{235}U) with a CSI of 2.0 • Removed the HEU broken metal or alloy cladding restrictions for ground and air transport • Removed the cladding restrictions for research reactor fuel elements and components, which were bounded by HEU bulk oxide • Updated the shielding evaluation presented in Chap. 5 using the MCNP Monte Carlo radiation transport code to perform the photon and neutron transport and dose rate calculations • Added Apps. 6.9.9 and 6.9.11 as the basis for the revised criticality safety evaluations	All

Date	Revision No.	Description	Affected Pages
6/26/17	2 Page Change 1	• Updated the Revision Log for Rev. 2 to clarify that the UF_4 was evaluated with a CSI of 2.0 • Revised Sects. 6.2.4 and 6.7.4 to be consistent with the analyses in App. 6.9.11.	Cover, title page, v, xxv, xxvi, 6-43, 6-118

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1. GENERAL INFORMATION

1.1 INTRODUCTION

This safety analysis report for packaging (SARP) presents the results of the safety analysis prepared in support of the Consolidated Nuclear Security, LLC (CNS) request for licensing of the Model ES-3100 package with bulk highly enriched uranium (HEU) contents and issuance of a Type B(U) Fissile Material Certificate of Compliance. This SARP, published in the format specified in the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 7.9 and using information provided in UCID-21218 and NRC Regulatory Guide 7.10, demonstrates that the Y-12 National Security Complex (Y-12) ES-3100 package with bulk HEU contents meets the established NRC regulations for packaging, preparation for shipment, and transportation of radioactive materials given in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] as well as U.S. Department of Transportation (DOT) regulations for packaging and shipment of hazardous materials given in Title 49 CFR.

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

A general description and a summary of the evaluation of the packaging are presented in this section. Subsequent sections address structural (Sect. 2) and thermal (Sect. 3) responses to Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) and the packaging's ability to contain the radioactive materials (Sect. 4) when subjected to the requirements of 10 CFR 71.71 and 71.73, respectively. A shielding evaluation was prepared to ensure adequate nuclear radiation shielding (Sect. 5). Criticality evaluations that are unique to the contents were prepared to ensure nuclear subcriticality (Sect. 6). Sections 7 and 8 discuss the operating procedures, the new packaging acceptance tests, and the maintenance program for the planned use and maintenance of the packaging. Section 9 describes the packaging quality assurance requirements as demonstrated by the *Packaging and Transportation Quality Assurance Program Plan* (QAP-Y-91-273860-1).

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

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

1.2 PACKAGE DESCRIPTION

A schematic of the ES-3100 shipping package is shown in Fig. 1.1, and an exploded view of the packaging components is presented in Fig. 1.2. The packaging design drawings (Appendix 1.3.7) provide material lists, dimensions, safety components, welding requirements, and gasket requirements. The maximum nominal gross shipping weight of the ES-3100 package with bulk HEU content is 187.81 kg (414.05 lb). The maximum authorized gross shipping weight of the ES-3100 package is 190.5 kg (420 lb). The certification drawing of the ES-3100 can be found in Appendix 1.3.1. The ES-3100 as specified in this SARP is classified as a Type B(U) fissile material Category I package (see Appendix 1.3.6).

1.2.1 Packaging

The main functions of the packaging are containment, shielding, and nuclear criticality safety. The bulk HEU contents create a maximum decay heat of ~5 W (Sect. 1.2.2.7 and 3.1.2); therefore, the packaging does not require any special design features such as coolant valves or continuous venting to meet the thermal requirements of 10 CFR 71.

1.2.1.1 Drum assembly

The drum assembly consists of a double open-head reinforced stainless-steel 30-gal drum, arched cover that forms the bottom, arched lid, inner liner, and top plug with cast refractory insulation (Kaolite) [Drawing M2E801580A001, Appendix 1.3.7]. The inside diameter of the drum is 46.36 cm (18.25 in.) with an overall height of 110.49 cm (43.5 in.) including the cover and lid (Drawings M2E801580A004 and M2E801580A001, Appendix 1.3.7). The outside diameter of the drum (including the hoops) is 49.2 cm (19.37 in.). The drum and lid are made from 16-gauge [~0.152-cm (0.0598-in.)-thick] Type 304 or 304L stainless steel. A 12-gauge [~0.267-cm (0.105-in.)-thick] stainless-steel arched cover (Drawing M2E801580A005, Appendix 1.3.7) is welded to the double open-head drum to create the bottom of the drum assembly. An inner liner (Drawing M2E801580A003, Appendix 1.3.7) is attached to the drum by an internal flange (angle) that is welded to both the drum and liner. The cavity created by the inner liner for placement of a containment vessel is a three-tier volume. The uppermost tier accommodates the top plug and has an inside diameter of 37.52 cm (14.77 in.) and is 13.26-cm (5.22-in.) deep (Drawing M2E801580A003, Appendix 1.3.7). The second tier, which accommodates the containment vessel flange, has a 21.84-cm (8.60-in.) inside diameter that is 5.59-cm (2.20-in.) deep (Drawing M2E801580A003, Appendix 1.3.7). The third tier, which accommodates the containment vessel body, has a 15.85-cm (6.24-in.) inside diameter that is 78.31-cm (30.83-in.) deep (Drawing M2E801580A003, Appendix 1.3.7). An additional cavity is created between the second and third tier liners. This cavity runs the full length of the third tier height [78.31 cm (30.83 in.)] and is ~3.00-cm (1.18-in.) thick (Drawing M2E801580A003, Appendix 1.3.7). This cavity is filled with a castable refractory (277-4 special dry mix) for neutron attenuation purposes. Aluminum foil tape is applied over the 277-4 cavity fill and vent holes (four places) located on the drum liner lower shelf (Drawing M2E801580A002, Appendix 1.3.7). The additional cavities between the liner and the drum are filled with an inorganic castable refractory material (Kaolite 1600), which acts as both an impact-absorbing and thermal-insulating material.

In accordance with NUREG/CR-3854, Part 4.2 for a Category I shipping package, an acceptable specification for drums used in any of the component safety groups is DOT Specification 17C or better. It should be noted that the Specification 17C package is no longer included in the DOT regulations (49 CFR 178). The drum used in the ES-3100 is fabricated in accordance with the dimensional requirements of Military Standard MS27683 and modified as shown on Drawing M2E801580A004 (Appendix 1.3.7). The fabrication requirements for the ES-3100 drum assembly are shown in Equipment Specification JS-YMN3-801580-A002 (Appendix 1.3.2). Material, fabrication, and quality control criteria are generally equivalent to those imposed for a DOT Specification 17C drum. Furthermore,

the drum of the ES-3100 is part of a performance-based package that has been tested and analyzed to demonstrate its ability to maintain confinement and containment of its contents under both NCT and HAC. By certifying that the outer shell of the drum assembly used in production meets the same specifications as those tested and analyzed, as described in subsequent sections of this SARP, the outer drum shell used for the ES-3100 is acceptable for a Category 1 shipping package.

As previously discussed, the drum has been modified by the attachment of an inner liner connected to the drum by an internal flange welded to both the drum and the liner. Weld studs are attached to the upper face of the internal flange. The body seams are welded. The following items are conducted in accordance with Sect. IX of the *American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code* (ASME Code, Sect. IX): welding procedures qualification and welders certification to these qualified procedures.

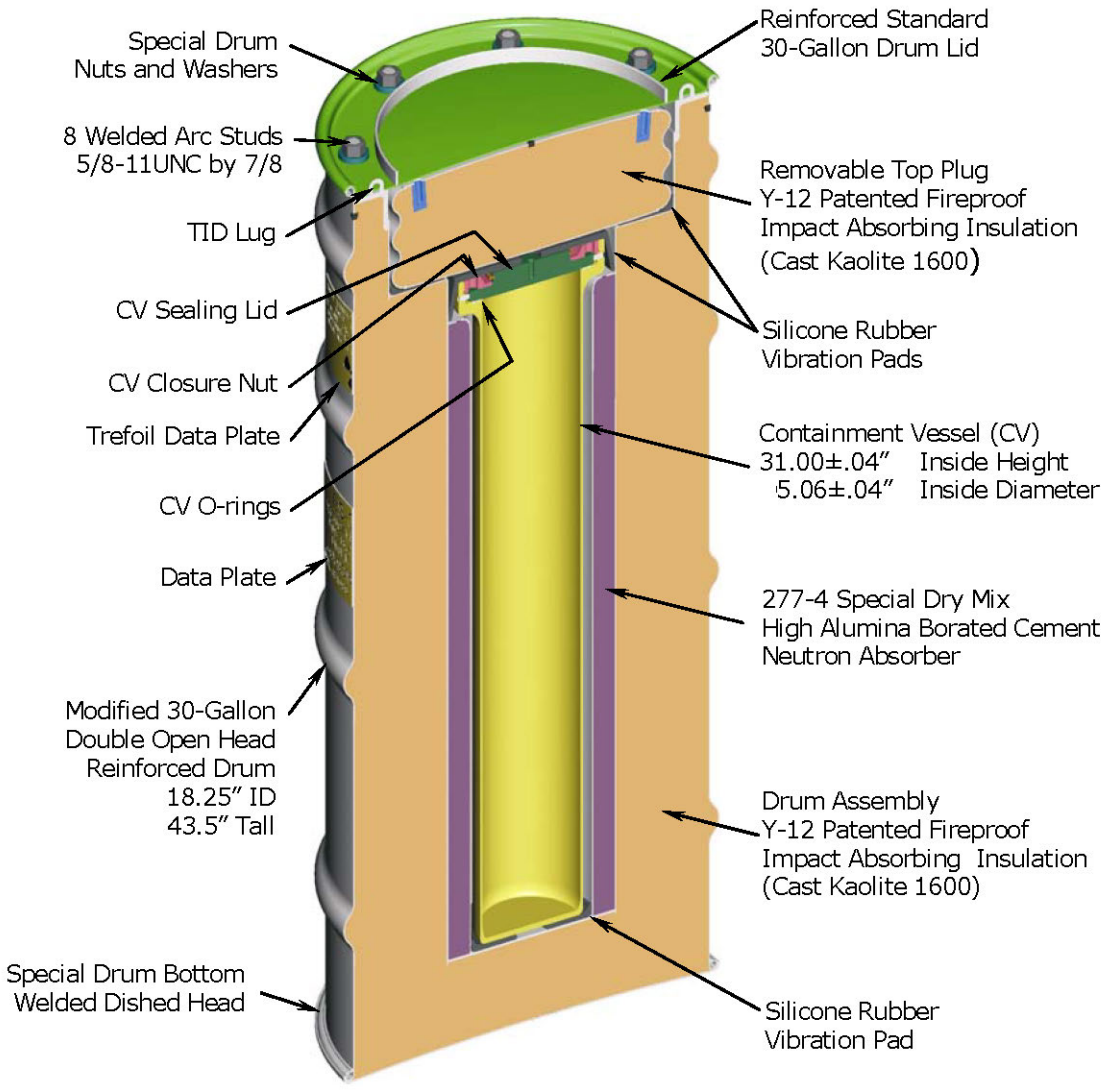


Fig. 1.1. Schematic of the ES-3100 shipping package.

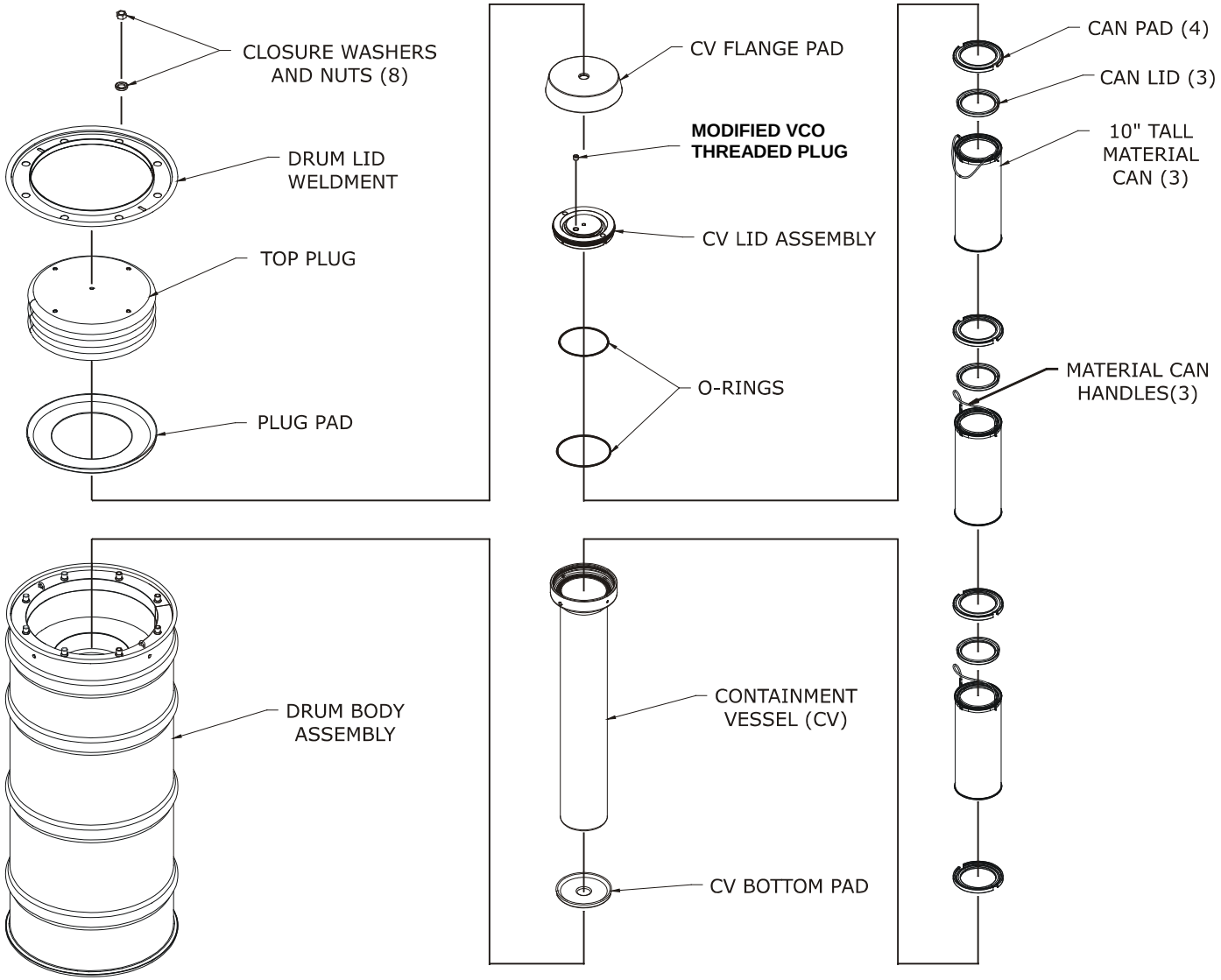


Fig. 1.2. Exploded view of the ES-3100 package with bulk HEU contents.

The drum has four circumferential hoops formed into the body. The drum has four 0.795-cm (0.313-in.)-diam holes equally spaced around the circumference ~3.81 cm (1.50 in.) from the top rim to relieve pressure in the drum in the event of a thermal accident (Drawing M2E801580A002, Appendix 1.3.7). Plastic plugs (Nylon 6/6, Micro Plastic, Inc., Item Number 62MP0312) are placed into these holes from the outside to prevent leakage of water into the drum during NCT and storage. The drum is fabricated with a data plate, trefoil data plate, paint, and two lid TID lugs for use with tamper-indicating devices (TIDs). The two electrochemically etched data plates are affixed to the exterior of the drum body in the locations, and with the methods, indicated on Drawing M2E801580A031 (Appendix 1.3.7). The trefoil data plate (M2E8015803A010-1) provides the owner's return address, container model, container serial number, and the trefoil symbol. The other data plate (M2E801580A010-2) provides the required DOT markings—certificate number, maximum gross weight, and "Type B" designation.

The removable lid is attached to the drum body by a flange with eight silicon bronze, 5/8-11 UNC-2B hex-head nuts [C65100, American Society for Testing and Materials (ASTM) F 467] with stainless-steel washers. These nuts are tightened onto the weld studs (Type 304 or 304L stainless steel, 5/8-11 UNC-2A, ASTM A 493 or F 593) to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) of torque with no sequence specified. A radio-frequency identification (RFID) system may be attached to the ES-3100 package if desired. If an RFID is attached to the package using the drum stud and nut assembly, the normal thread engagement of the external nut shall not be reduced when compared to adjacent stud and nut attachments.

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

The drum assembly also contains three silicone rubber pads. The first pad (CV bottom pad) is placed on the bottom of the innermost liner to support the containment vessel bottom during transport. The second pad (CV flange pad) is placed on top of the containment vessel lid during transport. The third pad (plug pad) is placed on the top shelf of the mid-liner to cushion the top plug during transport. The locations of these three pads are shown on Drawing M2E801580A001 (Appendix 1.3.7), and the dimensions of the pads are shown on Drawing M2E801580A009 (Appendix 1.3.7).

The ES-3100 is handled using industry-standard drum handling equipment. When using a forklift, it can be placed on the tines of the forklift from below, or it is designed for a forklift pincher assembly that can be used to grasp the exterior of the drum assembly. Based on analytical results for a similar package (the Model ES-2100), forklift gripping forces of up to 5400 lb can be used with no detrimental effects on the package (DAC-EA-801376-A003).

No tie-down devices are integral to the package, nor can any features be used for these purposes. The ES-3100 package is designed to be shipped using blocking, bracing, and tie-down equipment that meets industry-standard practices to prevent shifting in the conveyance during NCT.

1.2.1.2 Insulation

The void area formed by the drum and the attached inner liner is filled with an inorganic castable refractory material (Kaolite 1600) made by Thermal Ceramics, Inc., which acts as both a thermal insulating and an impact limiting material. The top plug assembly, which is placed between the containment vessel and the drum lid, is also filled with Kaolite 1600. This material is a mixture of cement and vermiculite and has a nominal cured density of ~358.8 kg/m^3 (22.4 lb/ft^3). Additional information regarding the characteristics and properties of this material is presented in several supporting documents (Kaolite product data sheet, Kaolite material safety data sheet, Y/DW-1661, ORNL-TM-2003/49, Y/DW-1890, Y/DW-1972, Y/LF-565, Moody 2004). Casting takes place while

the drum is being vibrated in an inverted orientation to ensure that the castable material penetrates into all areas in the void space formed by the drum and the inner liner and that no considerable voids are formed during this process. The Kaolite material is then baked in a furnace at elevated temperatures [~260°C (500°F)] as prescribed in Manufacturing Process Specification JS-YMN3-801580-A003, *Manufacturing Process Specification for Casting Kaolite 1600 into the ES-3100 Shipping Package*, the specification which controls manufacture of Kaolite 1600 for the ES-3100 (Appendix 1.3.4). A thermal ceramic material, such as Kaolite 1600, has been previously used as an impact limiting/thermal insulating material in other Y-12 owned and licensed Type B packages (i.e., ES-2100 and DPP-2). The original decision to use this material was the result of considerable research. This manufacturing process is protected under U.S. Patent 6,299,950 B1 (Byington et al. 2001). The United States Government has rights in this invention pursuant to Contract No. DE-NA0001942 between the National Nuclear Security Administration and CNS.

One of the design goals of Y-12's packaging development program was to build a shipping package entirely of materials that do not char, burn, or thermally decompose when exposed to the temperatures and conditions associated with HAC [800°C (1475°F)]. Cellulosic fiberboard and polyurethane foams, typically used for packaging applications, undergo decomposition when exposed to these HAC thermal conditions. During thermal decomposition, these materials offgas, producing conditions that are potentially detrimental to the performance of the package. The hot gases generated within the packaging can transfer heat to inner regions adjacent to the containment closure seals. Under severe circumstances, this process could lead to loss of containment due to overheating of containment seals. The Kaolite material is nonflammable and will not undergo chemical decomposition at temperatures below 1260°C (2300°F). When Kaolite is heated >100°C (212°F), water vapor from free water contained within the casting will form. Pressurization of the drum and top plug is prevented by pressure-relief holes (vent holes) located near the top of the drum and on the top center of the top plug (Sect. 1.2.1.1 and Drawings M2E801580A002 and M2E801580A008, Appendix 1.3.7). The cured Kaolite 1600 material does not decompose, and thus there are no exothermic chemical reactions that could produce superheated offgasses.

Extensive testing of Kaolite 1600 was performed by the Y-12 Development Division to determine the performance of the material for this type of application (Y/DW-1661). Testing showed that Kaolite 1600 has a tremendous ability to absorb shock over a wide range of material densities, curing temperatures and times, and material temperatures. The 10 CFR 71.73 HAC testing documented in Sect. 2.7 demonstrates that Kaolite 1600 is a robust impact limiter and good thermal insulating material for Type B shipping containers. Post HAC drop testing radiographs of a similar package, the ES-2100, showed some minor cracking of the Kaolite structure in some cases. However, subsequent thermal testing of these ES-2100 packages demonstrated that these cracks were inconsequential to the package's ability to meet regulatory requirements.

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

1.2.1.3 Shielding

The ES-3100 packaging does not require dedicated shielding materials of specific design to control external radiation levels for the bulk HEU contents. However, the intervening packaging materials of construction (stainless steel of the drum and containment vessel, the Kaolite material, and the 277-4 material) provide some attenuation of the relatively low levels of penetrating radiation emitted by the contents. The amount of shielding modeled for the NCT analysis is represented by the thickness and density of the materials reported in Sects. 1.2.1.1, 1.2.1.2, and 1.2.1.5 and the packaging dimensions

(Appendix 1.3.7). HAC physical testing showed that the containment vessel and insulation remain confined within the drum assembly. However, the HAC shielding evaluation conservatively assumes that only the containment vessel remains for shielding purposes (i.e., no shielding credit is taken for the drum and insulation in the HAC analysis).

1.2.1.4 Nuclear criticality safety

The packaging materials of construction in the ES-3100 provide neutron absorption (stainless steel and 277-4) and reflection (stainless steel and insulation). The 277-4 (or Cat 277-4 as it is sometimes referred) material is a noncombustible cast neutron-absorbing material. This material is cast into the innermost liner of the package adjacent to the containment vessel as shown in Fig. 1.1. The material is a high alumina borated concrete composed of aluminum, magnesium, calcium, boron, carbon, silicon, sulfur, sodium, iron, and water. The 277-4 material was manufactured specifically for the ES-3100 package by adding boron carbide to a standard material (Cat No. 277-0) and increasing the boron content from 1.56 wt % to 4.23 wt %. Additional information on the neutron-absorbing characteristics of this material is presented in Appendix 6.9.3. Properties of the 277-4 material are presented in Table 2.17 and several supporting documents (ORNL/TM-2004/290, Y/DW-1987, Y/DZ-2585, COR-NDA-04-93, Y/DV-1914). The cast material has a nominal density of 1681.9 kg/m^3 (105 lb/ft^3). The procedure for mixing this material and casting it into the ES-3100 shipping package is documented in JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package* (Appendix 1.3.5).

Although shown by tests up to HAC as not being credible, the criticality analysis considers water leakage into the containment vessel in accordance with 10 CFR 71.55(b). Depending on the content being shipped and the shipping configuration being used, criticality safety index (CSI) values for the ES-3100 package may range from 0 to 3.2 (Sect. 1.2.2).

1.2.1.5 Containment system

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

During fabrication, all ES-3100 containment vessels will be inspected and tested to the requirements specified on the design drawings (Appendix 1.3.7) and equipment specification (Appendix 1.3.3). Certification documents received from the vendor with each component acknowledge the use of these drawings and the specification. These certifications are on file with the Y-12 Quality Organization.

The containment boundary of the ES-3100 package is a pressure vessel that is designed, fabricated, examined, and tested in accordance with the ASME Code, Sect. III, Div. 1, Subsection NB. The ES-3100 containment vessel body is constructed of Type 304L stainless steel and may be fabricated by one of two methods. The first method uses a standard 5-in., schedule 40 stainless-steel pipe (ASME SA-312 Type TP304L), a machined flat-head bottom forging (ASME SA-182 Type F304L), and a machined top flange forging (ASME SA-182 Type F304L). Each of these pieces is joined with circumferential welds as shown on Drawing M2E801580A012 (Appendix 1.3.7). 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 flow forming 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.

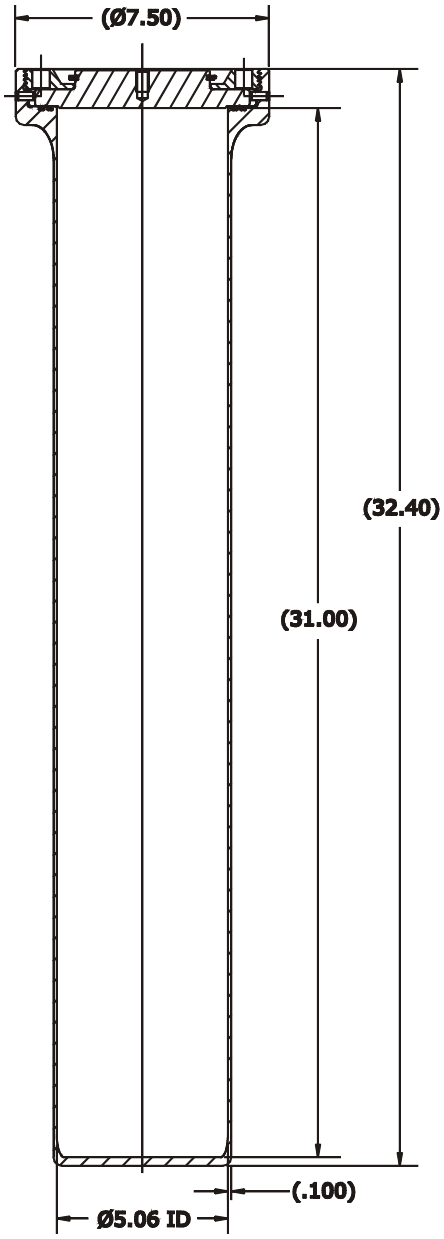


Fig. 1.3. Containment boundary of the ES-3100 shipping package.

The lid assembly, which completes the containment boundary structure, consists of a sealing lid, closure nut, and external retaining ring (Drawing M2E801580A014, Appendix 1.3.7). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.3.7) 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-test 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 and containment vessel body (with O-rings in place) are joined together by torquing

the closure nut 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. A leak-test 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. The O-rings on this containment vessel are ethylene propylene diene monomer (EPDM) fabricated to ASTM D 2000, M3BA712A14B13F17. The equipment specification for the EPDM O-rings is presented in Appendix 1.3.9.

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 thickness of the containment vessel 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 1.3.7). No penetrations, connections, or fittings into this sealed container exist.

1.2.2 Contents

The ES-3100 shipping package will be used to ship bulk HEU in the form of oxide (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, and UO_2-ZrO_2), uranium metal and alloy in the form of solid geometric shapes or broken pieces, uranium compounds, uranyl nitrate crystals (UNX), fuel elements from TRIGA reactors, and research reactor fuel elements or fuel components. Actual loading limits are determined in subsequent sections of the SARP. 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 exception of ^{237}Np) may be present in the HEU metal and alloy contents transported by ground at a maximum concentration of 800.0 µg/gU and at a maximum concentration of 40.0 µg/gU in all other contents. Contents to be transported by air are limited to a maximum transuranic concentration of 40.0 µg/gU, which meets the requirements in 10 CFR 71.88. The concentration of ^{237}Np is limited to 0.0250 g/gU. Unless otherwise specified, the contents described in this section pertain to ground transport only. A discussion of contents of air-transport is included in Sect. 1.2.2.1.

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

HEU Metal and Alloy

HEU metal and alloy (alloys of uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) may be in the form of solid geometric shapes. Solid shapes may include the following:

1. cylinders having a diameter no larger than 4.25 in. (maximum of one cylinder per convenience can);
2. square bars having a cross section no larger than 2.29 in. × 2.29 in. (maximum of one bar per convenience can); and
3. slugs having dimensions of 1.5-in. diam × 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.

Alloys of uranium may include aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium. Uranium-aluminum alloys are typically 70 to 95% aluminum. Uranium-molybdenum alloys are typically 1 to 12% molybdenum. Uranium/molybdenum alloys may be plated with, clad with, or contain traces of aluminum, gold, stainless steel, nickel and/or chromium. Other uranium alloys may contain up to 50% of the non-uranium constituents.

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).

For pyrophoric considerations, HEU metal and alloy must meet the following restrictions (Appendix 1.3.8):

1. Uranium metal and alloy (broken) pieces must have a surface-area-to-mass ratio of not greater than 1 cm^2/g or must not pass through a 3/8-in. (9.5-mm) mesh sieve (or equivalent size-grading method).
2. Particles and small shapes which do not pass the size restriction tests in #1, and powders, foils, turnings, and wires, are not permitted unless they are in a sealed, inerted container. Material meeting this criteria will be in the HEU metal or alloy turnings, fines, or powder category, and will be so limited.

Note: A "sealed, inerted container" is a container with an inert atmosphere that is leaktight as defined in ANSI N14.5-1997.

Metal and alloy may be shipped in tin-plated carbon-steel, stainless-steel, aluminum, or nickel-alloy convenience cans; Teflon convenience bottles; or Teflon bottles inside metal convenience cans. Solid form HEU contents (i.e., spheres, cylinders, bars, slugs) that will not fit in a convenience can may be bagged with no convenience can required around the content. The only hydrogenous packing materials that can be used inside the containment vessel when shipping broken HEU metal are those that have a hydrogen atom density less than or equal to that of water.

HEU Oxide

The HEU oxide content in the ES-3100 package includes UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, and UO_2-ZrO_2. Maximum overall uranium isotopic concentrations are presented in Table 1.2. The physical form of all contents is dense, loose powder (which may contain clumps) or pellets. Moisture content in oxide is limited to 3 wt % water (Note: Loading Restriction 8 in Sect. 1.2.2.8 also applies). Theoretical densities of UO_2, U_3O_8, and UO_3 are 10.96, 8.30, and 7.29 g/cm^3, respectively. Allowable oxide bulk densities are 0.5 to 6.54 g/cm^3. Oxide may be shipped in tin-plated carbon-steel, stainless-steel, or nickel-alloy convenience cans; polyethylene or Teflon convenience bottles; or glass (UO_2-Mg oxide only), polyethylene, or Teflon bottles inside metal convenience cans.

Table 1.2. Bounding uranium isotopic concentrations in oxide

Isotope	Bounding limit
^{232}U	40 ppb
^{233}U	0.6 wt %
^{234}U	2.0 wt %
^{235}U	100.0 wt %
^{236}U	40.0 wt %

Uranium oxide shipments must be completed within 12 months after sealing the containment vessel in order to prevent the buildup of hydrogen gas beyond 5 mol %. The time period begins when the containment vessel is sealed. Hydrogen generation calculations are provided in Appendix 3.5.4.

Research Reactor Fuel Elements and Components

Research reactor fuel elements or fuel components composed of clad U-Zr, U-Al, U_3O_8-Al, UO_2, oxides of U-Zr, UO_2-Mg, or U_3Si_2-Al will be shipped in the ES-3100 package. The fuel elements consist of multiple fuel components in the form of plates, rods, and tubes clad in aluminum, stainless steel, or zircalloy and held together as a single unit by other inert structural components. The fuel components are individual plates, rods, or tubes removed from fuel elements. The uranium in these fuel elements and components is enriched to 10 to 93.5 wt % ^{235}U.

The U-Al fuel in the research reactor fuel elements and components is an alloy of uranium and aluminum (U-Al) or in the form of $UA1_x$-Al (alloy in an aluminum matrix). The U-A1 fuel contains ~8 to 30 wt % uranium. The U_3O_8-Al fuel is in the form of a U_3O_8 compound contained in an aluminum metal matrix. The U_3O_8-Al contains ~8 to 40 wt % U_3O_8. The UO_2 fuel is a ceramic compound. The UO_2-Mg fuel is a ceramic UO_2 compound contained in a magnesium metal matrix. The UO_2-Mg fuel contains ~88 wt % UO_2.

The research reactor fuel elements and components will be bundled together and placed inside a modified convenience can [a 17.5-in.–tall can (two 8.75-in.–tall cans brazed together) or a 30-in.–tall can (three 10-in.–tall cans brazed together)] or protected on each end with an open-ended convenience can constructed of stainless steel, tin-plated carbon steel, or nickel alloy (see Fig. 1.4).

Intact TRIGA reactor elements and fuel pellets will also be shipped in the ES-3100. The fuel shall be unirradiated. The TRIGA fuel shall be in the form of uranium zirconium hydride ($UZrH_x$), where $x \leq 1.6$. Fuel from three types of TRIGA fuel elements are allowed: TRIGA Standard Fuel Elements, Instrumented TRIGA Standard Fuel Elements, and TRIGA Fuel Follower Control Rods. These fuel elements have three fuel pellets (or sections) per element. The TRIGA Standard Fuel Elements and Instrumented TRIGA Standard Fuel Elements have fissile loadings of 45.33-g ^{235}U per pellet (136-g ^{235}U per element) and the dimensions are 5 in. in length and 1.44 in. in diameter. The TRIGA Fuel Follower Control Rods have a fissile loading of 37.66-g ^{235}U per pellet (113-g ^{235}U per element) and the dimensions are 5 in. in length and 1.31 in. in diameter.

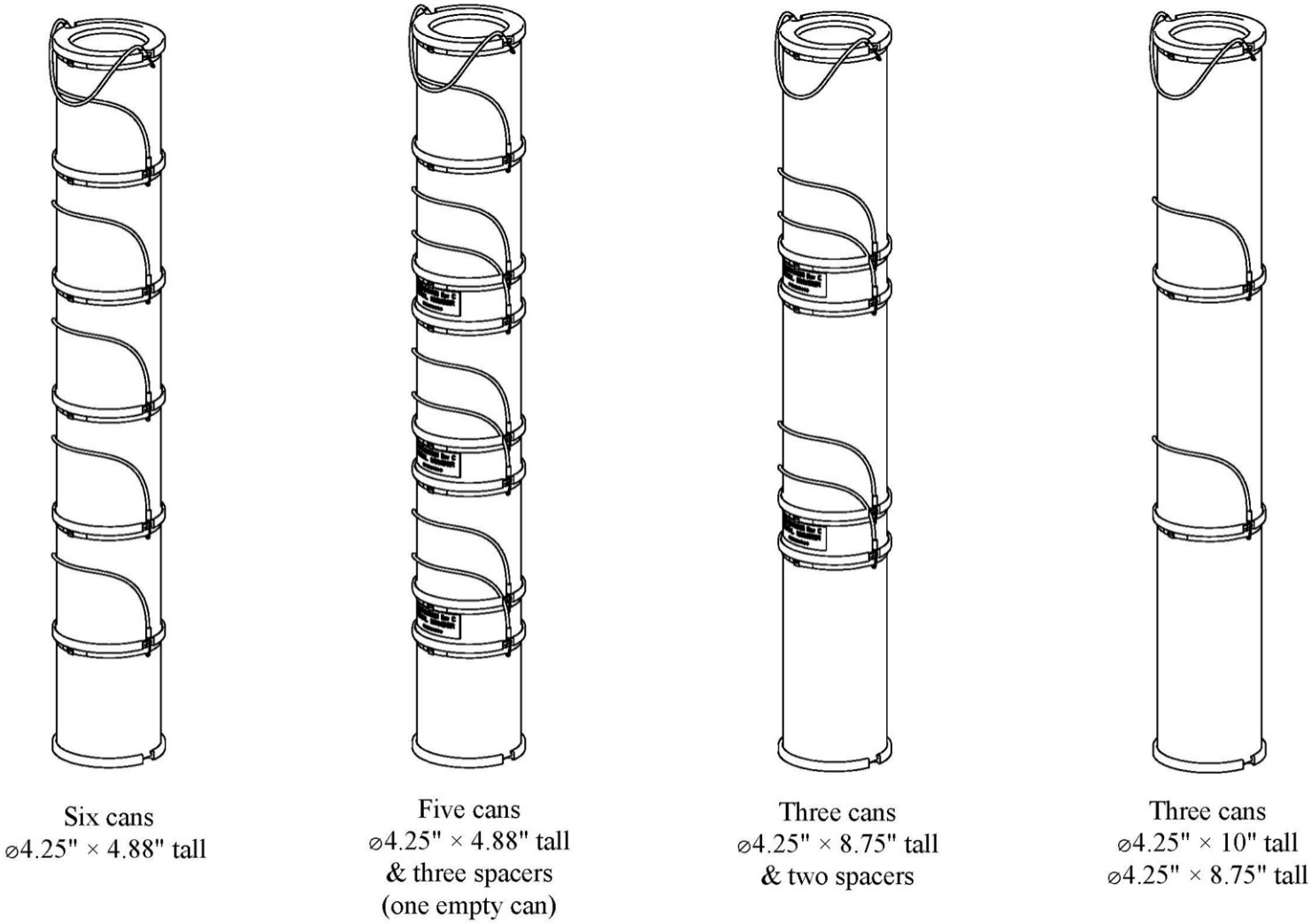


Fig. 1.4. Typical shipping configurations inside the ES-3100 containment vessel.

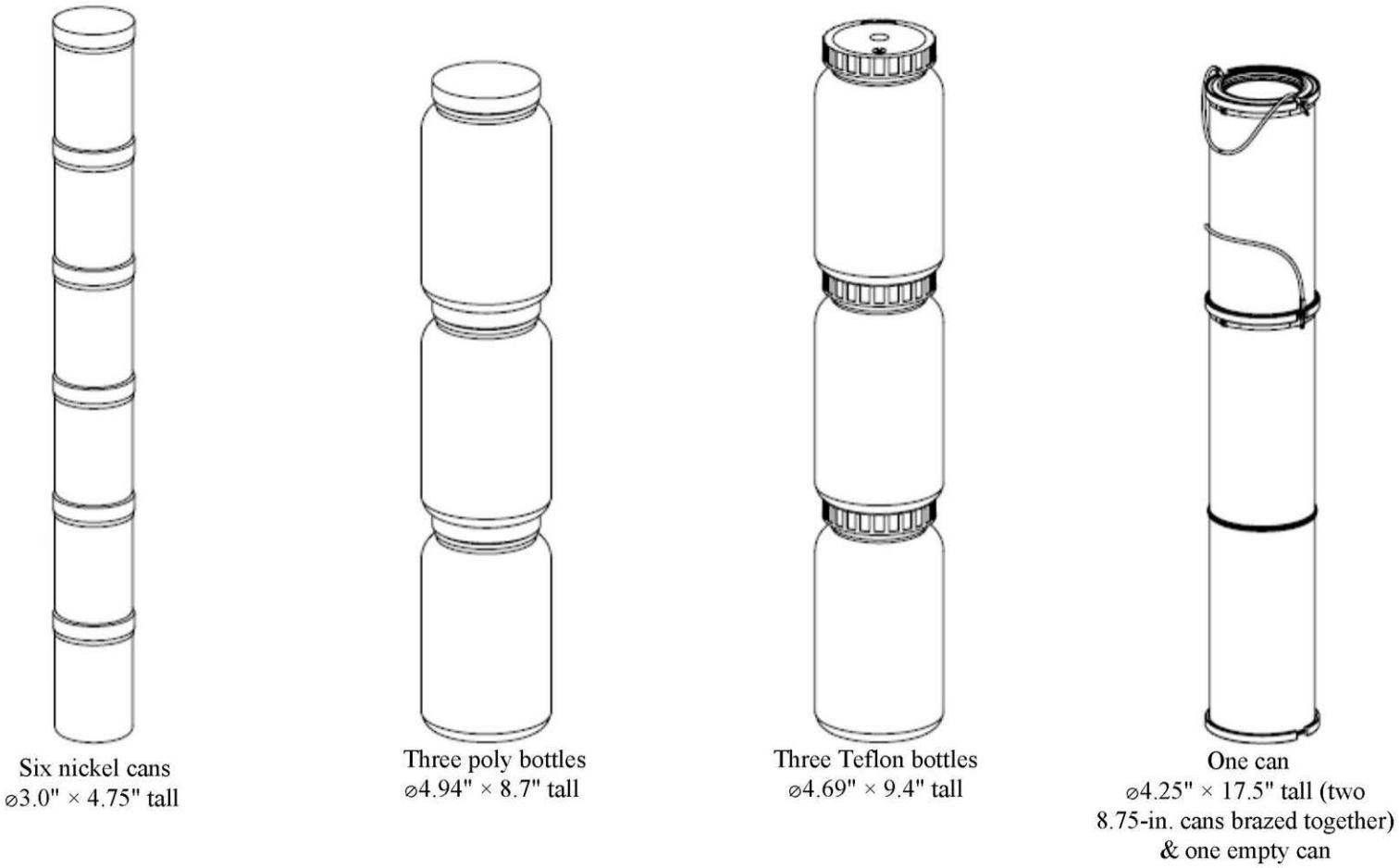
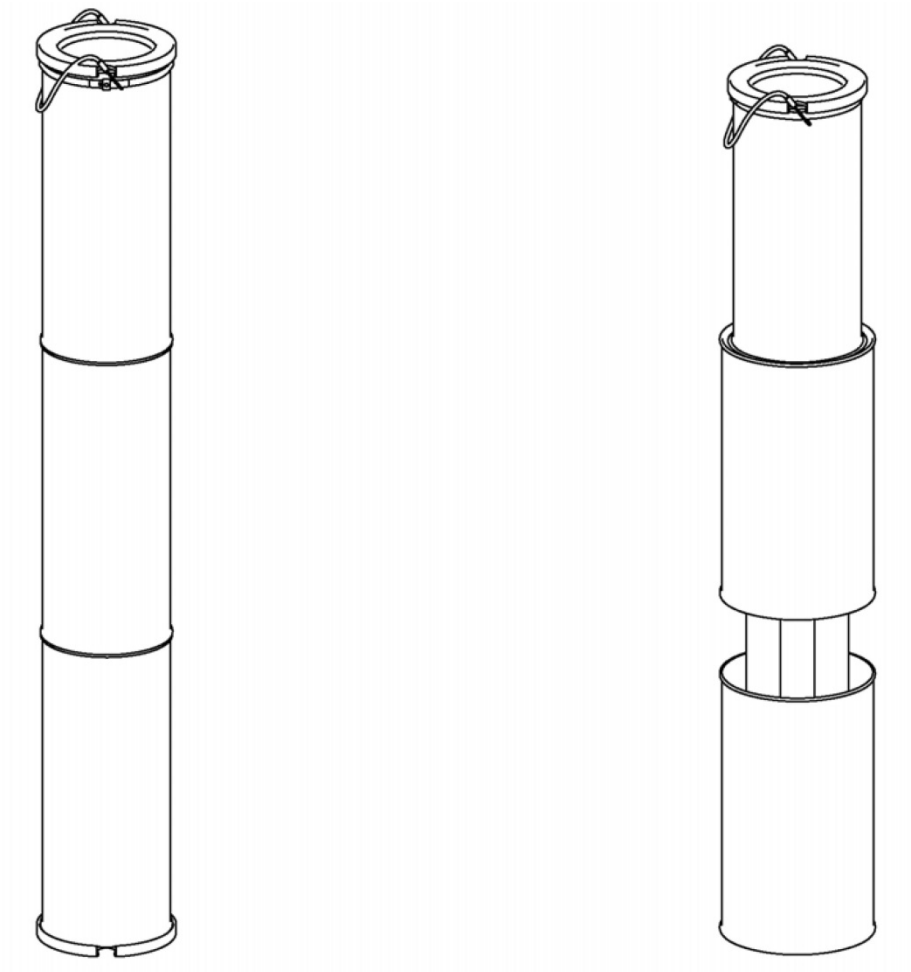


Fig. 1.4. Typical shipping configurations inside the ES-3100 containment vessel (cont.).



One can
⌀4.25" × 30" tall
(three 10-in. cans brazed together)

Two cans open ended
⌀≤5" × ≤10" tall
(one empty can or stainless steel scrubbers on top)

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

TRIGA fuel may be shipped as crimped fuel elements or as $UZrH_x$ fuel pellets (if disassembled), both of which shall be packed into convenience cans prior to shipment. Convenience cans of 4.25-in. diam by various lengths shall be used. Fuel pellets loaded into convenience cans shall be up to 5 in. in length (full-length) and no more than three full-length pellets shall be loaded into a convenience can. Crimped fuel rods are clad fuel pellets and can be up to 15 in. in length (full length of the fuel section from one fuel element). Cladding material is stainless steel or aluminum. Only the fuel section of the TRIGA fuel element is allowed to be shipped; however, there may be residual cladding up to ½ in. in length at either end of the crimped fuel rod. Up to three 15-in.-long crimped fuel elements shall be loaded into a single convenience can for shipping. Maximum loading of bare fuel pellets and crimped fuel elements shall be 3 fuel element equivalence per ES-3100 containment vessel. TRIGA fuel with enrichments up to 70% has been evaluated. For TRIGA Standard Fuel Elements and Instrumented TRIGA Standard Fuel Elements, the maximum allowable loading is 408-g ^{235}U per package, and for TRIGA Fuel Follower Control Rods, the maximum allowable loading is 339-g ^{235}U per package. No spacer cans are required.

Fuel elements or pins from the Systems for Nuclear Auxiliary Power (SNAP) reactor will also be shipped in the ES-3100 package. The SNAP reactor fuel pins are composed of $UZrH_x$ ($x \leq 2$) with Hastelloy N cladding. The fuel pins are ~1.25 in. in diameter and ~12.45 in. long. The SNAP reactor fuel pins are enriched to 93 wt % ^{235}U. The SNAP reactor fuel pins will be packed in appropriate length convenience cans or bundled together and protected on each end with an open-ended can. Up to three fuel elements may be packed into any one convenience can or any one bundle. Up to two loaded convenience cans or two bundles may be shipped in the ES-3100.

Uranium Compounds

Several compounds of uranium, including uranium tetrafluoride, uranyl fluoride, uranium carbide, uranium nitride, and uranium silicide, will be shipped in the ES-3100 package. The physical form of these uranium compounds is solid crystalline, granular, or powder. The uranium compounds contain no moisture.

Uranium tetrafluoride (UF_4), often called green-salt because of its characteristic color, is generally an intermediate in the conversion of UF_6 to either uranium oxide (U_3O_8 or UO_2) or uranium metal. UF_4 is a solid composed of agglomerating particles with a texture similar to baking soda. It is non-volatile and non-hygroscopic, but only slightly soluble in water. After exposure to water, UF_4 slowly dissolves and undergoes hydrolysis, forming several possible uranium compounds and hydrogen fluoride (HF). The density of solid UF_4 is 6.7 g/cm^3.

Uranyl fluoride (UO_2F_2) is an intermediate in the conversion of uranium hexafluoride (UF_6) to a uranium oxide or metal form and is a direct product of the reaction of UF_6 with moisture in the air. It is very soluble in water. Uranyl fluoride is hygroscopic and changes in color from brilliant orange to yellow after reacting with water. Uranyl fluoride is reported to be stable in air to 300°C, above which slow decomposition to U_3O_8 occurs. When heated to decomposition, UO_2F_2 emits toxic fluoride fumes. The density of UO_2F_2 is 6.37 g/cm^3.

Uranium carbide is a hard refractive ceramic material. It comes in several stoichiometries such as uranium monocarbide (UC), uranium sesquicarbide (U_2C_3), and uranium dicarbide (UC_2). Like uranium dioxide and some other uranium compounds, uranium carbide can be used as a nuclear fuel for nuclear reactors, usually in the form of pellets or tablets. Uranium carbide is a dull, dark charcoal-gray or flat black colored powder. The densities of UC, U_2C_3, and UC_2 are 13.63, 12.7, and 11.3 g/cm^3, respectively. Loadings for U_2C_3 and UC_2 fall under the general category of UC.

Uranium nitride (UN) and uranium sesquinitride (U_2N_3) are ceramic compounds used as nuclear fuel in nuclear test reactors whose properties are similar to uranium dioxide or uranium carbide. They can be synthesized by the reaction of nitrogen with uranium at 700 K. Uranium nitride is also formed as a product of uranium combustion in air. The densities of solid UN and U_2N_3 are 14.32 and 11.24 g/cm^3, respectively. Loadings for U_2N_3 fall under the general category of UN.

Uranium silicide, with U_3Si_2 as the primary constituent, is produced by melting together uranium metal and high purity silicon. The silicon content of the uranium silicide is ~7.5 wt %. Except for impurities, whose limits are shown in Table 1.2a, the balance of the uranium silicide is uranium. The composition of the uranium in uranium silicide is as follows: 19.75 ± 0.2 wt % ^{235}U, 0.5 maximum wt % ^{234}U, 1.0 maximum wt % ^{236}U, and the balance wt % ^{238}U. The bulk density range of uranium silicide powder is 5–7 g/cm^3.

Table 1.2a. Maximum impurities in uranium silicide [a, b]

Element	Parts per million (ppm)
Aluminum	600
Boron	30
Carbon	1000
Cadmium	20
Cobalt	10
Copper	100
Iron and nickel	1000
Hydrogen	200
Lithium	10
Nitrogen	500
Oxygen	7000
Zinc	1000

[a] Other individual elements not listed in table are limited to a maximum of 500 ppm. The total of all other elements is a maximum of 2500 ppm.

[b] The total impurity content in uranium silicide shall not exceed the equivalent boron content of 30 ppm on a weight basis relative to uranium silicide. The equivalent boron content is calculated as shown in TRTR-14.

Other uranium compounds consist primarily of finished tristructural-isotropic (TRISO) micro fuel particles; however, also included are pure/impure scrap materials generated during various stages of the manufacturing process. These materials have a ^{235}U assay ≤93.17% and are typically in a solid crystalline or granular form. A finished TRISO fuel particle consists of a kernel composed of UO_X (or sometimes UC or UCO) coated with four exterior layers of three isotropic materials. The four layers are a porous buffer layer made of carbon, followed by a dense inner layer of pyrolytic carbon (PyC), followed by a ceramic layer of SiC to retain fission products at elevated temperatures and to give the TRISO particle more structural integrity, followed by a dense outer layer of PyC.

Uranium compounds may be shipped in tin-plated carbon-steel, stainless-steel, or nickel-alloy convenience cans.

Uranyl Nitrate Crystals

Uranyl nitrate crystals are formed by dissolving uranium metal or any of the uranium oxides in nitric acid and the UNX crystalline precipitates are acquired through a variety of extraction, filtration,

and purification processes. The UNX crystals are soluble in water, forming a weak solution of nitric acid. Uranyl nitrate hexahydrate (UNH) has a chemical formula of $UO_2(NO_3)_2 \cdot 6H_2O$. 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 (Teflon bottles) as the convenience container.

Shipments of UNX crystals must be completed within the times shown in Table 1.3a in order to prevent the buildup of hydrogen gas beyond 5 mol %. The time period begins when the containment vessel is sealed. Hydrogen generation calculations are provided in Appendix 3.5.4.

1.2.2.1 Radioactive/fissile constituents

For the ES-3100 package with bulk HEU content, the maximum number of A_2s is 4752.8 (at 70 years) and the maximum activity is 0.72554 TBq (at 10 years) [Table 4.4].

Ground Transport

Fissile material loading limits for ground transport of the various contents of the ES-3100, as determined by criticality analyses, structural analyses, or hydrogen gas generation evaluations, are presented in Tables 1.3 and 1.3a.

Air Transport

Contents for air transport of the ES-3100 package are HEU in the form of metal/alloy, research reactor fuel elements and components, and HEU oxide (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, and UO_2-ZrO_2). Fissile material mass loading limits for these contents, as determined by the criticality analyses, are presented in Table 1.3b for air transport.

1.2.2.2 Chemical and physical form

The fissile material contents are in solid (HEU metal or alloy, uranium compounds, or research reactor fuel elements and components), crystalline (UNX), or powder (HEU oxide) form. Some moisture (up to 3 wt %) may be present in the HEU oxide material, thereby making the oxide content clump together.

As presented for shipment, the UNX crystals exist as crystalline solids; however, the melting point for uranyl nitrate hexahydrate, trihydrate, and dihydrate is reported as ~60°C, 113°C, and 184°C, respectively (Marshall 1951). Heating of uranyl nitrate hexahydrate crystals up to 200°C results in a stepwise release of water molecules of crystallization (Dash 1999 and Kozlova 2007), which in a closed system results in the partial dissolution of the crystals. During transport of UNH crystals, crystalline solids and a saturated solution of uranyl nitrate will coexist at a temperature above ~60°C (MCW-1424). Given that the NCT maximum containment vessel temperature with insolation is 91.92°C (197.46°F) and the HAC maximum predicted temperature inside the containment vessel at the location near the Teflon bottles is 140.36°C (284.64°F), the uranyl nitrate dihydrate and lower hydrates will remain in a solid phase during transportation. However, the trihydrate and higher hydrate crystals will release water molecules of crystallization upon heating above their melting point, thus converting them into a lower hydrate species, which require a successively higher temperature to release additional water molecules. The melting point for hexahydrate (~60°C) will be exceeded during NCT and HAC; and the melting point for trihydrate (~113°C) crystals will be exceeded during HAC. Upon cooling, the uranyl nitrate hydrate melt will recrystallize to a solid form.

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

Content description		Enrichment	CSI	No spacers, ^{235}U (kg)	Basis for limit	277-4 can spacers, [d] ^{235}U (kg)	Basis for limit
Solid HEU metal or alloy (specified geometric shapes) [e]	Cylinder A	≤100%	0.0	15.000	Crit.	25.000	Crit.
	Cylinder B	≤100%	0.0	18.000	Crit.	30.000	Crit.
	Square bars	≤100%	0.0	30.000	Crit.	35.200 [f]	Struct.
	Slugs	≤95%	0.0	17.374	Crit.	-	-
	Slugs	≤80%	0.0	-	-	29.318	Crit.
	Slugs	>80%, ≤95%	0.0	-	-	24.324	Crit.
	Slugs	>80%, ≤95%	0.4	-	-	34.749	Crit.
Broken HEU metal or alloy		>95%, ≤100%	0.0	Spacers req'd [d]		2.774	Crit.
			0.4	Spacers req'd		5.549	Crit.
			0.8	Spacers req'd		9.248	Crit.
			2.0	Spacers req'd		13.872	Crit.
			3.2	Spacers req'd		24.969	Crit.
		>90%, ≤95%	0.0	Spacers req'd		3.516	Crit.
			0.4	Spacers req'd		6.154	Crit.
			0.8	Spacers req'd		10.549	Crit.
			2.0	Spacers req'd		18.461	Crit.
			3.2	Spacers req'd		26.373	Crit.
		>80%, ≤90%	0.0	Spacers req'd		3.333	Crit.
			0.4	Spacers req'd		7.500	Crit.
			0.8	Spacers req'd		12.500	Crit.
			2.0	Spacers req'd		20.000	Crit.
			3.2	Spacers req'd		28.334	Crit.
		>70%, ≤80%	0.0	2.967	Crit.	4.450	Crit.
			0.4	5.192	Crit.	8.900	Crit.
			0.8	8.900	Crit.	16.317	Crit.
			2.0	17.059	Crit.	25.218	Crit.
			3.2	27.443	Crit.	28.184	Crit.
		>60%, ≤70%	0.0	3.249	Crit.	5.198	Crit.
			0.4	5.848	Crit.	12.996	Crit.
			0.8	13.646	Crit.	20.793	Crit.
			2.0	21.444	Crit.	24.692	Crit.
			3.2	24.692	Crit.	24.692	Crit.
		≤60%	0.0	5.576 kg U	Crit.	11.154 kg U	Crit.
			0.4	14.872 kg U	Crit.	28.813 kg U	Crit.
			0.8	28.814 kg U	Crit.	35.20 kg U [f]	Struct.
			2.0	35.20 kg U [f]	Struct.	35.20 kg U [f]	Struct.
			3.2	35.20 kg U [f]	Struct.	35.20 kg U [f]	Struct.

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

Content description	Enrichment	CSI	No spacers, ^{235}U (kg)	Basis for limit	277-4 can spacers, [d] ^{235}U (kg)	Basis for limit
HEU metal or alloy turnings, fines, or powders [g]	>95%, ≤100%	0.0	1.849	Crit.	Spacers not req'd	
		0.4	3.699	Crit.	Spacers not req'd	
		0.8	6.473	Crit.	Spacers not req'd	
		2.0	11.097	Crit.	Spacers not req'd	
		3.2	11.097	Crit.	Spacers not req'd	
	>90%, ≤95%	0.0	2.637	Crit.	Spacers not req'd	
		0.4	4.395	Crit.	Spacers not req'd	
		0.8	7.032	Crit.	Spacers not req'd	
		2.0	14.944	Crit.	Spacers not req'd	
		3.2	17.581	Crit.	Spacers not req'd	
	>80%, ≤90%	0.0	2.637	Crit.	Spacers not req'd	
		0.4	5.000	Crit.	Spacers not req'd	
		0.8	9.166	Crit.	Spacers not req'd	
		2.0	16.667	Crit.	Spacers not req'd	
		3.2	21.667	Crit.	Spacers not req'd	
	>70%, ≤80%	0.0	2.967	Crit.	Spacers not req'd	
		0.4	5.192	Crit.	Spacers not req'd	
		0.8	8.900	Crit.	Spacers not req'd	
		2.0	17.059	Crit.	Spacers not req'd	
		3.2	19.284	Crit.	Spacers not req'd	
	>60%, ≤70%	0.0	3.249	Crit.	Spacers not req'd	
		0.4	5.848	Crit.	Spacers not req'd	
		0.8	13.646	Crit.	Spacers not req'd	
		2.0	21.444	Crit.	Spacers not req'd	
		3.2	24.692	Crit.	Spacers not req'd	
	≤60%	0.0	5.576 kg U	Crit.	Spacers not req'd	
		0.4	14.872 kg U	Crit.	Spacers not req'd	
		0.8	28.814 kg U	Crit.	Spacers not req'd	
		2.0	35.20 kg U [f]	Struct.	Spacers not req'd	
		3.2	35.20 kg U [f]	Struct.	Spacers not req'd	

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

Content description		Enrichment	CSI	No spacers, ^{235}U (kg)	Basis for limit	277-4 can spacers, [d] ^{235}U (kg)	Basis for limit
HEU oxide [h, i] (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, [j] UO_2-ZrO_2)		≤100%		15.13 kg oxide	H_2 gen.	Spacers not req'd	
bulk density 2.0–6.54 g/cm^3			0.0	9.682 kg ^{235}U	Crit.	Spacers not req'd	
bulk density 2.0–6.54 g/cm^3			0.4	12.323 kg ^{235}U	Crit.	Spacers not req'd	
bulk density ≥1.75 g/cm^3, <2.0 g/cm^3			0.0	9.46 kg ^{235}U	Crit.	Spacers not req'd	
bulk density ≥1.5, <1.75 g/cm^3			0.0	8.36 kg ^{235}U	Crit.	Spacers not req'd	
bulk density ≥1.25, <1.5 g/cm^3			0.0	7.04 kg ^{235}U	Crit.	Spacers not req'd	
bulk density ≥1.0, <1.25 g/cm^3			0.0	5.94 kg ^{235}U	Crit.	Spacers not req'd	
bulk density ≥0.75, <1.0 g/cm^3			0.0	4.84 kg ^{235}U	Crit.	Spacers not req'd	
bulk density ≥0.5, <0.75 g/cm^3			0.0	3.52 kg ^{235}U	Crit.	Spacers not req'd	
Research reactor fuel elements and components [k]	$UZrH_x$ (TRIGA)	≤20%	0.0	0.921 [l]	Crit.	Spacers not req'd	
		>20%, ≤70%	0.0	0.408 [l]	Crit.	Spacers not req'd	
	$UZrH_x$ (SNAP)	≥93%	0.0	0.857 [l]	Crit.	Spacers not req'd	
	U-Zr	≤100%	varies	See limit for broken metal or alloy	Crit.	*Spacers as req'd*	
	U-Al	≤100%	0.0	7.333 kg U-Al 1.117 kg U 1.050 kg ^{235}U	Crit.	Spacers not req'd	
	U_3O_8-Al	≤100%	0.0	15.13 kg oxide 9.682 kg ^{235}U	Crit.	Spacers not req'd	
			0.4	15.13 kg oxide 12.323 kg ^{235}U	Crit.	Spacers not req'd	
	UO_2	≤100%	0.0	21.937 kg UO_2 19.308 kg ^{235}U	Crit.	Spacers not req'd	
	Oxides of U-Zr [m]	≤100%	0.0	15.13 kg oxide 9.682 kg ^{235}U	Crit.	Spacers not req'd	
			0.4	15.13 kg oxide 12.323 kg ^{235}U	Crit.	Spacers not req'd	
	UO_2-Mg	≤100%	0.0	15.13 kg oxide 9.682 kg ^{235}U	Crit.	Spacers not req'd	
			0.4	15.13 kg oxide 12.323 kg ^{235}U	Crit.	Spacers not req'd	
	U_3Si_2-Al [n]	≤100%	0.0	5.825 kg U_3Si_2-Al 2.277 kg U 450 g ^{235}U	Crit.	Spacers not req'd	

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

Content description		Enrichment	CSI	No spacers, ^{235}U (kg)	Basis for limit	277-4 can spacers, [d] ^{235}U (kg)	Basis for limit
Uranium compounds	UF_4	≤100%	0.0	3 kg UF_4 2.267 kg ^{235}U	Crit.	Spacers not req'd	
			2.0	24.0 kg UF_4 18.136 kg ^{235}U	Crit.	Spacers not req'd	
	UO_2F_2	≤100%	0.0	3 kg UO_2F_2 2.067 kg ^{235}U	Crit.	Spacers not req'd	
	UC	≤100%	0.0	2 kg UC 1.815 kg ^{235}U	Crit.	Spacers not req'd	
	UN	≤100%	0.0	2 kg UN 1.888 kg ^{235}U	Crit.	Spacers not req'd	
	TRISO	≤100%	0.0	2 kg TRISO 1.815 kg ^{235}U	Crit.	Spacers not req'd	
	U_3Si_2 [n]	≥19.7%, <40%	0.0	13 kg U_3Si_2	Crit.	Spacers not req'd	
		≥40%, ≤60%	0.0	7 kg U_3Si_2	Crit.	Spacers not req'd	

[a] With the exception of the UNX crystals (Sect. 1.2.2.2), which are loaded in crystalline solid form, HEU in solution form is not permitted for shipment in the ES-3100.
[b] All limits are expressed in kg ^{235}U unless otherwise indicated.
[c] Mass loadings cannot be rounded up.
[d] 277-4 can spacers as described on Drawing M2E801580A043 (Appendix 1.3.7).
[e] HEU bulk metal and alloy not covered by these specific geometric shapes must be put into the broken metal category. Geometries of solid shapes are as follows:
- Cylinder A is larger than 3.24-in. diam but no larger than 4.25-in. diam: maximum of 1 cylinder per can.
- Cylinder B is no larger than 3.24-in. diam: 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. diam × 2.0-in. tall: a maximum of 10 per convenience can where the actual number permitted is restricted by the stated loading limit.

[f] Maximum planned content weight is 35.20 kg. Maximum analyzed for criticality safety is 35.32 kg.
[g] If the mass of metal or alloy turnings, fines, or powders is ≤ 50 g, then it may be shipped as the parent form (e.g., broken metal, reactor fuel, etc.).
[h] Seal time must be 12 months or less. Seal time is the length of time after the ES-3100 containment vessel is sealed that the shipment must be complete.
[i] Allowable HEU oxide bulk densities are 0.5–6.54 g/cm^3 and the total mass of oxide in all cases is limited to 15.13 kg. Moisture content in oxide is limited to 3 wt % water.
[j] UO_2-Mg will be shipped in a glass bottle inside a metal convenience can under an inert cover gas.
[k] For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
[l] Evaluation limit based on specific fuel type as opposed to a maximum calculated limit for $UZrH_x$.
[m] Oxides of U-Zr are UO_2-Zr and UO_2-ZrO_2.
[n] The maximum impurities in uranium silicide are shown in Table 1.2a.

Table 1.3a. Uranyl nitrate crystal content loading limits for ground transport

Product [a, b]	Seal time [c] (months)	CSI	Loading limit [d, e] (kg UNX)	U content [f] (wt %)
UNX, $0 < X \leq 3$	2	0.4	11.90	$52 < U \leq 61$
	4	0.4	6.70	$52 < U \leq 61$
UNX, $X > 3$	2	0.4	9.17	$46 < U \leq 52$
	4	0.0	4.75	$46 < U \leq 52$

[a] UNX is uranyl nitrate hydrate $[UO_2(NO_3)_2 \cdot XH_2O]$ where $0 < X \leq 6$.
[b] Must be shipped in Teflon bottles.
[c] Seal time—length of time after the ES-3100 containment vessel is sealed that the shipment must be complete. Seal times listed in this table are much lower than the calculated values shown in Table 3.5.4.1 in Appendix 3.5.4 and have been reduced for additional conservatism.
[d] Total mass of UNX crystals. Spacers are not required for this content type.
[e] Loading limits for uranyl nitrate crystals are based on hydrogen generation calculations presented in Appendix 3.5.4.
[f] Enrichment up to 100%.

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

Content description	Enrichment	CSI	^{235}U (kg)
HEU metal or alloy	≤100%	— [d]	7.00
HEU metal or alloy turnings, fines, or powder [e]	≤100%	— [d]	7.00
Research reactor fuel elements and components ($UZrH_x$, [f] U-Zr, U-Al, U_3O_8-Al, UO_2, oxides of U-Zr, [g] UO_2-Mg, U_3Si_2-Al)	≤20%	— [d]	0.921
	>20%	— [d]	0.408
HEU oxide [h, i] (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, [j] UO_2-ZrO_2)	≤100%	— [d]	5.281

[a] All limits are expressed in kg ^{235}U unless otherwise indicated.
[b] Mass loadings cannot be rounded up.
[c] The loading limit for mixed-mode transportation is taken as the most restrictive limit for either ground or air mode of transportation (Table 1.3 or 1.3b).
[d] CSI and spacer use are governed by ground transport mode.
[e] If the mass of metal or alloy turnings, fines, or powders is ≤ 50 g, then it may be shipped as the parent form (e.g., broken metal, reactor fuel, etc.).
[f] For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
[g] Oxides of U-Zr are UO_2-Zr and UO_2-ZrO_2.
[h] Seal time must be 12 months or less. Seal time is the length of time after the ES-3100 containment vessel is sealed that the shipment must be complete.
[i] Allowable uranium oxide bulk densities are 2.0–6.54 g/cm^3. Moisture content in oxide is limited to 3 wt % water.
[j] UO_2-Mg will be shipped in a glass bottle inside a metal convenience can under an inert cover gas.

1.2.2.3 Reflectors, absorbers, and moderators

The reflectors, absorbers, and moderators present in the ES-3100 package are those associated with the materials of construction. For example, the thermal insulation acts as a neutron reflector to the contents of a single package and as a neutron moderator in an array of packages. The degree of neutron moderation is a function of the hydrogen content in the Kaolite 1600 and 277-4 materials. The stainless-steel materials of the containment vessel and the drum also act as neutron reflectors to the contents of a single package but act as neutron absorbers in an array of packages. The nuclear properties of the materials of construction and of the contents are important and have been taken into account in the criticality safety evaluation (Sect. 6). In

addition to the materials of construction in the ES-3100 shipping package mentioned above, the 277-4 material has been specifically added to the ES-3100 package for the purpose of enhancing the neutron absorption characteristics for safety purposes (see Sect. 6 for additional discussion of the neutron-absorbing characteristics of this material).

1.2.2.4 Shipping configurations

Authorized content convenience containers for the ES-3100 are cans constructed of stainless steel, tin-plated carbon steel, aluminum, or nickel-alloy (Series 200, passivated), and polyethylene and Teflon convenience bottles. Modified convenience cans are constructed by brazing two 8.75-in.–tall cans together to create a 17.5-in.–tall can or by brazing three 10-in.–tall cans together to create a 30-in.–tall can. Research reactor fuel elements and fuel components may also be bundled together and protected on each end with open-ended convenience cans having an outer diameter ≤5 in. Solid form HEU contents (i.e., spheres, cylinders, bars, slugs) that will not fit in a convenience can may be bagged only with no convenience can required around the content. Enriched uranium oxide in the form of UO_2-Mg will be packed inside glass bottles, which are placed inside sealed, inerted metal convenience cans. These convenience containers are used to hold the HEU contents for shipment in the ES-3100 package and to assure that the inside of the containment vessel does not become contaminated with HEU under NCT. Convenience containers used in the ES-3100 package must have an outer diameter less than or equal to 12.7 cm (5 in.). The height can vary up to the full internal height of the containment vessel or 78.74 cm (31 in.). Some contents require the use of can spacers (see Table 1.3). These can spacers are thin-walled stainless-steel cans filled with 277-4 material (Drawing M2E801580A043, Appendix 1.3.7). 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 convenience cans having ≤5.0-in. diam and various heights [such as 4.75 in., 4.88 in., 8.75 in., 10 in., 17.5 in. (two 8.75-in. cans brazed together), and 30 in. (three 10-in. cans brazed together)], 4.94-in.-diam by 8.7-in.-tall polyethylene bottles, and 4.69-in.-diam by 9.4-in.-tall Teflon bottles. Although any combination of the convenience cans that will fit inside the internal volume of the containment vessel may be used, content forms shall not be mixed in a single package (i.e., HEU oxides may not be packed with HEU metal). Empty cans and/or stainless-steel scrubbers may be used to fill the void space at the top of the containment vessel. If empty cans are shipped, a minimum 0.32-cm (0.125-in.)-diam hole must be placed through the lid to prevent over-pressurization of the can in the event of a thermal accident. These empty cans may be placed above or below 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. If metal cans or polyethylene bottles are used as convenience containers, the total amount of offgassing material (including polyethylene bottles, polyethylene bagging, and lifting slings) is limited to 500 g per package. If Teflon bottles are used as convenience containers, the total amount of offgassing material (including Teflon bottles, polyethylene bagging, and lifting slings) is limited to 1490 g per package (limit established by assuming three 330-g Teflon bottles and 500-g polyethylene bagging). If closed convenience cans with an outer diameter greater than 4.25 in. are used, at least 55 $in.^3$ of free or void volume must exist inside the containment vessel to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC. The only hydrogenous materials that can be present in the containment vessel

when shipping HEU broken metal are those that have a hydrogen atom density less than or equal to that of water. In some shipping configurations, silicone rubber pads will be placed between the convenience cans to reduce vibration.

1.2.2.5 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 215.24 kPa (31.218 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 DAC-M900000-0003.

1.2.2.6 Maximum and minimum weight

The maximum allowable gross shipping weight for the ES-3100 package is 190.5 kg (420 lb). The largest nominal gross shipping weight of the ES-3100 package with HEU content is 187.81 kg (414.05 lb) [Table 2.8]. The total weight of the tested ES-3100 units ranged from 157.4 to 204.6 kg (347 to 451 lb) [Table 2.9].

The weight of HEU contents in the ES-3100 shipping package is limited to 35.2 kg (77.60 lb). This limit has been established as a bounding case for the maximum structural, thermal, and containment limit for the package. There is no minimum content weight requirement. Actual mass restrictions for the various contents based on the various analyses presented in the SARP are listed in Tables 1.3, 1.3a, and 1.3b. The maximum allowable payload weight of any configuration, including packing components (convenience cans and bottles, polyethylene bags, silicone pads, can spacers, etc.), is 40.82 kg (90 lb). ES-3100 shipping package weights are discussed in greater detail in Sect. 2 and are broken down into individual component weights in Tables 2.8 and 2.9.

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

1.2.2.7 Maximum decay heat

As shown in Sect. 3.1.2, the conservatively calculated maximum heat generation rate of the contents is ~5 W. The ES-3100 package was designed for a maximum heat load of 20 W. Thermal analyses have been performed assuming heat sources of 5, 10, 15, 20, 25 and 30 W in the ES-3100 containment vessel (DAC-PKG-801940-A001).

1.2.2.8 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, aluminum, or nickel alloy convenience cans, polyethylene bottles, or Teflon bottles. Solid form HEU contents (i.e., spheres, cylinders, bars, slugs) that will not fit in a convenience can may be bagged only with no convenience can required around the content. For contents that are bagged only, stainless-steel metal scrubbers may be placed on the top and bottom of this assembly inside the containment vessel. For these bagged contents, the void volume

requirement stated in Loading Restriction 8 must still be satisfied. Enriched uranium oxide in the form of UO_2-Mg will be shipped in glass bottles inside a metal convenience can. 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 (~31 in.).

(3) In situations where empty convenience cans are shipped in the package, they may be placed either above or below 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; concentration limits for uranium oxide are shown in Table 1.2.

(5) For pyrophoric considerations, HEU metal or alloy pieces must have a specific area not greater than 1 cm^2/g or must not pass through a 3/8-in. (9.5-mm) mesh sieve (or equivalent size-grading method). Incidental small pieces that do not pass the size restriction tests, and powders, foils, turnings, and wires, may only be shipped if they are in a sealed, inerted container. Glass bottles containing enriched uranium oxide in the form of UO_2-Mg must be placed in a sealed, inerted container.

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

(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) If metal cans are used as convenience containers, the amount of polyethylene bagging and lifting slings is limited to 500 g per package. If Teflon bottles are used as convenience containers, the total amount of offgassing material (including Teflon bottles, polyethylene bagging, and lifting slings) is limited to 1490 g per package. If metal cans or polyethylene bottles are used as convenience containers, the total amount of offgassing material (including polyethylene bottles, polyethylene bagging, and lifting slings) is limited to 500 g per package (see Item 7 in Sect. 6.2.4). If closed convenience cans with an outer diameter greater than 4.25 in. are used, at least 55 $in.^3$ of free or void volume must exist inside the containment vessel to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC. These mass limits do not include moisture in oxide. Moisture is accounted for in criticality safety calculations (Sect. 6.1.2).

(9) The only hydrogenous packing materials that can be used in the containment vessel when shipping broken HEU metal are those that have a hydrogen atom density less than or equal to that of water.

(10) Shipments of UNX crystals must be completed in the time period noted in Table 1.3a. Shipments of uranium oxide must be completed in 12 months. This time period begins when the containment vessel is sealed.

(11) The mass of any unidentified constituents in content to be shipped in the ES-3100 must be counted against the fissile mass loading limit. Content must not contain unevaluated moderating materials.

(12) Allowable HEU oxide bulk densities are 0.5–6.54 g/cm^3 for ground transport and 2.0–6.54 g/cm^3 for air transport.

(13) As noted in Table 1.3, Note e, ground transport of solid HEU metal or alloy of specified geometric shapes is limited to one item per convenience container, with the exception of slugs, which are limited to a maximum of 10 per convenience container.

(14) For air transport, the total free water permitted in the ES-3100 packaging is limited to 12 lb (5,443 g).

1.2.3 Special Requirements for Plutonium

The contents to be shipped in the ES-3100 have only trace amounts of transuranic isotopes [<0.74 TBq (20 Ci)]. Therefore, the requirements in 10 CFR 71.63 are not applicable.

1.2.4 Operational Features

The ES-3100 package is a Type B(U) 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 maintenance 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.

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 APPENDICES

1.3.1 Package Certification Drawing

1.3.2 Equipment Specification JS-YMN3-801580-A002, *ES-3100 Drum Assembly*

1.3.3 Equipment Specification JS-YMN3-801580-A001, *ES-3100 Containment Vessel*

1.3.4 Equipment Specification JS-YMN3-801580-A003, *Manufacturing Process Specification For Casting Kaolite 1600™ into the ES-3100 Shipping Package*

1.3.5 Equipment Specification JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package*

1.3.6 Package Category Determination

1.3.7 ES-3100 Design Drawings

1.3.8 Pyrophoricity of Uranium Metal

1.3.9 SPC-M801580-0002, *Equipment Specification for Ethylene Propylene Diene Monomer (EPDM) Containment Vessel O-rings*

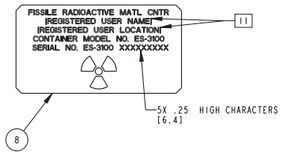
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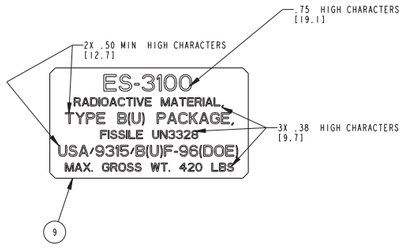
Appendix 1.3.1

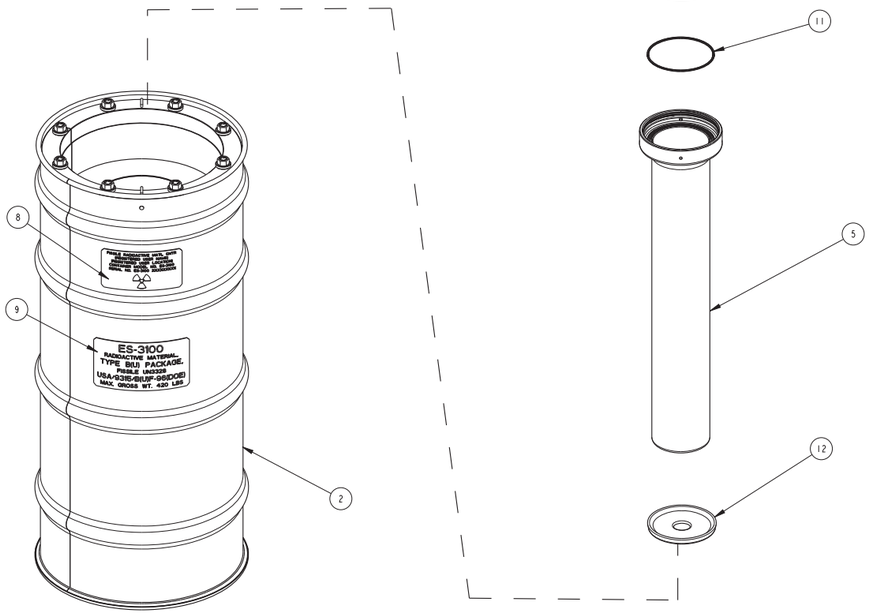
Package Certification Drawing

Drawing No.	Rev.	Title
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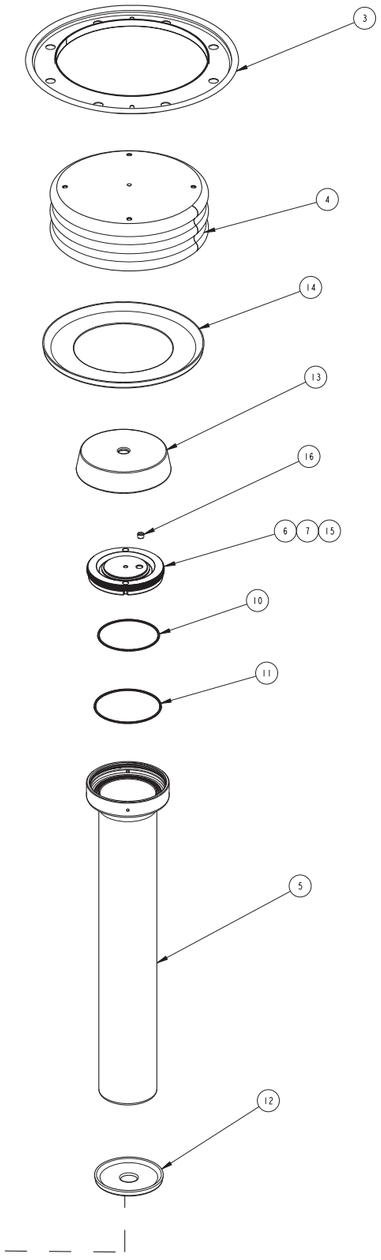
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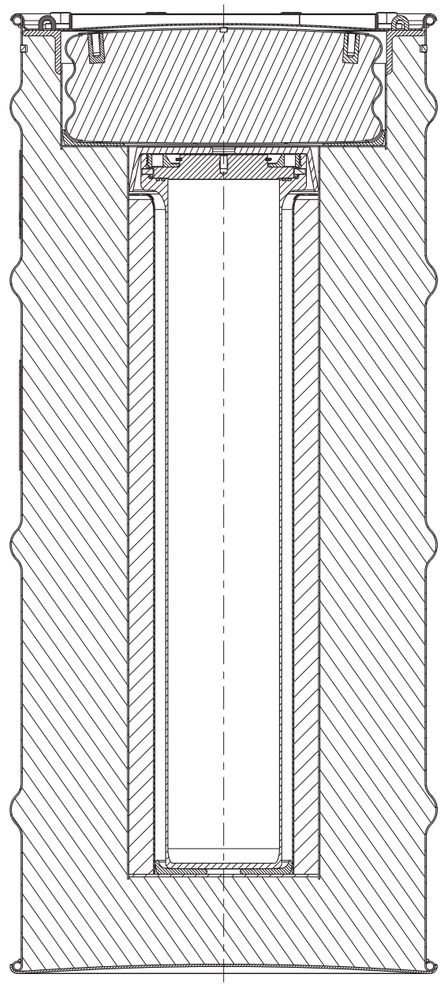






-1 MAIN ASSEMBLY





NOTES

1. DELETED
2. DELETED
3. APPROXIMATE WEIGHT: 325 LBS [147.4 Kg] FOR F/N 1 EMPTY.
4. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
5. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002 ES-3100 DRUM ASSEMBLY.
6. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A001 ES-3100 CONTAINMENT VESSEL.
7. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A003 MANUFACTURING PROCESS SPECIFICATION FOR CASTING KAOLITE 1600™ INTO THE ES-3100 SHIPPING PACKAGE.
8. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A005 CASTING CATALOG # 277-4 NEUTRON ABSORBER FOR THE ES-3100 SHIPPING PACKAGE.
9. DURING INSTALLATION OF O-RINGS APPLY A THIN COAT OF SUPER-O-LUBE
10. DURING INSTALLATION OF CONTAINER VESSEL LID ASSEMBLY, APPLY A LIGHT COAT OF KRYTOX GREASE TO THE THREADS AND UNDER THE NUT.
11. SEE PROCUREMENT DOCUMENTS FOR PROPER REGISTERED USER NAME AND LOCATION.
12. DELETED

	AR	KRYTOX K240AC OR EQUAL THREAD LUBRICANT	FLUORINATED GREASE MILLER-STEPHENSON CHEMICAL CO.	NA	18
10	AR	SUPER-O-LUBE OR EQUAL O-RING LUBRICANT	CLEAR DIMETHYL SILOXANE POLYMER PARKER HANNIFIN CORP	NA	17
	1	MODIFIED VCO THREADED PLUG	BRASS	3	16
9	1	EXTERNAL RETAINING RING	302 SST	3	15
	1	PLUG PAD	SILICONE RUBBER 27±5 SHORE A COLOR BLACK/GRAY	1	14
	1	CV FLANGE PAD		1	13
	1	CV BOTTOM PAD		1	12
G	1	OUTER O-RING Ø5.859±.035 ID X Ø.139 ±.004	ETHYLENE PROPYLENE DIENE MONOMER 70±5 SHORE A COLOR BLACK	1	11
	1	INNER O-RING Ø5.359±.035 ID X Ø.139±.004		1	10
5	1	ES3100 DATA PLATE	16 GA 304/304L SST ASTM SA240	1	9
5	1	ES3100 TREFOIL DATA PLATE		1	8
6	1	CONTAINMENT VESSEL CLOSURE NUT	NITRONIC 60 SST ASME SA-479 UNS-S21800	3	7
6	1	CONTAINMENT VESSEL SEALING LID	304 SST ASME SA-479	3	6
6	1	CONTAINMENT VESSEL BODY	304L SST	3	5
7 5	1	TOP PLUG WELDMENT	16 GA 304/304L SST ASTM SA240	2	4
5	1	DRUM LID WELDMENT		2	3
8 7 5	1	DRUM WELDMENT		2	2
	X	MAIN ASSEMBLY		1	1
	-	NOMENCLATURE OR DESCRIPTION	MATERIAL / SPECIFICATION	SHEET NO	FIND NO
	←	QTY REQ'D NEXT ASSEMBLY	PARTS LIST		

UNCLASSIFIED

THIS DOCUMENT HAS BEEN REVIEWED AND CONFIRMED TO BE UNCLASSIFIED.

NAME/DATE: This document has been reviewed and confirmed to be UNCLASSIFIED. Name: Stian Thomas Date: 07/19/2016 — Stian (TSW) Thomas

TITLE: Y-12 ENGINEER

ORGANIZATION: Y-12 ENGINEERING

NUCLEAR CRITICALITY SAFETY

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY.

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

APPROVALS

DES	KW JOHNSON	NCS	AD WILKINSON
	Kevin W (KZH) Johnson		Alan D. (WA9) Wilkinson
DE	GA BYINGTON		
	G A (GAB) Byington		
CHKR	JL ROBERSON		
	Larry (LRN) Roberson		
DVR	ML GOINS		
	Monty L (MLG) Goins		
DW/PE	JC ANDERSON		
	James C (JSA) Anderson		
PM	JG ARBITAL		
	Jeffrey G (AJU) Arbital		

EFFECTIVE DATE: REFER TO DESIGN MANAGER APPROVAL

REVISION DESCRIPTION	NEXT ASSEMBLY/ REFERENCE DOCUMENTS
UPDATED FORMAT, DELETED VITON OPTION IN F/N's 10 & 11 AND DELETED NOTES 1 & 2.	N/A

TOLERANCES UNLESS OTHERWISE SPECIFIED

FRACTIONS	
XX DECIMALS	±.01
XXX DECIMALS	±.005
ANGLES	±0.5°
BREAK SHARP EDGES	.01 - .06
FINISH	125 RMS MAX
THIRD ANGLE PROJECTION	

I — IMPORTANT TO FORM-FIT-FUNCTION INDEPENDENT VERIFICATION REQUIRED

S — IMPORTANT TO SAFETY SHALL BE 100% INSPECTED AND NOT DEVIATED WITHOUT APPROVAL

SCALE: NOTED

SHEET SIZE REPRESENTATION: 1 INCH SQUARE AT FULL SIZE

SCALE PROVIDED FOR REFERENCE ONLY DO NOT SCALE

APPROXIMATE WEIGHT: N/A

DIMENSIONING AND TOLERANCING: ASME Y14.5M - 1994

ALL DIMENSIONS ARE IN: INCHES [mm]

SOFTWARE: CREO 2.0

Y-12 NATIONAL SECURITY COMPLEX
CONSOLIDATED NUCLEAR SECURITY, LLC
P.O. BOX 2009, OAK RIDGE, TN 37831

US GOVERNMENT CONTRACT: DE-NA0001942

USERS MUST REFER TO THE TRANSMITTAL DOCUMENTS THAT ACCOMPANIED DELIVERY OF THIS DRAWING FOR ANY APPLICABLE DISCLAIMERS GOVERNING THE DRAWING.

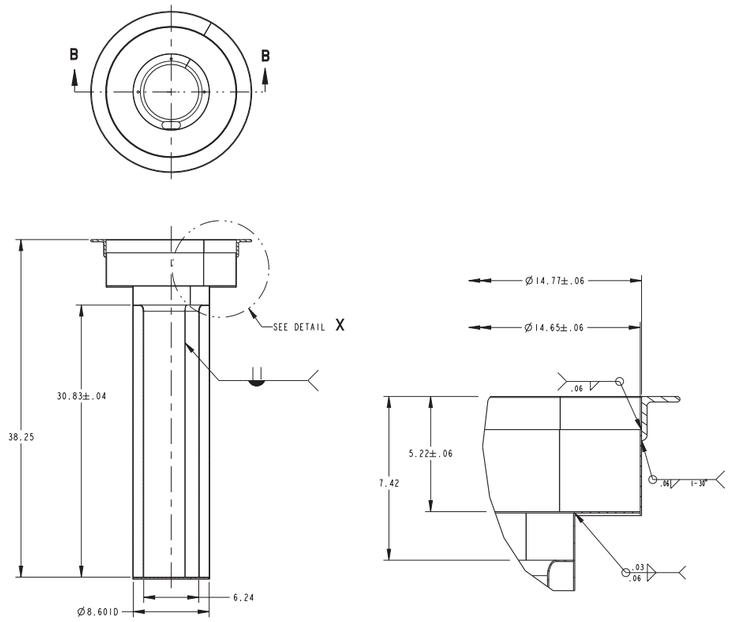
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TITLE: CONSOLIDATED ASSEMBLY DRAWING

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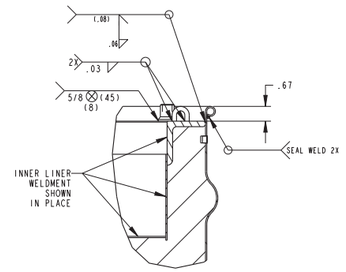
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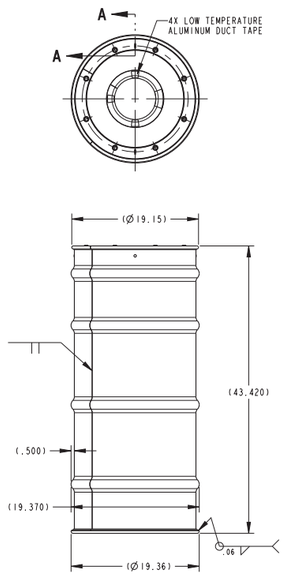
SECTION B-B

DETAIL X

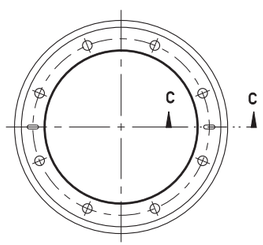
INNER LINER WELDMENT



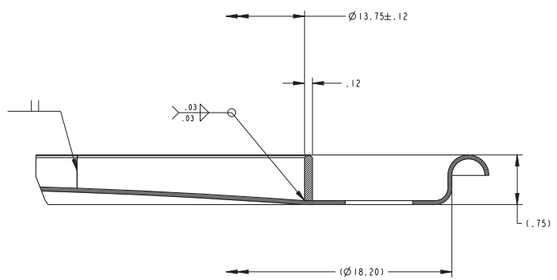
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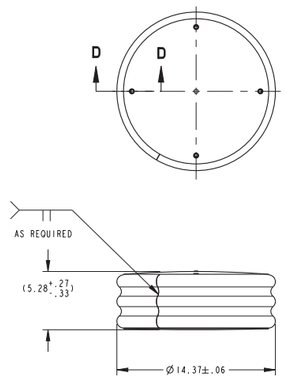
-2 DRUM WELDMENT



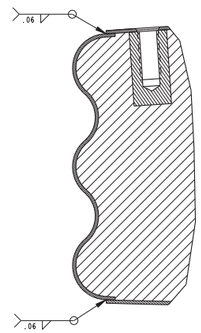
-3 DRUM LID WELDMENT



SECTION C-C



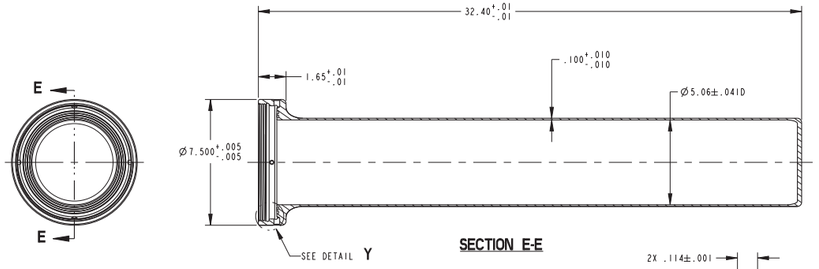
-4 TOP PLUG WELDMENT



SECTION D-D

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	TITLE: CONSOLIDATED ASSEMBLY DRAWING		
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USERS MUST REFER TO THE TRANSMITTAL DOCUMENTS THAT ACCOMPANIED DELIVERY OF THIS DRAWING FOR ANY APPLICABLE DISCLAIMERS GOVERNING THE DRAWING.	RECORD NO: N/A	STATE: IF	SHEET: 2 OF 3

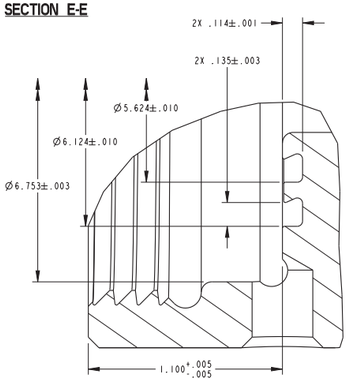
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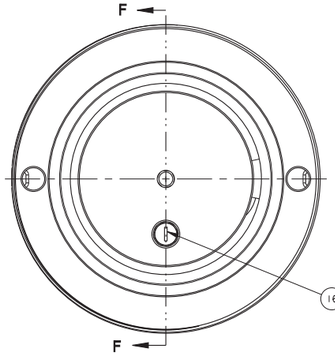
-5 CONTAINMENT VESSEL BODY

OPTIONAL WELDED CONSTRUCTION SHOWN ON SHEET 6

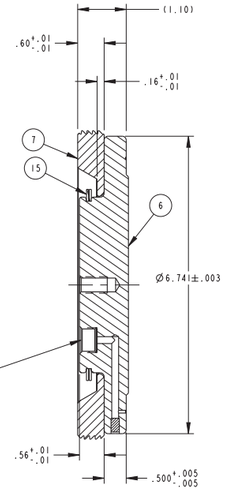
SECTION E-E



DETAIL Y



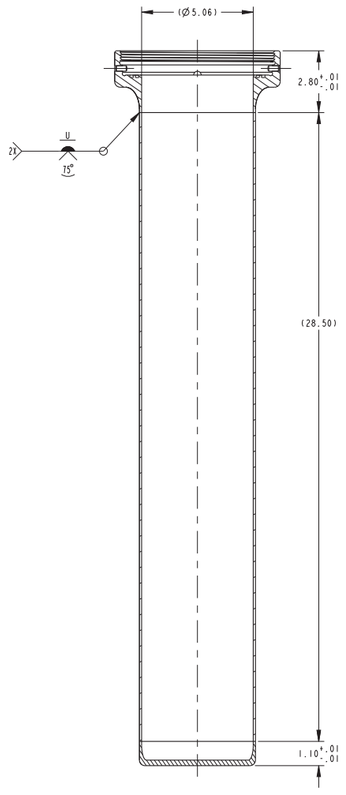
CONTAINMENT VESSEL SEALING LID ASSEMBLY



SECTION F-F

WELD NOTES:

1. ALL WELDS ON THE CONTAINMENT VESSELS SHALL BE DONE EITHER BY THE GTAW OR GMAW PROCESS, MANUAL OR AUTOMATIC, AT THE DISCRETION OF THE SELLER UNLESS SPECIFICALLY CALLED OUT ON THE DRAWINGS. BACKING RINGS, EVEN IF REMOVED AFTER THE WELD HAS BEEN MADE, SHALL NOT BE USED. AS PREVIOUSLY STATED, WELD SYMBOLS ARE PROVIDED ON THE DRAWING INDICATING FOR EACH WELD THE TYPE OF WELD AND DIMENSIONS OF THE WELD.
2. EXCEPT AS LIMITED BY THIS SPECIFICATION, THE APPLICABLE REQUIREMENTS OF NB-4300 AND NB-4400 SHALL APPLY TO THE CONTAINMENT VESSEL.
3. PRIOR TO WELDING, ALL WELD PREPARATION AREAS AND THE SURFACES WITHIN ONE INCH OF THE WELD AREA SHALL BE EXAMINED VISUALLY AND WITH LIQUID PENETRANT. THE ACCEPTANCE CRITERIA FOR THESE EXAMINATIONS ARE THOSE STATED IN NB-5130 (A) THROUGH NB-5130 (D). THE RESULTS OF THESE SURFACE EXAMINATIONS SHALL BE REPORTED TO THE COMPANY TOGETHER WITH THE WELD EXAMINATION REPORTS, SEE SECTION 3.4 OF THIS SPECIFICATION.
4. WELDERS PERFORMING TWO OR MORE WELDS IN ONE DAY THAT ARE REJECTED BASED UPON WELDER TECHNIQUE SHALL BE SUBJECT TO BE RE-QUALIFIED TO THE APPROPRIATE WELDING PROCEDURES, SEE SECTION IX, PARAGRAPH QW-320 OF THE ASME CODE.
5. THE APPLICABLE REQUIREMENTS IN PARAGRAPHS NB-5110, NB-5120, NB-5210, NB-5220, NB-5260, AND NB-5300 SHALL APPLY TO THE CONTAINMENT VESSELS. THE PLUG WELD SHOWN ON DRAWING M2E801580A015 SHALL BE EXAMINED VISUALLY AND WITH PENETRANT. THE APPLICABLE REQUIREMENTS IN PARAGRAPHS NB-5110, AND NB-5350 SHALL APPLY TO THE PLUG WELD. NOTE THAT THE REFERENCE TO THE INSPECTOR IN NB-5112, FOR THE PURPOSES OF THIS SPECIFICATION IS EITHER THE COMPANY'S INSPECTOR OR A SUBCONTRACTOR DESIGNATED BY THE COMPANY.
6. MATERIALS USED IN THE PENETRANT EXAMINATION OF WELDS AND IN THE FINAL SURFACE EXAMINATION OF FINISHED COMPONENTS (SEE SECTION 3.7) SHALL BE SPECIFICALLY RECOMMENDED BY THEIR SUPPLIERS FOR USE WITH AUSTENITIC STAINLESS STEELS, AND COPIES OF THE CERTIFICATION OF CONTAMINANT CONTENT OF MATERIALS USED (SEE SECTION V, ARTICLE 6, T-641) SHALL BE SUPPLIED TO THE COMPANY WITH THE EXAMINATION REPORTS.
7. REPAIR WELDING SHALL MEET THE APPLICABLE REQUIREMENTS OF NB-2500.
8. CERTIFIED WRITTEN WELD EXAMINATION REPORTS TOGETHER WITH THE CORRESPONDING MATERIAL SURFACE EXAMINATION REPORTS, AND WELD MAP SHALL BE SUBMITTED TO THE COMPANY AS STATED IN THE PROCUREMENT SPECIFICATION FOR THE ES-3100 CONTAINMENT VESSEL. WELD EXAMINATION REPORTS FOR ALL WELD AND SURFACE EXAMINATION SHALL INCLUDE: THE CONTAINMENT VESSEL SERIAL NUMBER, A WELD MAP SHOWING THE LOCATION OF THE WELD AND EXAMINATION AREA, THE WELDER'S NAME, THE EXAMINER S NAME, THE TIME AND DATE OF THE WELD EXAMINATION, THE EXAMINATION PROCEDURE(S) NUMBER USED, THE WPS NUMBER, THE HEAT NUMBERS OF THE MATERIALS JOINED, THE HEAT NUMBER OF THE WELD FILLER, AND EXAMINER S REMARKS. THE EXAMINER'S REMARKS SHALL INCLUDE THE RESULTS OF THE EXAMINATION AND ACCEPTANCE, OR REJECTION OF THE WELD BASED ON THE STATED CRITERIA. ONE SET OF RADIOGRAPHS SHALL BE PROVIDED TO THE COMPANY WITH RADIOGRAPHIC EXAMINATION REPORTS. IF THE WELD OR SURFACE IS REJECTED, A DESCRIPTION OF THE DEFECT AND SKETCH SHOWING THE LOCATION SHALL BE PROVIDED.
9. IF A WELD IS REJECTED, THE AREA SHALL BE WELD REPAIRED BY THE SELLER AND RE-EXAMINED. AFTER TWO UNSUCCESSFUL REPAIR ATTEMPTS, THE COMPANY SHALL BE NOTIFIED FOR APPROVAL TO PERFORM MORE REPAIR ATTEMPTS. THE COMPANY MAY, AT ITS OPTION, CHOOSE TO REJECT FURTHER REPAIR EFFORTS AND REQUIRE THAT A REPLACEMENT PART BE FABRICATED.



CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION

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

Y-12 NATIONAL SECURITY COMPLEX
CONSOLIDATED NUCLEAR SECURITY, LLC
P.O. BOX 2009 OAK RIDGE, TN 37831

US GOVERNMENT CONTRACT: DE-NA0001942

USERS MUST REFER TO THE TRANSMITTAL DOCUMENTS THAT ACCOMPANIED DELIVERY OF THIS DRAWING FOR ANY APPLICABLE DISCLAIMERS GOVERNING THE DRAWING.

PROJECT: ES-3100 SHIPPING PACKAGE

TITLE: CONSOLIDATED ASSEMBLY DRAWING

DRAWING NUMBER: M2E801580A037 | PART: 000 | REV: G

RECORD NO: N/A | STATE: IF | SHEET: 3 OF 3

M2E801580A037 REV G SHEET 3 OF 3

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Appendix 1.3.2

Equipment Specification JS-YMN3-801580-A002,
ES-3100 Drum Assembly

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EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

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

ENGINEERING AND PLANT APPROVALS

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

REVISIONS/ENGINEERING AND PLANT APPROVALS

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

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

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

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

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- 3.2 Welding 3
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- 3.4 Cleaning and Passivation 5
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LIST OF COMPANY DRAWINGS

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

1.0 SCOPE

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

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

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

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

2.0 APPLICABLE CODES AND STANDARDS

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

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

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

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

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

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

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

- American Society For Testing Materials, ASTM A 380-99^{e1}, Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems.

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

3.0 DETAILED REQUIREMENTS

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

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

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

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

The following additional requirements apply as follows:

3.1 Materials

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

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

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

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

3.2 Welding

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

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

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

3.3 Weld Examination

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

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

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

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

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

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3.4 Cleaning and Passivation

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

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

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

3.5 Dimensional Inspection Reports

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

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

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Appendix 1.3.3

Equipment Specification JS-YMN3-801580-A001,
ES-3100 Containment Vessel

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EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

SPECIFICATION NO.	REV.	ISSUE DATE
JS-YMN3-801580-A001	H	10-15-03
PAGE	REVISION DATE	
i OF ii	7-11-16	
PROCURED BY	INSTALLED BY	
B&W Y-12 LLC	B&W Y-12 LLC	

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

ENGINEERING AND PLANT APPROVALS

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

REVISIONS/ENGINEERING AND PLANT APPROVALS

REV. NO.	DESCRIPTION OF REVISION
A	Issued Approved
B	Included the requirements for a Containment Vessel that was fabricated by welding a forged bottom, a forged top flange and a cylindrical shell as shown on the revised drawing, M2E801580A012, Rev B.
C	In all locations removed the references to the Procurement Specification document number OO-PP-1210. Modified the Weld Repair reject and re-qualification requirements in Section 3.3 in the fourth paragraph. In Section 3.9, first, third, and fourth paragraphs changed the units from ref-cm3/sec to cm3/sec helium. Also added new Section 3.6 Welding Documentation Submittals.
D	Added two paragraphs to the end of Section 3.1 for reference to ASTM A 262 in accordance with REDC #PE-05-046-A. Added a sentence to the beginning of the first paragraph in Sect. 3.9 in accordance with REDC # PE-06-059.
E	Section 3.0, paragraph 3, the phrase "the Company's written approval" has been revised to "the Company's written approval, and regulatory authority's written approval."
F	Removed statement about metal spinning in Section 3.1, page 4. Also made many editorial changes on page 9 to support SARP defined in EC-801940-0001.
G	Added Viton O-ring drawing as a optional O-ring. Changed Procurement Specification OO-PP-986 to Equipment Specifications SPC-M801580-0001 (for Viton O-ring) and SPC-M801580-0002 (for EPDM O-ring).
H	Removed Viton O-ring as an optional O-ring.

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY L. Roberson	7/19/16	PROJECT ENGINEER L. Roberson	7/28/16
DISCIPLINE MANAGER James C. Anderson	7/21/16	OPERATIONS MANAGER/SYSTEM OWNER: N/A	
DESIGN VERIFICATION Monty Harris	7/20/16	Program Manager J.C. Walls	7/25/16

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

Name: Stan Thomas Stan Thomas Date: 07/19/16

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LIST OF COMPANY DRAWINGS

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

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EQUIPMENT SPECIFICATION
ES-3100 Containment Vessel

SPECIFICATION NO.	REV.
JS-YMN3-801580-A001	H
ISSUE DATE	REVISION DATE
10-15-03	7-11-16
PLANT	PAGE
Y-12	1 OF 9

1.0 SCOPE

This specification, equipment specification SPC-M801580-0002, *ES-3100 Ethylene Propylene Diene Monomer (EPDM) CV O-rings*, the Company's drawing, and the referenced codes and standards in Sect. 2.0 of this specification state the requirements for the procurement of materials and components, fabrication, inspection, examination, assembly, and testing of the containment vessels for the ES-3100 shipping package. If conflicting requirements appear between the Company's drawings and specifications, the Seller shall immediately notify the Company, so that these can be resolved. The Seller shall provide the number of completed assemblies specified in the purchase order.

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

2.0 APPLICABLE CODES AND STANDARDS

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

- ANSI N14.5-1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment,* American National Standards Institute.
- *ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1 - Subsections NB and NCA, Class 1 Components, 2001 Edition and 2002 and 2003 addenda.
- *ASME Boiler and Pressure Vessel Code*, Sect. II, Parts A and C, 2001 Edition and 2002 and 2003 addenda.
- *ASME Boiler and Pressure Vessel Code*, Sect. V, 2001 Edition and 2002 and 2003 addenda.
- *ASME Boiler and Pressure Vessel Code*, Sect. IX, 2001 Edition and 2002 and 2003 addenda.
- ASTM A 380-99^{e1}, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems,* American Society for Testing and Materials.

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- SNT-TC-1A-1992, *Recommended Practice for Nondestructive Testing Personnel Qualification and Certification*, American Society for Nondestructive Testing, Dec 1992.
- SSPC SP 5/NACE No. 1, *White Metal Blast Cleaning*, Society for Protective Coatings.

3.0 DETAILED REQUIREMENTS

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

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

Any material substitution or other deviation from the requirements shown on the Company's drawings or stated in the Company's specifications is not permitted without the Seller submitting a written request for waiver or deviation, and Company's written approval, and regulatory authority's written approval.

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

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

The following additional requirements apply as follows:

3.1 Materials and Material Examinations

The containment vessel body (Drawing M2E-801580-A012), the sealing lid, (Drawing M2E-801580-A015), and the closure nut (Drawing M2E-801580-A016), shall be considered pressure retaining materials as defined in NB-2110, and meet the applicable requirements of NB-2120. Documented Certified Material Test Reports (CMTRs) shall be provided to the Company for the

materials used to fabricate these components in accordance with NCA-3860. The suppliers of these materials shall meet the requirements of NCA-3800. Such parts shall be traceable to each containment vessel by means of a serial number assigned by the Company. The Seller shall maintain control of materials to ensure this traceability. Other metallic materials, and the O-ring seals shall be supplied with Certificate of Compliances in accordance with NCA-3862(g) and (h).

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

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

The Seller shall provide the Company with CMTRs, certified material examination reports and Certificates of Compliance for the materials stated above as required.

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

The formed containment vessel body, Part M2E801580A012-1, shall be flow formed from a single forged billet or bar. Special requirements for this part are given as follows.

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

The formed, heat treated, and finished machined containment vessel body, Part M2E801580A012-1, shall meet the applicable requirements of ASME SA-182 for Grade F304L for a forged component. After final forming, parts shall be solution annealed and quenched per the requirements of ASME SA-182 for Grade F304L. In addition, the requirements of NB-2180 shall also apply. A certified heat treatment

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report shall be provided stating for each furnace charge the following information: the serial numbers of the containment vessel bodies heat treated in the furnace charge, the time and date of the heat treating, the person responsible for the heat treating, the time-temperature profile of the furnace and representative parts of the furnace charge, the quench medium, and all other pertinent details of the heat treating. Such a heat treating report is required for all heat treating, both in process annealing and final heat treatment.

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

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

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

The heat treating procedure must be qualified by measuring the annealing temperatures, soak times and cooling rates of the furnace batch, and then testing heat treated specimens that represent the lowest annealing temperatures, soak times and cooling rates for that furnace batch for sensitivity to intergranular corrosion using Practice E of ASTM A 262. For subsequent annealing operations, the

temperatures, soak times, and cooling rates of subsequent furnace batches must be measured and compared to the qualified procedure. Other factors, such as variations of the size and arrangement of the furnace batch that can affect part temperatures and part cooling rates, and the calibration of the furnace temperature sensors must be assessed in the procedure qualification to ensure that minimum temperatures and cooling rates of production heat treating batches can be properly compared to those of the qualified procedure. Such a procedure should be requalified for each individual furnace used, and for significantly different furnace batch sizes. The procedure shall be requalified annually, or if it has not been used for a period of at least three months.

3.2 Forming, Fitting and Alignment

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

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

3.3 Welding and Weld Repair

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

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

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

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

3.4 Weld Examination

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

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

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

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

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

3.5 NDE Examiner Qualifications

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

3.6 Welding Documentation Submittals

Submittal of the following are required with the bid unless the current revisions of these submittals have been previously approved by the Company. Submittals that do not demonstrate compliance with this specification will be cause for rejection of the proposal.

- Typical WPS for the applicable code.
- Procedure qualification records (PQR).
- Typical welder performance qualification (WPQ) records for the appropriate code.

Submittal of the following documents are required prior to welding unless the current revisions of these submittals have been previously approved by the Company.

- WPS.
- PQR.
- WPQ records, including evidence of process usage updates.
- Visual examination and nondestructive examination procedures.
- Certification records of examination personnel.
- CMTR.

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

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

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

3.7 Hydrostatic Testing

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

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

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

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3.8 Final Examination of Finished Surfaces

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

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

3.9 Leak Testing

There are three leak tests to be performed on the ES-3100 containment vessel. The leak testing is to be performed after hydrostatic testing. Following the hydrostatic pressure test and prior to conducting any leak test, the containment vessel and O-ring cavities must be thoroughly dried. The leak testing is to be performed in accordance with the applicable sections of ANSI N14.5-1-1997. A written leak test procedure(s) shall be prepared to perform this testing and submitted to the Company for approval. The written test procedure(s) and leak testing report shall comply with the applicable requirements of Sect. V of the ASME Code. The leak testing for the first two leak tests shall have the sensitivity to detect a leak less than or equal to 5×10^{-8} ref-cm^3/sec of air, or 1×10^{-7} cm^3/sec helium and shall use the leak test fixtures shown on the Company's Drawings M2E801580A021, M2E801580A022, and M2E801580A023.

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

The first leak test shall be performed with the containment vessel body assembled as shown on Drawing M2E801580A023, (Part M2E801580A023-1, *Containment Vessel Body Leak Test Assembly*). Note that the outer O-ring in the containment vessel body is not to be installed for this test. The leak testing acceptance criteria is that the assembly shall not have an integrated leak rate greater than 1×10^{-7} ref-cm^3/sec of air, or 2×10^{-7} cm^3/sec helium.

The second leak test shall be performed with the containment vessel lid assembly as shown on Drawing M2E801580A023, (Part M2E801580A023-2, *Containment Vessel Lid Leak Test Assembly*). The leak testing acceptance criteria is that the assembly shall not have an integrated leak rate greater than 1×10^{-7} ref-cm^3/sec of air, or 2×10^{-7} cm^3/sec helium.

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The third leak test is to be performed with the containment vessel assembled as shown on Drawing M2E801580A011. The leak testing acceptance criteria is that the assembly shall not have an air leak rate greater than 1×10^{-4} ref-cm^3/sec and the sensitivity of the leak testing procedure shall be less than or equal to 5×10^{-5} ref-cm^3/sec.

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

3.10 Cleaning, Passivation, and Bead Blasting

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

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

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

3.11 Dimensional Inspection Reports

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

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Appendix 1.3.4

Equipment Specification JS-YMN3-801580-A003,
Manufacturing Process Specification for Casting Kaolite 1600™
into the ES-3100 Shipping Package

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EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

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

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

SPECIFICATION FOR

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

SSC IDENTIFICATION NUMBER

ENGINEERING AND PLANT APPROVALS

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

REVISIONS/ENGINEERING AND PLANT APPROVALS

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

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY G.A. Byington	6/1/06	PROJECT MANAGER: George Singleton	6/1/06
DISCIPLINE MANAGER C.M. Arnold for W.I. North	6/1/06	CRITICALITY SAFETY: J.F. Clark	6/1/06
DESIGN VERIFICATION Monty L Goins	6/1/06	QUALITY ASSURANCE: D.W. Eckert	6/1/06

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

Name: R. D. Gin Date: 06/01/06

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ATTACHMENTS

A	**Kaolite Mixing Control**
B	**Body Weldment**
C	**Top Plug Assembly Vibration Casting Control**
D	**Furnace and Baking Control**
E	**Wet Density Mixer Time Vibration Casting**
F	**Baked Qualification Density Sample Vibration Casting**

1 Scope

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

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

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

2 Applicable Documents

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

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

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

3 Kaolite 1600™ Processing Requirements

3.1 General

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

3.1.1 Kaolite 1600™ Receiving and Storage Instructions

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

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

3.1.2 Cleaning Instructions

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

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

3.1.3 Mixing Water and Mixing Equipment Requirements

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

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

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

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

3.2 Mixing of Kaolite 1600™

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

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

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

The Kaolite 1600™ mixing shall be performed as follows:

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

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

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

3.3 Vibration Casting and Curing of Kaolite 1600™ into Assemblies

3.3.1 Body Weldment Casting Instructions

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

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

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

Casting operations shall be performed as follows:

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

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

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

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

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

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

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

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

3.3.2 Body Weldment Curing Instructions

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

Curing operations shall be performed as follows:

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

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

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

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

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

3.3.3 Top Plug Assembly Casting Instructions

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

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

Casting operations shall be performed as follows:

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

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

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

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

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

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

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

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

3.3.4 Top Plug Assembly Curing Instructions

Curing operations shall be performed as follows:

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

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

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

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

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

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

3.4.1 Baking Instructions

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

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

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

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

3.4.2 Baking Documentation

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

The baking furnace heating cycle shall be completed as follows:

a. Place the assemblies into the furnace.

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

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

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

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

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

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

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

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

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

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

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

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

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Acceptance criteria:

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

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

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

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

3.5 Mixer Qualification for Kaolite 1600™ Casting Placement

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

3.5.1 Wet Density Mixing Test

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

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

Plot the wet mix density of the two pails versus the mix time in an Excel file. An Excel file generated by the Company can be provided for this task upon request. Curve fit the data

using a third order polynomial curve and show the equation. Plot the target density of 56.2 lb/ft^3 on a chart in Excel along with the wet mix density. Where the curves intersect the target density line is the mixer's target mix time. Consult the Company for verification of this data. Use the Company verified mix time for the Mixer Baked Density Qualification Castings in Section 3.5.2.

3.5.2 Mixer Baked Density Qualification Castings

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

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

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

4. Quality Assurance Requirements

4.1 General

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

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

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

4.1.4 The Seller shall generate the documentation necessary to show compliance with the approved quality assurance program plan. All records shall be identified based on the assembly serial numbers. The Seller shall maintain quality-related documentation in accordance with requirements in the procurement specification. The Company reserves the right to request any

such documentation and to witness all aspects of the fabrication process in accordance with this specification. The Seller shall ensure that the specified manufacturing and inspection records are generated and supplied to the Company as part of the certification package.

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

4.2 Material and Equipment Certification

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

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

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

4.3 Nonconformance Control

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

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

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

4.4 Operator and Witness Qualifications

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

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4.4.1 Kaolite 1600™ Mixing Process Qualifications

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

a. Location and time.

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

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

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

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

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

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

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

4.4.2 Kaolite 1600™ Vibration Casting Process Qualifications

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

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

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

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

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

4.4.3 Kaolite 1600™ Baking Process Qualifications

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

EXEMPT FROM IO-155

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[d] Use the above weights to calculate the Density as shown below. If the density is greater than 25.4 lb/ft^3 then proceed with Baking Cycle 1A. If the density is, less then 19.4 lb/ft^3 then contact the Company for disposition.

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

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

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

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

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

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

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

EXEMPT FROM IO-155

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

EXEMPT FROM IO-155

Appendix 1.3.5

Equipment Specification JS-YMN3-801580-A005,
Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package

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EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

SPECIFICATION NO.	REV.	ISSUE DATE
JS-YMN3-801580-A005	G	02-18-05
PAGE	REVISION DATE	
i of ii	08/31/2009	
PROCURED BY	INSTALLED BY	
BWXT Y-12 L.L.C.	B&W Y-12 L.L.C.	

PROJECT TITLE	PLANT	BUILDING
ES-3100 Shipping Package	Y-12	AREA
JOB TITLE	W.O. OR E.S.O.	RECORD NUMBER
Production Design Definition	7ADDEQ01	Y2003-0328
SPECIFICATION FOR		SSC IDENTIFICATION NUMBER
Casting Catalog No. 277-4 Neutron Absorber For The ES-3100 Shipping Package		NA

APPROVALS

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

REVISIONS/APPROVALS

REV. NO.	DESCRIPTION OF REVISION
A	Issued for Procurement.
B	Changed the minimum LOD from 25.3% to 30.1% at three locations on page 13 section 4.7.3 and one location on page 23 Form D.
C	General changes. Went from an off the shelf item to a two part system of boron carbide plus high alumina cement.
D	General revision. Reformatted sections and attachments. Deleted references to drawing numbers.
E	The mass limits were changed to account for volume tolerances in the 277-4 annulus. Section 3.3.8, Item l, "inner liner" was replaced with "can". A.3.1 was separated into two sections; the second part of A.3.1 became A.3.1.a with the title "Net Count Rate Time Determination". Section A.6.3 was modified by adding "Define the repeatable accuracy for" before the first sentence. JS-YMN3-801580-A005-5 was expanded to include more approval data requirements. A typo was fixed on JS-YMN3-801580-A005-6. Added Rev level to Forms and headers.
F	In Section 3.3.9.3, added maximum and minimum LOD% table based upon cured density and made reference to table on Form F.
G	Shieldwerx, supplier of 277-0 was Thermo Electron Corporation. Added Figures 9, 10, & 11 to represent design and procurement changes made to the ES-3100 Heavy Spacer Can Assembly, see drawing M2E801580A043 Rev. 0 for supplementary details. Added additional reference to M2E801580A043.

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY Michael Ensley /s/	09/10/09	PROJECT ENGINEER Larry Roberson /s/	09/10/09
DESIGN VERIFICATION Drew Winder /s/	09/10/09	CRITICALITY SAFETY John DeClue /s/	09/10/09
DISCIPLINE MANAGER Walter North /s/	09/10/09		

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

Name: Roger D. Aigner /s/ Date: 09/10/09

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ATTACHMENTS

Appendix A Prompt Gamma-ray Neutron Activation Analysis Testing Setup & Tooling 16

FORM A 277-4 Dry Blend Batch Control

FORM B 277-4 Wet Mix Control (Overcast or Special Batch)

FORM C ES-3100 Body Weldment Casting Control

FORM D ES-3100 Neutron Absorber Form Casting Control

FORM E ES-3100 Heavy Can Spacer Assembly Casting Control

FORM F ES-3100 Companion Sample Casting Control and Tests

FORM AA PGNAA Tooling Setup Control

FORM AB PGNAA Standard Setup

FORM AC PGNAA Daily Standard Setup Control

FORM AD PGNAA Measurements

Offer Apprasial Data - Subcontractor, JS-YMN3-801580-A005-1

Approval Data - Subcontractor, JS-YMN3-801580-A005-2

Certified Data - Subcontractor, JS-YMN3-801580-A005-3

Offer Apprasial Data - PGNAA Subcontractor, JS-YMN3-801580-A005-4

Approval Data - PGNAA Subcontractor, JS-YMN3-801580-A005-5

Certified Data - PGNAA Subcontractor, JS-YMN3-801580-A005-6

1.0 Scope

1.1 This specification describes the requirements for the procurement, preparation, casting, and verification of a neutron absorber material into the ES−3100 shipping package. The neutron absorber material shall be cast into ES−3100 Body Weldment (Figure 1), Neutron Absorber Form (Figures 4 and 5), Heavy Can Spacer Assembly (Figure 6 and 9), and 10 oz. double friction can (Figures 7, 8, 10 and 11) with tooling, i.e., Neutron Absorber Casting Funnel Assembly (Figure 2), and Body Weldment and Casting Funnel Assembly (Figure 3).

1.2 Definitions

277-0 - Shieldwerx Catalog No. SWX-277-0 or equivalent, Heat Resistant Shielding "Non-Borated" high alumina cement.

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

Companion Sample Cans - The 10 oz. double friction cans in Figures 7 and 8 or 10 oz. crimp style cans in Figures 10 and 11 used for sampling.

Company – B&W Y-12 L.L.C.

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

Dry Blend Batch - A thoroughly mixed Dry Batch.

Heavy Can Spacer Assembly - The 10 oz. double friction can in Figure 6 or 10 oz. crimp style can in Figure 9.

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

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

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

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

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

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

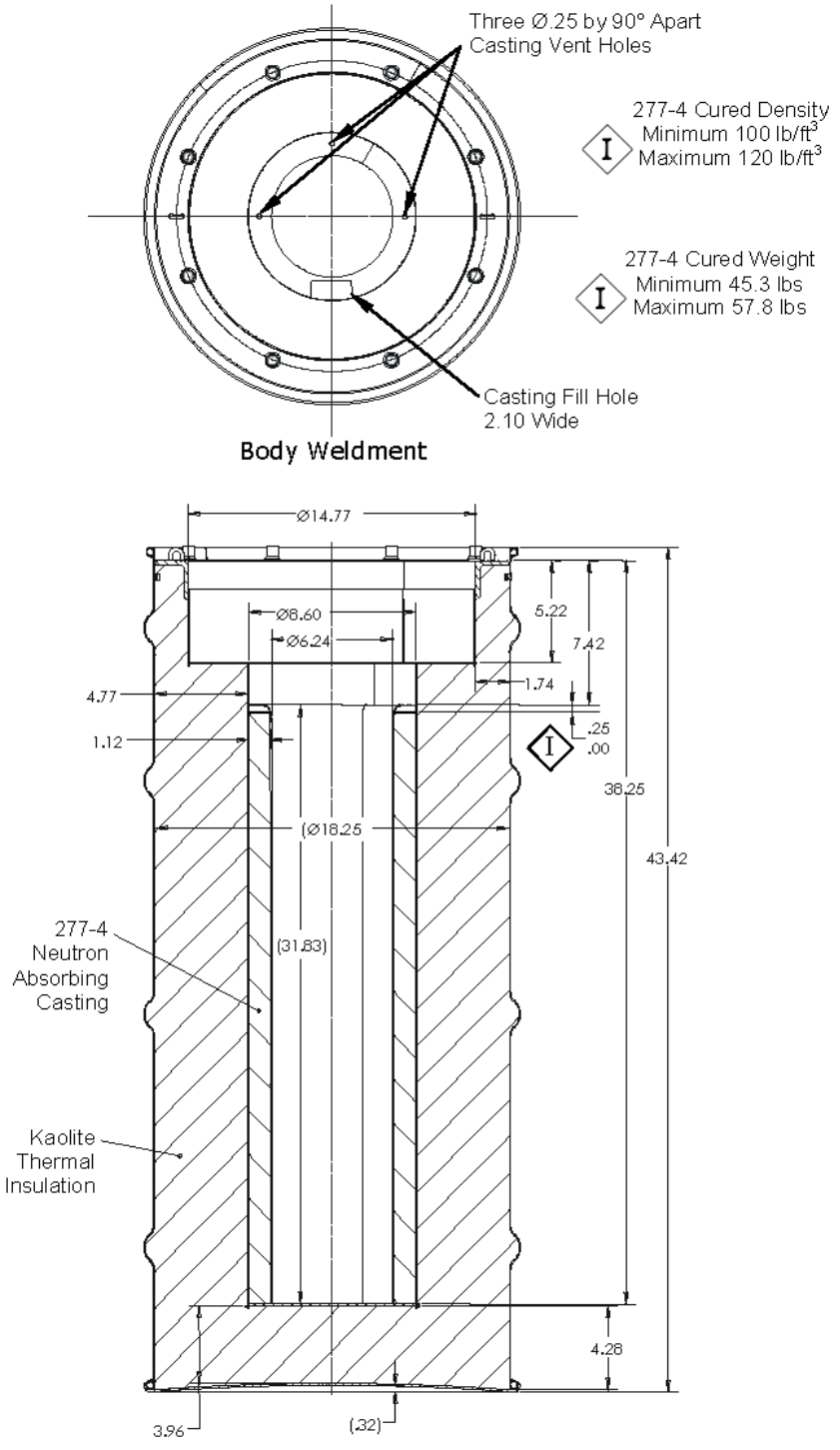
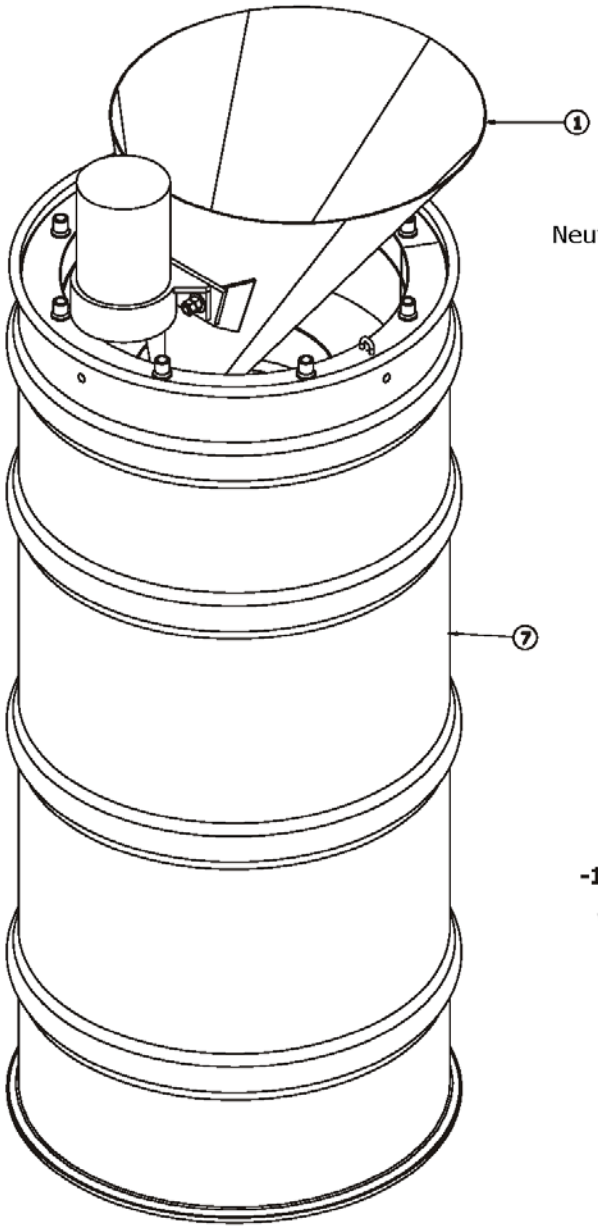


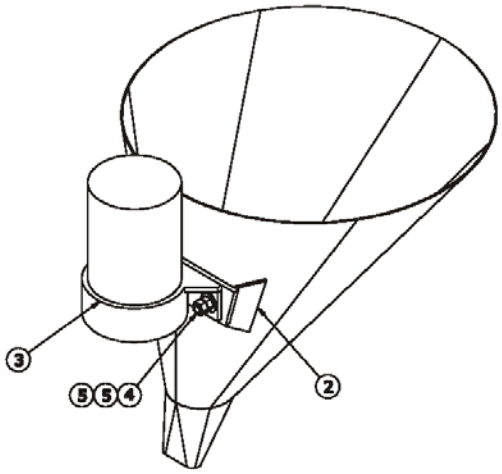
Figure 1 ES-3100 Neutron Absorbing Casting



-6 BODY WELDMENT AND CASTING FUNNEL ASSEMBLY

Figure 3

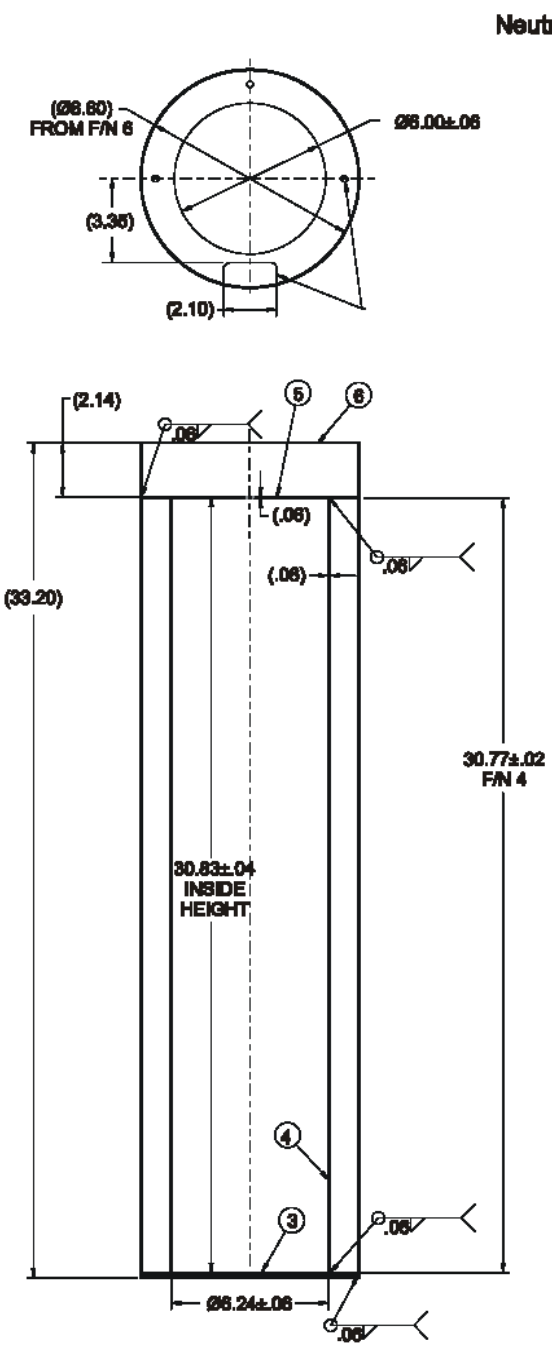
Neutron Absorber Casting Funnel Assembly



-1 NEUTRON ABSORBER CASTING FUNNEL ASSEMBLY

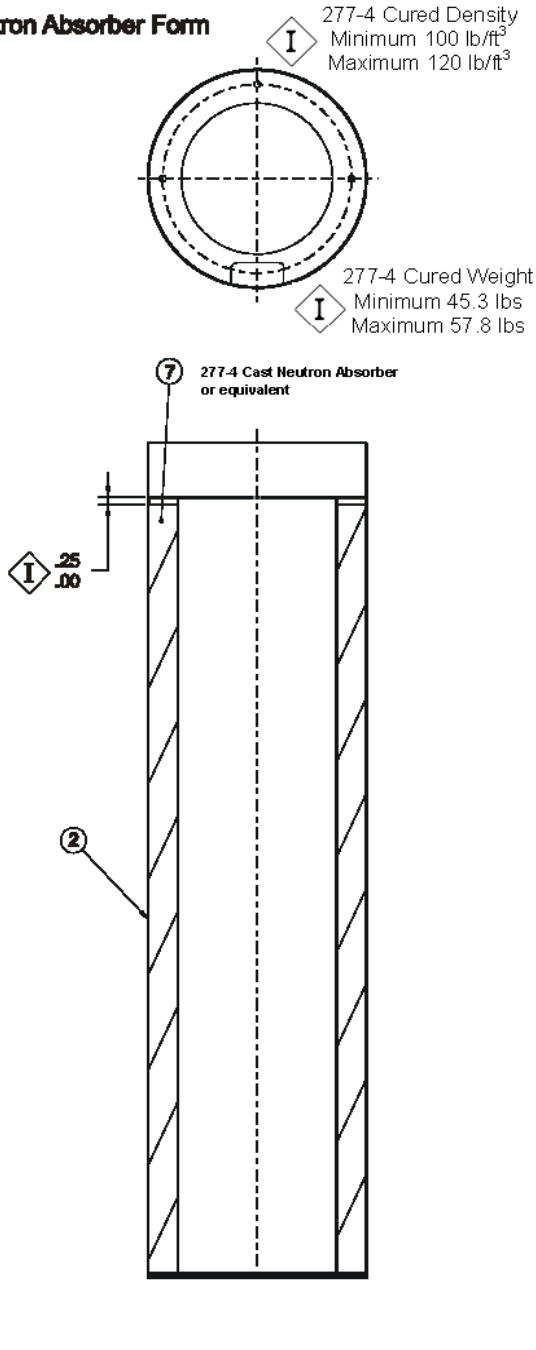
VIBRATOR POWERED CASTING FUNNEL

Figure 2



-2 NEUTRON ABSORBER FORM WELDMENT

Figure 4



-1 NEUTRON ABSORBER FORM ASSEMBLY

Figure 5

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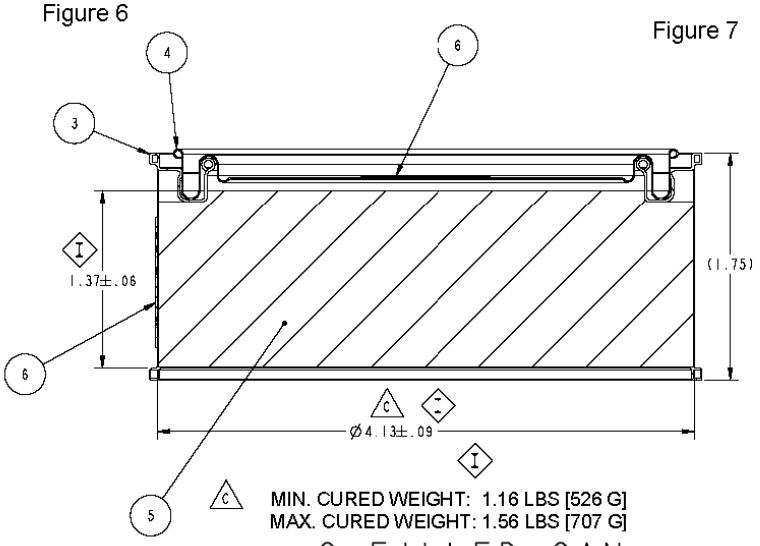
HEAVY CAN SPACER ASSEMBLY

Figure 6



10oz DOUBLE FRICTION CAN
FILLED WITH 277-4

Figure 7



10oz DOUBLE FRICTION CAN
FILLED WITH 277-4

Figure 8



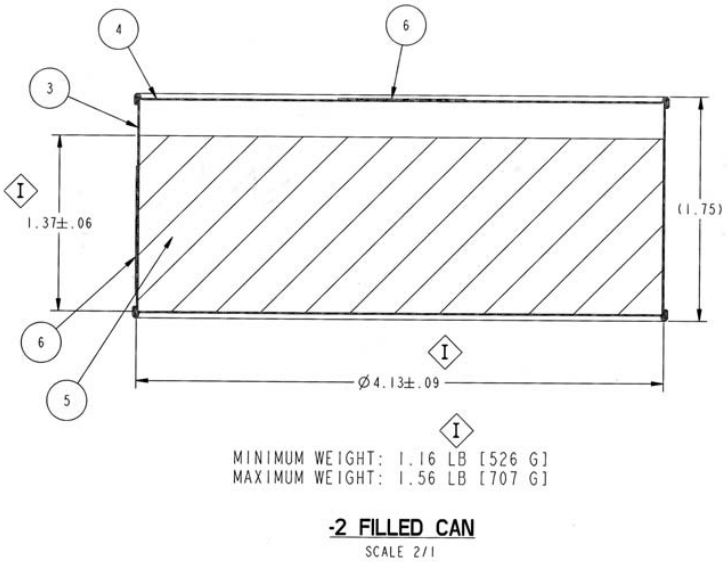
HEAVY CAN SPACER ASSEMBLY

Figure 9



10oz CRIMP STYLE CAN
FILLED WITH 277-4

Figure 10



-2 FILLED CAN
SCALE 2/1

10oz CRIMP STYLE CAN
FILLED WITH 277-4

Figure 11

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2.0 Applicable Documents

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

2.2 Standards

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

2.3 Company Documents

JS-YMN3-801580-A002	*ES-3100 Drum Assembly*
JS-YMN3-801580-A003	*Manufacturing Process Specification for Casting Kaolite ™ Into the ES-3100 Shipping Package*
M2E801580A026 and M2E801580A043	*Heavy Can Spacer Assemblies*

2.4 Referenced Documents (Not Provided with Request for Proposal)

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

3.0 Requirements

3.1 General Requirements

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

3.2 Equipment Requirements

3.2.1 Certified Scales

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

3.2.2 Dry Blending the 277-0 and B_4C

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

3.2.3 Mortar or Plaster Mixer

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

3.2.4 Small Plaster Mixer

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

3.2.5 Vibration Powered Funnel Assembly

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

3.2.6 Heavy Duty Drum Vibrator

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

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3.2.7 Bench Vibrator

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

3.3 277-4 Neutron Absorber

3.3.1 Raw Casting Material Requirements and Inspection

3.3.1.1 277-0

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

3.3.1.2 Type 1 Nuclear-Grade Boron Carbide Powder

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

3.3.1.3 Water

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

3.3.2 Dry Blending Process

3.3.2.1 Dry Batch

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

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

The data shall be recorded on Form A.

3.3.2.2 Blended Dry Batch

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

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

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

3.3.3 Wet Mixing

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

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

3.3.4 Body Weldment and Neutron Absorber Form Vibration Casting

3.3.4.1 Vibration Casting Requirements for Body Weldment and Neutron Absorber Form

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

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

3.3.4.2 Overcast Requirements for Body Weldment and Neutron Absorber Form

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

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

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

3.3.4.3 Curing Requirements Body Weldment and Neutron Absorber Form

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

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

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

3.3.5 Heavy Can Spacer Assembly

The Heavy Can Spacer Assembly shown in Figure 6 or 9 shall be the 10-oz. double friction metal can as shown in Figures 7 and 8, or 10-oz. crimp style metal can as shown in Figures 10 and 11. The cured casting weight for each can shall be measured and the cured casting density recorded on Form E. A cured cast density of 100 to 120 lb/ft^3 and a cured weight range of 1.16 to 1.56 lbs shall be acceptable. If the cured casting density is outside the acceptable range, a copy of the form shall be sent to the Company.

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

3.3.6 PGNAA Acceptance Standards

The PGNAA Acceptance Standards shall be made with a Company representative witnessing the manufacturing processes of weighing, blending, wet mixing, and casting. The PGNAA Acceptance Standards shall be the 10-oz. double friction metal can as shown in Figures 7 and 8, or 10-oz. crimp style metal cans as shown in Figures 10 and 11. The cured casting weight for each can shall be measured and the cured casting density recorded on Form E. A cured casting density of 100 to 120 lb/ft^3 and a cured casting weight of 1.16 to 1.56 lbs shall be acceptable. If the cured casting density is outside the acceptable range, a copy of the form shall be sent to the Company.

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

3.3.7 Companion Sample Cans

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

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

3.3.8 Casting the 10 oz. Double Friction Metal Cans or 10 oz. Crimp Style Cans

a. Select a labeled can which has a drawing and serial number per drawings M2E801580A026 or M2E801580A043.
b. Weigh the empty labeled can and lid and record the casting can data on Forms C, D, or E. It is acceptable to weigh ten cans with ten lids for each purchase order of cans and to use the average can and lid weight on each form.
c. Weigh the water and measure the water temperature. Record this data on Form C, D, or E. Fill with water only up to the bottom of the inside rim. The can lid shall be on the scale. It is acceptable to weigh the water weight of the first ten cans with ten lids of the same lot of cans and to use the average water weight for each of the following cans if the measurements are consistent.
d. Remove the water from the cans.
e. Prepare the Wet Mix Batch following Section 3.3.3.
f. Hold the can on the bench vibrator during filling with the 277-4 wet mix. Quickly vibrate and continue to add wet mix to the can lip.
g. Once all of the cans are full of wet mix, return the first can back to the vibrator for at least 3 minute at a high frequency setting. During the 3 minutes of vibration, continue to add 277-4 wet mix until the can stays full. Repeat this process for all the cans in the casting lot.
h. Between 1 to 24 hours after casting, scrape the top of the casting to meet 1.37±0.06 dimension from bottom of can noted on Figures 8 and 11.

i. Clean the can rim around the edge per Section 3.4.2.
j. Perform an in-process measurement of the scraped casting height to ensure that the casting height parameters are met shown in Figures 8 and 11.
k. Cover the casting by placing the properly labeled can lid on the can for 7 days.
l. Remove the can lid and let the can air dry or use either or both vacuum and heat to create an acceptable density and weight. If heat is used, the maximum temperature of the can shall not exceed 250°F.
m. Measure casting height and weigh the can with lid. Record this data on Forms C, D, or E.
n. Record the final Companion Sample Can casting density, weight, or casting height measurements data on Form F.
o. Crimp lid onto crimp style can, as applicable.

3.3.9 Verification

All verification shall be completed after the casting is cured.

3.3.9.1 Cured Casting Density Verification

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

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

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

3.3.9.2 Companion Sample Can Cured Casting Density Verification

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

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

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

3.3.9.3 Companion Sample LOD Verification

The companion sample cans identified in Section 3.3.7.b shall be LOD tested. The acceptable LOD percent range shall be based upon the companion sample can cured casting density in Section 3.3.9.2. The Acceptable Maximum and Minimum LOD% at Density is in this table developed from data in DAC-PKG-801624-A001 Table 7, 277-4 Composition @ Extreme Densities and LOD% and compared to the average values as manufactured.

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

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

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

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

3.3.9.4 PGNAA Verification

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

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

3.4 Cleaning Requirements

3.4.1 Contact with Chlorides or Fluorides

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

3.4.2 Satisfactory Cleanliness

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

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

4.0 Quality Assurance

4.1 Quality Assurance Program

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

4.2 ES−3100 Casting Quality Assurance Requirements

4.2.1 ES−3100 Documentation Package

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

a. Material measuring, dry blending, wet mixing, casting, sampling, and inspection forms, i.e, Forms A through F.
b. A Certificate of Compliance for each lot of the 277-0 Heat Resistant Shielding "Non-Borated" dry mix documentation with the expiration date identified on each container.

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

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

4.2.2 Batch Processes

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

4.2.3 Materials Traceability

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

4.2.4 Procedures

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

4.2.5 Training and Qualification of Personnel

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

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

5.0 Preparation for Delivery

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

6.0 Manufacturer's Data

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

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

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

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

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

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

Prompt Gamma-ray Neutron Activation Analysis (PGNAA) of boron performs one of the acceptances of the ES-3100 277-4 casting. Specifically, ^{10}B gives rise to a 478-keV gamma-ray produced by the recoil of the lithium nucleus from the neutrons captured in ^{10}B. The gamma-ray is Doppler broadened by 10–15 keV. The PGNAA shall be performed upon a companion sample can cast made during the drum casting in accordance with JS-YMN3-801580-A005 and Body Weldment (Figure 1), Neutron Absorber Form (Figure 5), Heavy Can Spacer Assembly (Figure 6 or 9), and the cast companion samples in the same 10-oz. double friction metal can on (Figures 7 and 8), or 10-oz. crimp style metal cans as shown in (Figures 10 and 11). PGNAA is a relative measurement therefore daily baselines are required to define the acceptance values.

Canberra Industries to perform the PGNAA testing.

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

A.2 PGNAA Quality Assurances

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

A.3 PGNAA Measurements Setup

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

A.3.1 Net Count Rate Measurements

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

A.3.1.a Net Count Rate Time Determination

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

A.3.2 Neutron Source

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

ATTACHMENT A
(Page 2 of 4)

A.3.3 Collimator and Neutron Source Setup

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

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

A.3.4 Detector

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

A.3.5 Detector Net Count Rate Determination

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

A.3.6 Detector Location Setup

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

ATTACHMENT A
(Page 3 of 4)

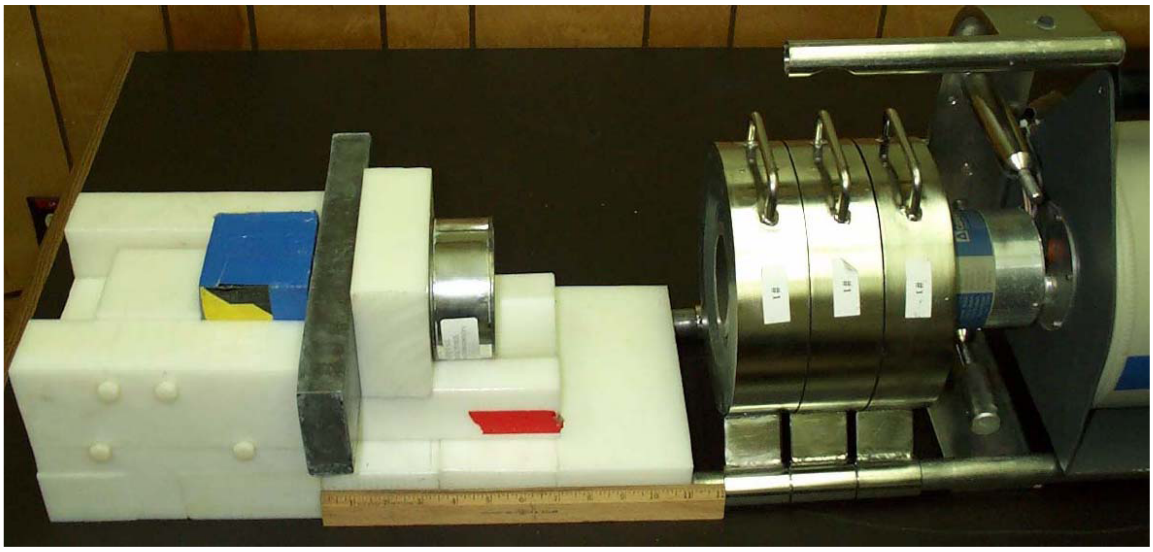


Figure A.1 Preliminary Tooling Generated for PGNAA

A.3.7 Detector Operation Setup

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

A.3.8 Net Count Rate Baseline Measurements

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

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

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

ATTACHMENT A
(Page 4 of 4)

A.4 Net Count Rate Acceptance Measurements

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

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

A.5 Documentation of the Acceptance or Rejection Measurements

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

A.6 Results

A.6.1 Equipment and Software Quality Assurances

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

A.6.2 Certified Tooling Setup and Repeatable Dimensions

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

A.6.3 Measurement Time and Repeatable Accuracy

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

A.6.4 Measurement Software and Methodology

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

A.6.5 Forms AA through AD

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

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

A.6.6 Can Disposition

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

FORM A 277-4 Dry Blend Batch Control **Rev G** **Page 1 of 1**

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

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

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

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

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

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

EXEMPT FROM O-155 (8-02)

FORM C ES-3100 Body Weldment Casting Control **Rev G Page 1 of 1**

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

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

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

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

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

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

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

EXEMPT FROM IO-155 (8-02)

FORM D ES-3100 Neutron Absorber Form Casting Control Rev G Page 1 of 1

Casting Company Name			Body Weldment Casting Control # [a]		
Part Serial Number			Drawing Number M2E801580A034		
Measured Weights ±0.5 lb	Casting Information		Comments		Operator
	Weight	Date			
Clean and Empty					
Filled with Water [b]					
Water Information	Water Weight ±0.5 lb	Water Temp. [b]	Comments		Operator
Water Conditions [b]	lb	°F			
Vibration Settings [c]	lbf	VPM			
Wet Mix Control	Blended Dry Batch Control No.		Dry Blend Batch Expiration Date		
(Target Water = 277-4 Weight × 27±1 wt%)	277-4 Weight	lb	Water Weight	lb	
	Air Temperature	°F	Water Temperature	°F	
	Mix Time		Mix Finish Time		
Companion Samples [d]	−1		−2		

	Time	Date	Comments	Operator
Vibration Start				
Vibration Stop				
Overcast WMCN				
After Casting	lb	Date		
After Cured and Clean	lb	Date		

Measurements (I)	Height [e] (in)	Pass or Fail Height	Cured Weight (lb)	Pass or Fail Cured Weight [e]	Cured Density [f] (lb/ft^3)	Pass or Fail 100−120 (lb/ft^3)
Neutron Absorber Form						

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

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

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

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

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

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

EXEMPT FROM IO-155 (8-02)

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

Casting Company Name	Can Lot Serial Number [a]	Drawing Number M2E801580A026 or M2E801580A043
Average 10 Can and Lid **Empty** Weight	Temperature of Water Weight (°F)	Average 10 Can and Lid **Water** Weight

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

Wet Mix Control Number (Overcast), if required

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

Operator	Comments

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

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

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

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

EXEMPT FROM O-155 (8-02)

FORM F ES-3100 Companion Sample Casting Control and Tests **Rev G Page 1 of 1**

Casting Company Name		Ave. 10 Can and Lid Empty Weight [a]		Ave. 10 Can and Lid Water Wgt. [a]		Temp. of Water Weight (°F)		Drawing Number M2E801580A026 or M2E801580A043	
Serial Numbers		Can Measurement Weights ±0.01 (lb)			For Record Only	Loss On Drying (Odd Serial Numbered Cans)		PGNAA (Even Serial Numbered Cans)	
Part # or Can Lot#	Companion Sample Can [b]	After Casting Weight	Cured Weight	LOD Weight	Cured Density (lb/ft³)	Calculated LOD%	Pass Or Fail per Sec. 3.3.9.3	PGNAA (PMN) [c]	Pass Or Fail
Complied by					Comments				

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

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

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

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

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

EXEMPT FROM 10 155 (6 CC)

FORM AA PGNAA Tooling Setup Control **Rev G Page 1 of 1**

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

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

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

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

Operator

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

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

[c] Use one 277-4 cast 10-oz. double friction metal can per drawing M2E801580A026 or 10-oz. crimp style can per drawing M2E801580A043 as the PGNAA reference to verify the Tooling Setup.

EXEMPT FROM IC-755 (8-02)

FORM AB PGNAA Standard Setup **Rev G Page 1 of 1**

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

	277-4 Standard Can Serial Numbers	Counts			Count Time (sec)	Net Count Rate (Net Counts/Sec)
		Gross	Compton	Net		
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
Average Values						

Comments

Operator

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

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

EXEMPT FROM IC-155 (8-02)

FORM AC PGNAA Daily Standard Setup Control **Rev G** **Page 1 of 1**

Inspecting Company Name		Casting Company Name				
PGNAA Daily Standard Setup [a]		PGNAA Tooling Setup Number (with –#)				
277-4 Standard Can Serial Numbers [b]		Counts			Count Time (sec)	Net Count Rate (Net Counts/Sec)
		Gross	Compton	Net		
1						
2						
3						
4						
5						
Average Values						
Standard Deviation						
3 × Standard Deviation						
(Pass Rate) Minimum Acceptable Net Count Rate = Average − 3 × Standard Deviation =						

Comments

Operator

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

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

EXEMPT FROM IC-755 (8-02)

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

Inspecting Company Name		Casting Company Name					
PGNAA Measurement Number (PMN) [a]		PGNAA Daily Standard Setup Num.		PGNAA Pass Rate (Net Cnt/Sec)			
Even Serial Numbers [b]		Counts (Cnt)			Count Time (sec)	Net Cnt Rate (NetCnt/Sec)	Pass or Fail
Drum/Neutron Absorber Form/Lot#	Sample #	Gross	Compton	Net			
Comments							
Operator							

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

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

EXEMPT FROM IC-755 (8-02)

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-1	Revision G
	Issue Date 2/17/2005	Revision Date 08/31/2009
		Page 1 of 1

MANUFACTURER'S DATA REQUIREMENTS

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

[a]Indicate the following:

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

EXEMPT FROM IC-755 (8-02)

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-2		Revision G
	Issue Date 2/17/2005	Revision Date 08/31/2009	
		Page 1 of 1	

MANUFACTURER'S DATA REQUIREMENTS

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

[a]Indicate the following:

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

EXEMPT FROM IC-755 (8-02)

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-3		Revision G
	Issue Date 2/17/2005	Revision Date 08/31/2009	
		Page 1 of 1	

MANUFACTURER'S DATA REQUIREMENTS

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

[a]Indicate the following:

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

EXEMPT FROM IC-755 (8-02)

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-4	Revision G
	Issue Date 2/17/2005	Revision Date 08/31/2009
		Page 1 of 1

MANUFACTURER'S DATA REQUIREMENTS

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

[a]Indicate the following:

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

EXEMPT FROM IC-1551 (8-02)

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-5		Revision G
	Issue Date 2/17/2005	Revision Date 08/31/2009	
		Page 1 of 1	

MANUFACTURER'S DATA REQUIREMENTS

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

[a]Indicate the following:

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

EXEMPT FROM IC-755 (8-02)

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-6	Revision G
	Issue Date 2/17/2005	Revision Date 08/31/2009
		Page 1 of 1

MANUFACTURER'S DATA REQUIREMENTS

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

[a]Indicate the following:

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

EXEMPT FROM IC-755 (8-02)

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Appendix 1.3.6

Package Category Determination

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Appendix 1.3.6

Package Category Determination

The ES-3100 with HEU content package has a maximum activity of 0.72554 TBq (19.6092 Ci) at 10 y after initial fabrication; the maximum number of A2s carried is 4752.8 at 70 y after initial fabrication (Table 4.4). Based on the guidance from Nuclear Regulatory Commission Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)*, this package is classified in Table 1.1 of NUREG-1609 as a Category I package.

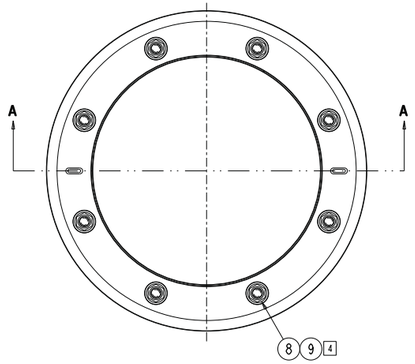
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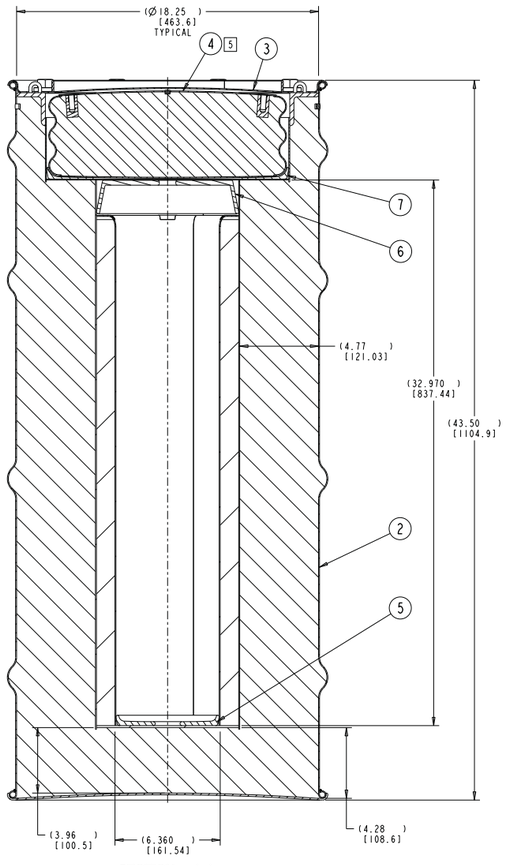
Appendix 1.3.7

ES-3100 Design Drawings

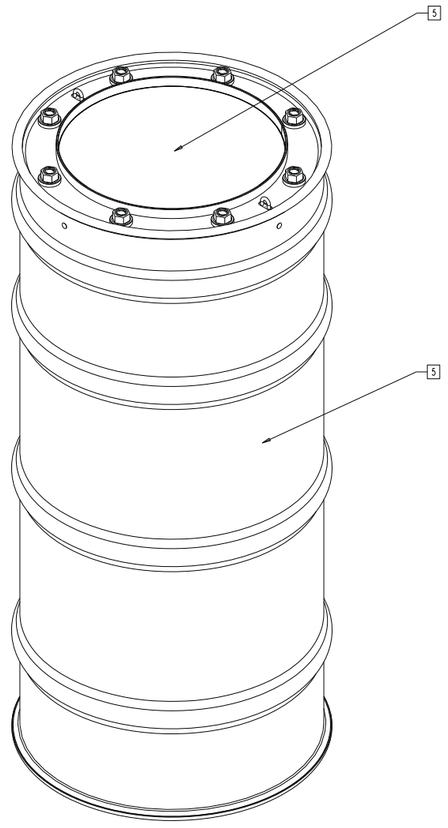
Drawing No.	Rev.	Title
M2E801580A001	C	Drum Assembly
M2E801580A002	B	Body Weldment
M2E801580A003	B	Inner Liner Weldment (2 sheets)
M2E801580A004	B	Double Open Head Reinforced Drum
M2E801580A005	E	Misc. Details
M2E801580A006	B	Drum Lid Weldment
M2E801580A007	B	18.25" Diameter Drum Lid
M2E801580A008	B	Top Plug Weldment
M2E801580A009	D	Pad Details
M2E801580A010	E	Data Plate Details
M2E801580A011	G	Containment Vessel Assembly
M2E801580A012	C	Containment Vessel Body Assembly (2 sheets)
M2E801580A013	D	Containment Vessel O-ring Details
M2E801580A014	B	Containment Vessel Lid Assembly
M2E801580A015	C	Containment Vessel Sealing Lid
M2E801580A016	B	Containment Vessel Closure Nut
M2E801580A023	E	Containment Vessel Leak Test Assemblies
M2E801580A024	C	Containment Vessel Vibration Absorbing Silicone 4.25” Can Pads
M2E801580A031	G	Main Assembly
M2E801580A043	B	Heavy Can Spacer Assembly (SST)
T2E801827A008	A	Leak Check Flange Assembly

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SECTION A-A



ISOMETRIC VIEW

NOTES

1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.

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

3 DIMENSIONS ARE IN INCHES [mm]. THE [mm] ARE ONLY FOR REFERENCE.

[4] TORQUE HEX NUTS TO 30±5 ft-lb AT ASSEMBLY.

[5] IN APPROXIMATE LOCATIONS SHOWN, USING BLACK ENAMEL PAINT (F/N 10). PAINT DRAWING NUMBER, REVISION LETTER AND FIVE DIGIT SERIAL NUMBER IN 1.00" HIGH CHARACTERS ON F/N 2, F/N 3, AND F/N 4.

6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.

7 FOR REF. ONLY APPROXIMATE WEIGHT: 289.2 LBS [131.2 Kg].

C [8] REFERENCE CONFIGURATION CONTROL EQUIPMENT DATA SHEET DS-PKG-801580-A001.

[5]	AR		PAINT, BLACK ENAMEL	FED SPEC 595B-17038	10
[4]	8	M2E801580A005-3	DRUM HEX NUT		9
	8	M2E801580A005-4	DRUM WASHER		8
	1	M2E801580A009-3	PLUG PAD		7
	1	M2E801580A009-2	CV FLANGE PAD		6
	1	M2E801580A009-1	CV BOTTOM PAD		5
	1	M2E801580A008-1	TOP PLUG WELDMENT		4
	1	M2E801580A006-1	DRUM LID WELDMENT		3
	1	M2E801580A002-1	BODY WELDMENT		2
C [8]	AR	-1	DRUM ASSEMBLY		1
MATERIAL CODE		PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL / SPECIFICATION	FIND NO
		QTY REQ'D NEXT ASSEMBLY	PARTS LIST		

-1 DRUM ASSEMBLY [8] C
SCALE 3/8

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

REVISION	DATE	SAE APPROVAL
C	09/10/09	J.F. DECUF

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

Name: R.D. AIGNER Date: 09/10/09

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE
C	ADDED REFERENCE NOTE 8.	MLE	JRJ	MLE	DEW	WIN	9/10/09	LR	9/10/09	JGA	9/14/09
B	GEN REV; TORQUE IN NOTE 4 WAS 10 +/- 1 REVISED NOTES 4 & 7; F/N 8 & 9 WAS VENDOR SUPPLIED MOVED NUT & WASHER DETAILS TO A005.	JRP	SMM	GAB	RDA	DPS	11/13/05	GAB	2/10/05	JGA	2/10/05
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK: AR CV ST HV EM FP PD EE IE M NP | DRAWING APPROVALS | DATE

SCALE:	NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED	
FRACTIONS	
XX DECIMALS	
XXX DECIMALS	
ANGLES	
BREAK SHARP EDGES .06 MAX	
FINISH	

DRW	JR JACKSON	10/29/03
CHKR	JS LOWERY	10/29/03
DE	GA BYINGTON	10/29/03
DVR	JL HECK	10/29/03
DM	JC WALLS	10/29/03
PE	MR FELDMAN	10/29/03
PM	DB MILLER	10/29/03

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

PROJECT NAME: ES-3100 SHIPPING PACKAGE

DRUM ASSEMBLY

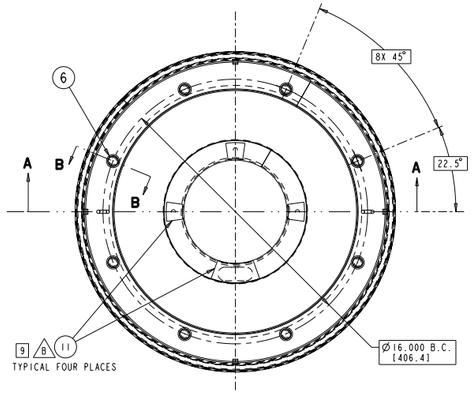
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	M	L	F		Y-12	NA	NA	1	1	A	U
51		52		53		REV					
CM		PKG		IN		M2E801580A001					C

M2E801580A001

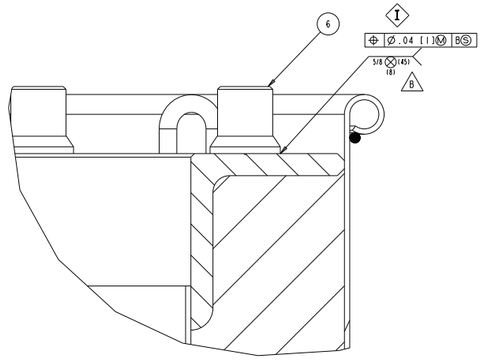
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P THIS DRAWING PRODUCED ON PRO/ENGINEER

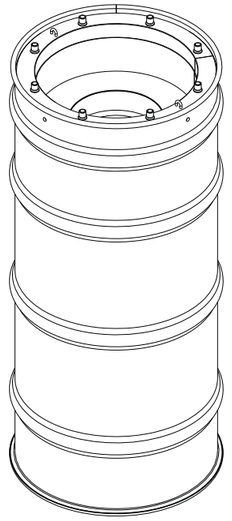
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-1 BODY WELDMENT
SCALE 3/8



SECTION B-B
SCALE 2/1



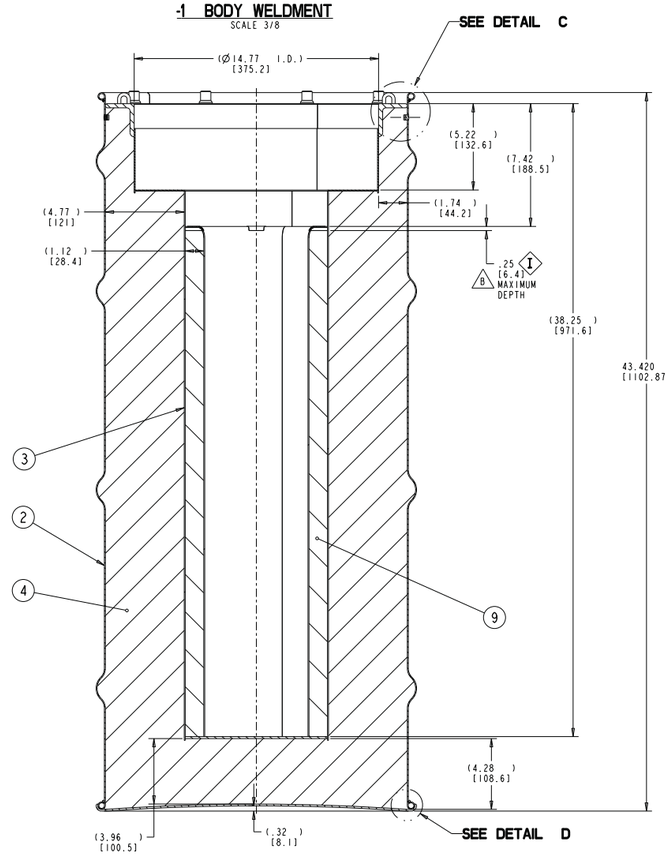
ISOMETRIC VIEW
SCALE 1/4

NOTES

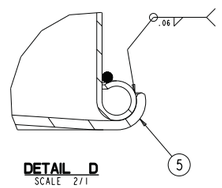
1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm].
4. OD OF ANGLE TURNED TO ID OF DRUM AT ASSEMBLY.
5. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
7. DIMENSIONS AND FEATURES FLAGGED BY A I SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
8. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A003 FOR REQUIREMENTS OF KAOLITE PROCESSING.
9. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A005 FOR REQUIREMENTS OF CATALOG 277-4 PROCESSING AND APPLYING THE F/N 11 OVER FILL/VENT HOLES.
10. FOR REFERENCE ONLY APPROXIMATE WEIGHT: 259.7 LBS [117.8 Kg]

KAOLITE:
VOLUME: 4.82 CU. FT.
DENSITY: 22.4 LBS/CU. FT.
WEIGHT: 108.0 LBS [49.0 Kg]

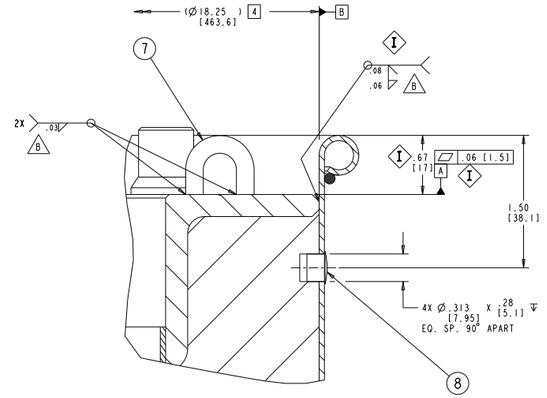
CATALOG 277-4:
VOLUME: 0.466 CU. FT.
DENSITY: 105.0 LBS/CU. FT.
WEIGHT: 48.89 LBS [22.18 Kg]



SECTION A-A
SCALE 3/8



DETAIL D
SCALE 2/1



DETAIL C
SCALE 2/1

B 9	AR	7616A21 OR EQUAL	LOW TEMPERATURE (-40° to +250°F)	ALUMINUM FOIL DUCT TAPE 2" WIDE	McMASTER- CARR ATLANTA, GA	11
	AR		WELD FILLER METAL	PER WELD PROCEDURES		10
B 9	AR	-9	CATALOG NO. 277-4	THERMO ELECTRON CORP., THERMOREAX, 504 AIRPORT ROAD, SANTA FE, NM 87507 PHONE 505-428-3508, FAX 505-428-3535		9
	4	62MP0312 OR EQUAL	PLUG, NYLON 6/6	MICRO PLASTIC INC. FLIPPIN, AR 72634		8
	2	M2E801580A005-2	TID LUG			7
	8	ARC FT 5/8-11 X 7/8 LG	ARC WELD STUD	304 / 304L SST	ASTM A493 OR ASTM F593	6
	1	M2E801580A005-1	DRUM FLAT COVER			5
8	AR	-4	KAOLITE 1600 VIBRATED CAST	THERMAL CERAMICS AUGUSTA, GA 30903-0923		4
	1	M2E801580A003-1	INNER LINER WELDMENT			3
	1	M2E801580A004-1	DOUBLE OPEN HEAD REINFORCED DRUM			2
AR	X	-1	BODY WELDMENT			1
M2E801580 A002	-1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		QTY REQ'D NEXT ASSEMBLY	PARTS LIST			

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

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

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

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

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE	WE	DATE	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP	DATE
B	GEN REV ADDED F/N 11, 5/8 WAS 1/2, F/N 9 WAS BOROBOND 4; MOD. GEN. NOTE 9; MOD. WELD SYMS. IN DET. C; MOD. WTS AND VOLS. IN NOTE 10	JRP	SMM	GAB	RDA	DPS	1/11/05	GAB	2/10/05	JGA	2/10/05	DJE	2/11/05												
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03														

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

SCALE: NOTED	DRW J.R. JACKSON	10/29/03
TOLERANCES UNLESS OTHERWISE SPECIFIED	CHKR J.S. LOWERY	10/29/03
	DE G.A. BYINGTON	10/29/03
FRACTIONS	DVR J.L. HECK	10/29/03
XX DECIMALS ±.03	DM J.C. WALLS	10/29/03
XXX DECIMALS ±.005	PE M.R. FELDMAN	10/29/03
ANGLES ±0.5°	PM D.B. MILLER	10/29/03
BREAK SHARP EDGES .06 MAX		
FINISH 125 RMS		

DRAWING APPROVALS

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

PROJECT NAME

ES-3100 SHIPPING PACKAGE

BODY WELDMENT

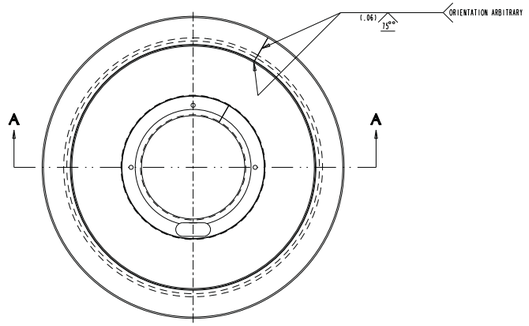
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6	M	L	F	Y-12	NA	NA	I I	A	U
51		52		53	M2E801580A002				REV B
CM		PKG		IN					

M2E801580A002

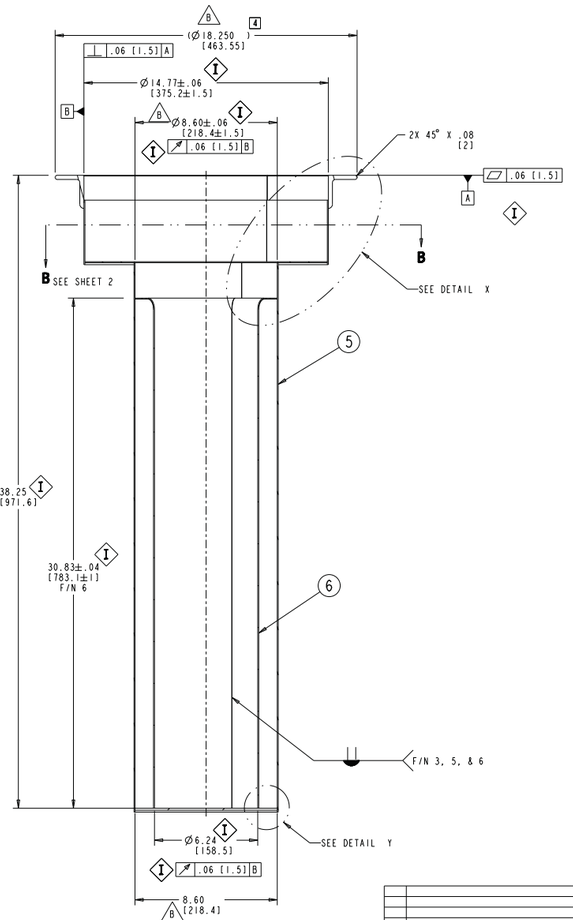
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THIS DRAWING PRODUCED ON PRO/ENGINEER

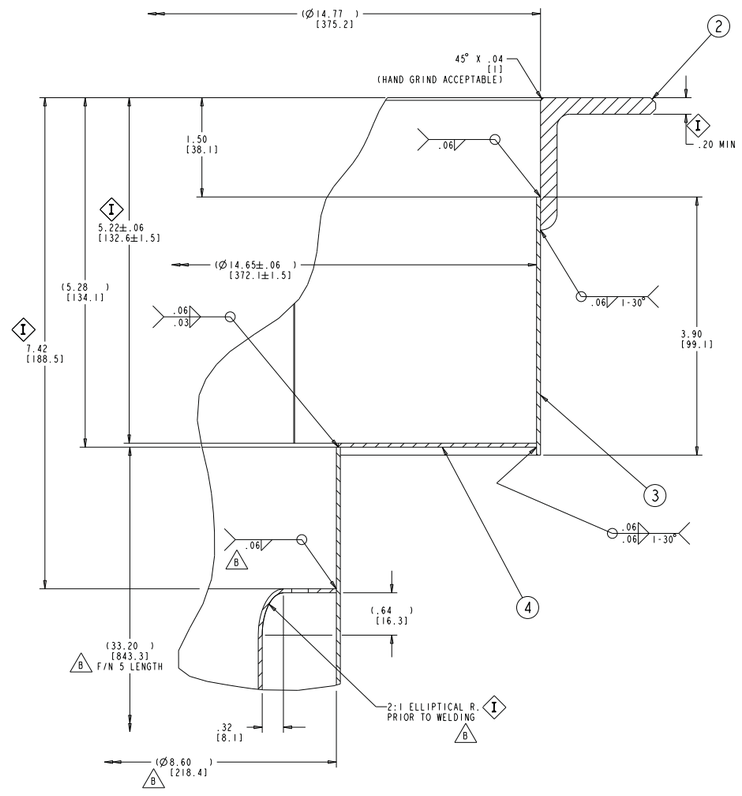
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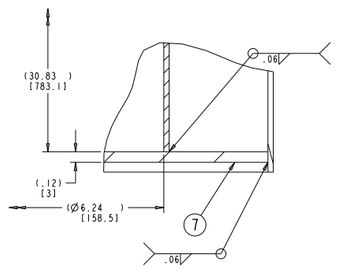
-1 INNER LINER WELDMENT
SCALE 3/8



SECTION A-A



DETAIL X
SCALE 3/2



DETAIL Y
SCALE 2/1

NOTES

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

M2E801580 A003	QTY REQ'D NEXT ASSEMBLY	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	AR		WELD FILLER METAL			8
	1	-7	BOTTOM PLATE	11 GAGE SHEET 304/304L SST	ASME SA240	7
	1	-6	LOWER INNER RING	16 GAGE SHEET 304/304L SST		6
	1	-5	LOWER OUTER RING			5
	1	-4	UPPER FLOOR PLATE			4
	1	-3	UPPER OUTER RING			3
4	1	-2	2 X 2 X 1/4 ANGLE MODIFIED	304/304L SST	ASME SA479	2
	AR	-1	INNER LINER WELDMENT			1

PARTS LIST

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	PE	PM	NE	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP
B	DELETED F/N 7, RENUMBERED F/N 8 TO 7 AND F/N 9 TO 8. CHANGED F/N 5 Ø8.80 TO Ø8.60. LENGTH 2.14 TO 33.20. F/N 6 OD WAS Ø9.13 NOW Ø8.60. REMOVED NOTE #8	JRP 1/10/05	SMM 1/10/05	GAB 1/10/05	RDA 1/10/05	DPS 1/10/05	GAB 2/10/05	JGA 2/10/05	DJE 2/11/05											
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ 10/29/03	JSL 10/29/03	GAB 10/29/03	JLH 10/29/03	JCW 10/29/03	MRF 10/29/03	DBM 10/29/03												

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

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

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

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

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

SCALE:	NOTED	
TOLERANCES UNLESS OTHERWISE SPECIFIED		
FRACTIONS		
XX DECIMALS	±.03	
XXX DECIMALS	±.005	
ANGLES	±0.5°	
BREAK SHARP EDGES	.06 MAX	
FINISH	125 RMS	

DRW	J.R. JACKSON	10/29/03
CHKR	J.S. LOWERY	10/29/03
DE	G.A. BYINGTON	10/29/03
DVR	J.L. HECK	10/29/03
DM	J.C. WALLS	10/29/03
PE	M.R. FELDMAN	10/29/03
PM	D.B. MILLER	10/29/03

DRAWING APPROVALS | DATE

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

PROJECT NAME: ES-3100 SHIPPING PACKAGE

INNER LINER WELDMENT

1	48	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	1	2	S	U

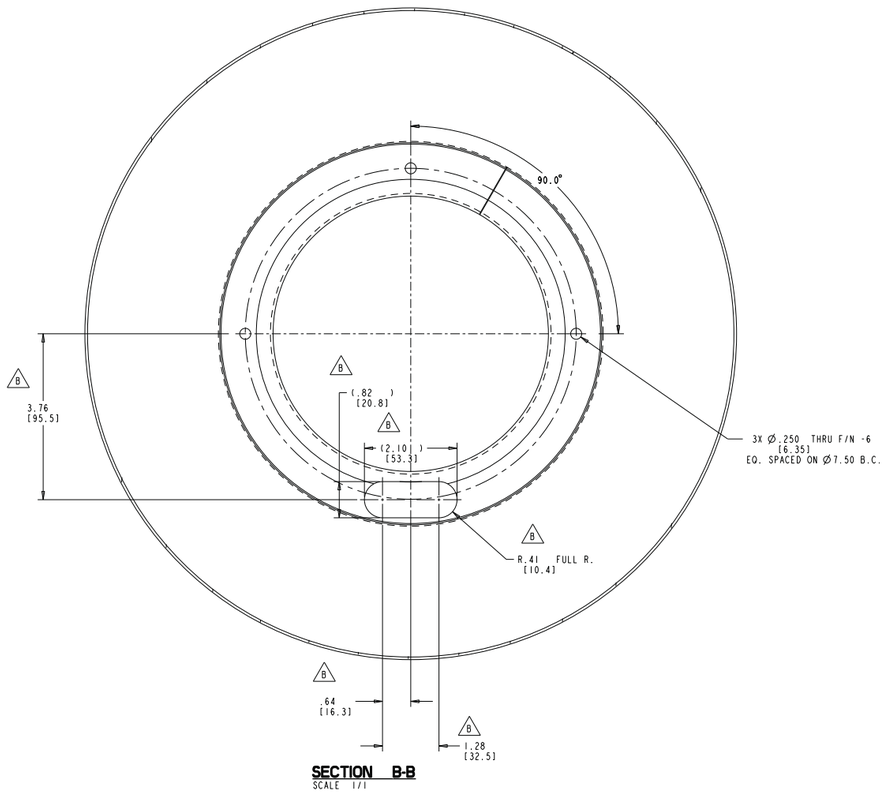
51	52	53	REV
CM	PKG	IN	B

M2E801580A003

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THIS DRAWING PRODUCED ON PRO/ENGINEER

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SECTION B-B
SCALE 1/1

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THIS DRAWING PRODUCED ON PRO/ENGINEER

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

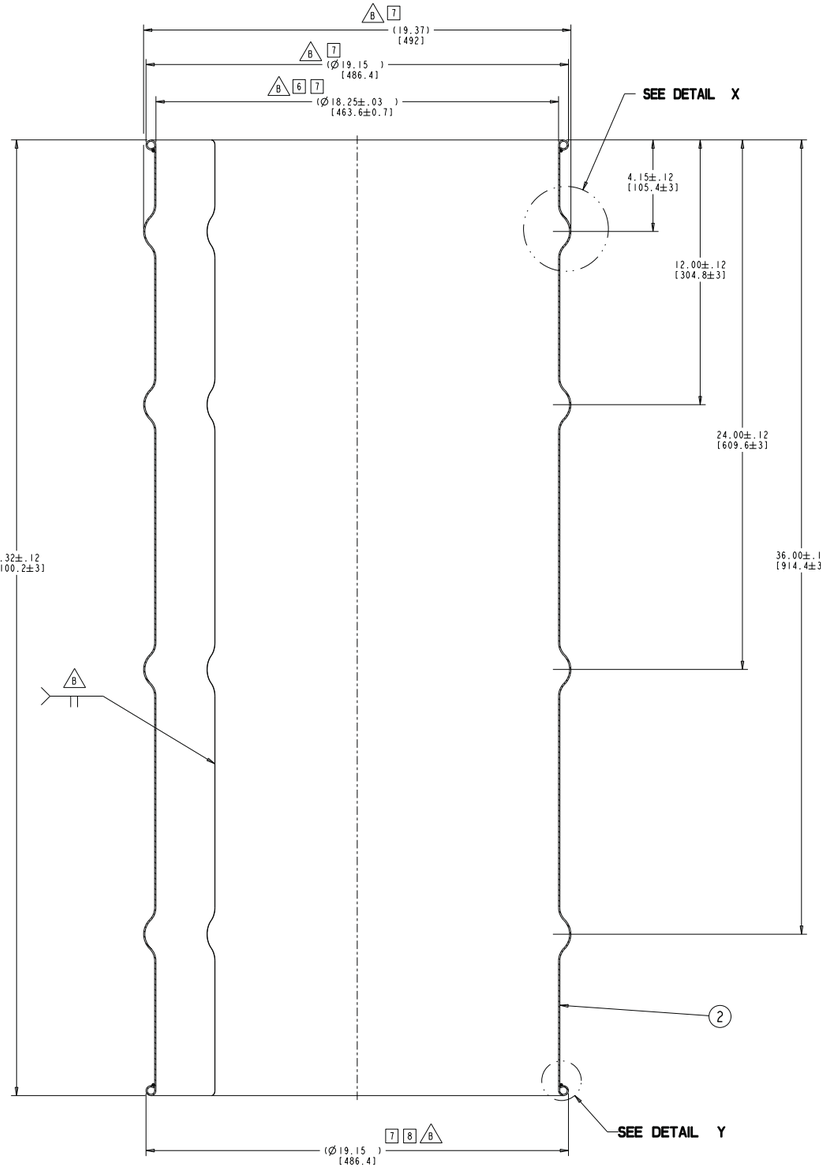
PROJECT NAME
ES-3100 SHIPPING PACKAGE

INNER LINER WELDMENT

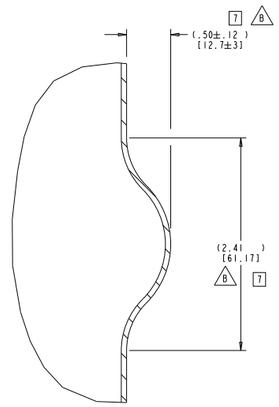
1	AB	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	2	2	S	U
51		52		53	M2E801580A003				REV	
CM		PKG		IN					B	

M2E801580A003

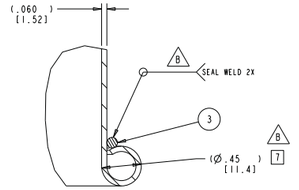
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-1 DOUBLE OPEN HEAD REINFORCED DRUM
SCALE 1/2



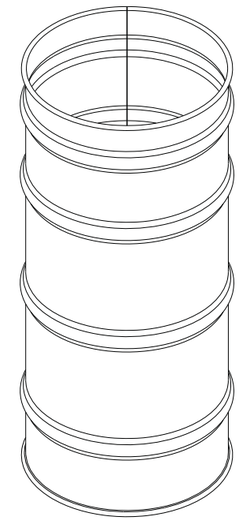
DETAIL X
SCALE 2/1
(4X)



DETAIL Y
SCALE 2/1
(2 X)

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. INSPECT THE I.D. OF THE DRUM TO DETERMINE THE ACTUAL DIAMETER DIMENSION FOR FABRICATION INTERFACE WITH M2E801580A003. REFERENCE NOTE 4 ON DWG. M2E801580A002.
7. DRUM DIAMETERS, CORRUGATIONS, AND MANUFACTURING SHALL MEET THE REQUIREMENTS OF MILITARY STANDARD, MS27683-7 (DRUM, METAL SHIPPING AND STORAGE 16 TO 80 GALLS). THE SEAM WELD OF THE DOUBLE OPEN-HEAD DRUM SHALL BE TESTED BY APPLYING AN INTERNAL AIR PRESSURE TO 10 PSIG (MIL-D-6054F, PARAGRAPH 4.6.1 PROCEDURE B) AND BY CONDUCTING A ROUGH HANDLING TEST (MIL-D-6054F, PARAGRAPH 4.6.2).
8. INSPECT THE O.D. OF THE DRUM FOR INTERFACE DIMENSION WITH M2E801580A005-1, DRUM FLAT COVER. REFERENCE NOTE 5 ON DRAWING M2E801580A005.



ISOMETRIC VIEW
SCALE 1/4

	AR		WELD FILLER METAL	PER WELD PROCEDURES	4
	AR	Ø1/8	WELD WIRE	ER308L	ASME SFA 5.9	3
B 7	1	-2	DRUM 16 GA (.0595)	304/304L SST	ASME SA240	2
	AR	-1	DOUBLE OPEN HEAD REINFORCED DRUM			1
M2E801580	—	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		QTY REQ'D NEXT ASSEMBLY	PARTS LIST			

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

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

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE	ME	DATE
B	GEN REV REMOVED TOL ON 18.25 DIA. REMOVED (I) ON 19.15 DIA. REMOVED BOX 9 DIM. UPDATED NOTE NUM. 6 TO 8, REVISED NOTE 7, MOD. WELD SYMBOLS, ADDED REF DIMENSIONS IN DETAIL X	JRP	SMM	GAB	RDA	DPS	1/7/2005	GAB	2/10/05	JGA	2/10/05		
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03		

REVISION OR ISSUE PURPOSE

REVISION APPROVALS														
REV	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP
DATE											

SQUAD CHECK

DRAWING APPROVALS

		DATE
DRW	J.R. JACKSON	10/29/03
CHKR	J.S. LOWERY	10/29/03
DE	G.A. BYINGTON	10/29/03
DVR	J.L. HECK	10/29/03
DM	J.C. WALLS	10/29/03
PE	M.R. FELDMAN	10/29/03
PM	D.B. MILLER	10/29/03

SCALE: NOTED

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.03
XXX DECIMALS ±.010
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

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

PROJECT NAME: ES-3100 SHIPPING PACKAGE

DOUBLE OPEN HEAD REINFORCED DRUM

1	48	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	1	1	S	U

51	52	53	
CM	PKG	IN	M2E801580A004 B

M2E801580A004

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P THIS DRAWING PRODUCED ON PRO/ENGINEER

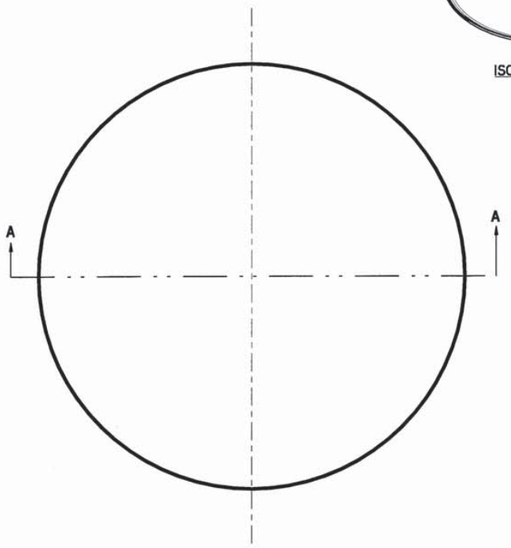
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NOTES

E 1 DELETED
E 2 DELETED
E 3 DELETED
E 4 DELETED
5 DRUM FLAT COVER SHALL BE FABRICATED TO INTERFACE WITH DOUBLE OPEN HEAD REINFORCED DRUM DIMENSION. TOLERANCE SHALL BE -.01 TO -.04. REFERENCE NOTE 9 ON DRAWING M2E801580A004.
6 FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
E 7 THE MODIFIED DRUM NUT SHALL MEET THE REQUIREMENTS IN EQUIPMENT DATA SHEET DS 801580-0001.
8 THE DRUM NUT MECHANICAL PROPERTY MARKING, F467K, SHALL BE FULLY VISIBLE AFTER MODIFICATION.

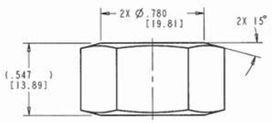


ISOMETRIC VIEW
SCALE 1/4



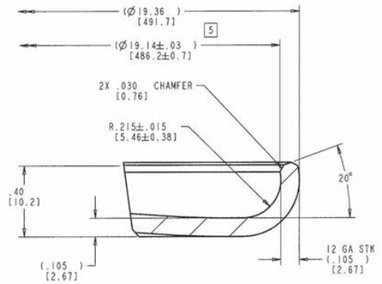
SECTION A-A

-1 DRUM FLAT COVER
SCALE 1/2

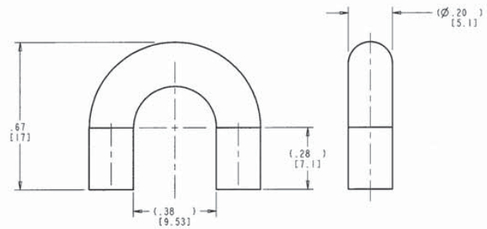




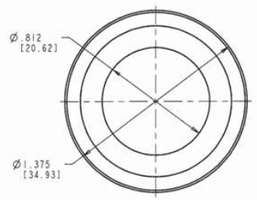
-3 MODIFIED DRUM NUT 7 8
SCALE 3/1

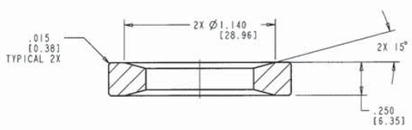


DETAIL Z
SCALE 4/1



-2 TID LUG
SCALE 4/1





-4 DRUM WASHER
SCALE 3/1

QTY REQ'D NEXT ASSEMBLY	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
8	-4	DRUM WASHER	300 SERIES SST	ASTM A240 OR A276	4
8 7	-3	MODIFIED DRUM NUT	C65100 SILICON BRONZE	ASTM F-467 ANSI B18.2.2	3
2	MODIFIED 339251 OR EQUAL	TID LUG	304L SST CHAIN 3/16" TRADE SIZE, .20 DIA. MATERIAL, INSIDE LINK SIZE .38 WD, .95L	McMASTER-CARR SUPPLY CO. ATLANTA, GA 30374	2
1	-1	DRUM FLAT COVER	12 GA 304/304L SST	ASME SA240	1

M2E801580 M2E801580 A002-1

PARTS LIST

M2E801580A005 REV E SHEET 1 OF 1

UNCLASSIFIED

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NAME: STAN THOMAS
DATE: 03/01/16
TITLE: PKG. ENGR.
ORGANIZATION: PACKAGING

CURRENT ISSUE APPROVALS

DES	KW JOHNSON	NCS	AD WILKINSON
DR	GA BYINGTON		
CHKR	L ROBERSON		
DVR	WL GOINS		
SE	N/A		
PE	L ROBERSON		
DM	JC ANDERSON		

NUCLEAR CRITICALITY SAFETY

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

REV	DATE	REVISION DESCRIPTION
E	3/31/2016	UPDATED FORMAT, REVISED NOTE 7 & DELETED NOTES 1-4
D	3/17/10	ADDED NOTE 8, REVISED FORMAT
C	9/10/08	ADDED REFERENCE NOTE 7.
B	2/11/05	REVISED F/N 2; ADDED F/N 3 & 4 REMOVED TOL FROM DETAIL Z DIM.
A	10/29/03	ISSUED FOR PROTOTYPE PROCUREMENT

NEXT ASSEMBLY/ REFERENCE DOCUMENTS: N/A

SCALE: NOTED
SHEET SIZE REPRESENTATION: 1 INCH SQUARE AT FULL SIZE
SCALE PROVIDED FOR REFERENCE ONLY DO NOT SCALE

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ±.01
XX DECIMALS ±.005
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .01-.06
FINISH .125 RMS
THIRD ANGLE PROJECTION

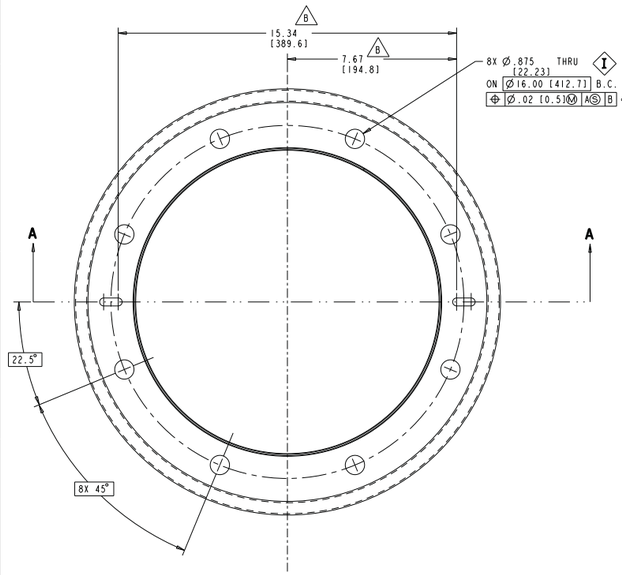
I IMPORTANT TO FORM-FIT-FUNCTION INDEPENDENT VERIFICATION REQUIRED
S IMPORTANT TO SAFTEY SHALL BE 100% INSPECTED AND NOT DEVIATED WITHOUT APPROVAL

APPROXIMATE WEIGHT: N/A
DIMENSIONING AND TOLERANCING: ASME Y14.5M - 1994
ALL DIMENSIONS ARE IN: INCHES
SOFTWARE: CREO 2.0

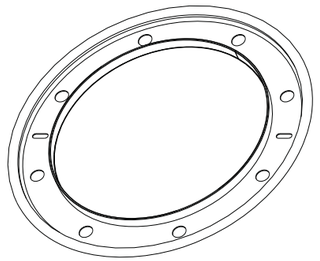
Y-12 NATIONAL SECURITY COMPLEX
CONSOLIDATED NUCLEAR SECURITY, LLC
P.O. BOX 2009 OAK RIDGE, TN 37831
US GOVERNMENT CONTRACT: DE-NA0001942
USERS MUST REFER TO THE TRANSMITTAL DOCUMENTS THAT ACCOMPANIED DELIVERY OF THIS DRAWING FOR ANY APPLICABLE DISCLAIMERS GOVERNING THE DRAWING.

PROJECT: ES-3100 SHIPPING PACKAGE
TITLE: MISC. DETAILS
DRAWING NUMBER: M2E801580A005 PART 000 REV E
RECORD NO: N/A TECS: N/A STATE: AR SHEET: 1 OF 1

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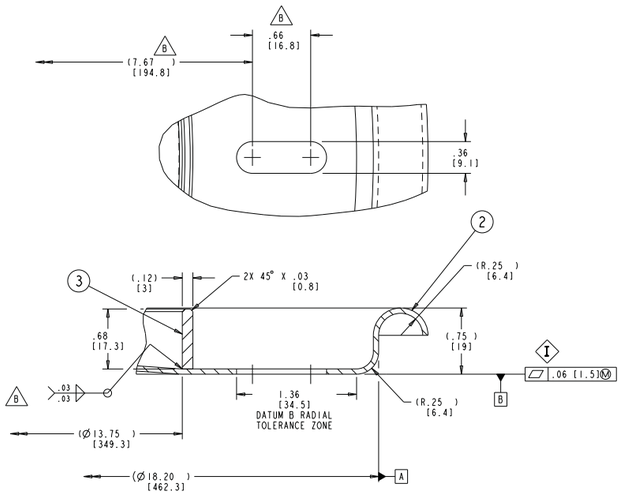
-1 DRUM LID WELDMENT
SCALE 1/2



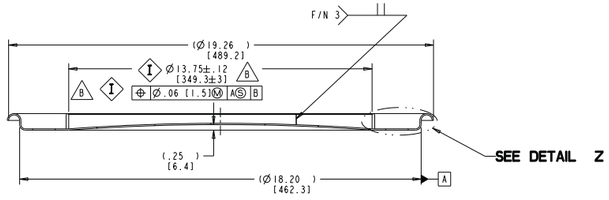
ISOMETRIC VIEW
SCALE 3/8

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. (B) WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. DIMENSIONS AND FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
7. FOR REFERENCE ONLY APPROXIMATE WEIGHT: 9.1 LBS [4.1 Kg]



DETAIL Z
SCALE 2/1



SECTION A-A

	AR		WELD FILLER METAL	PER WELD PROCEDURES		4
	1	-3	11 GA (.1197) SHEET	304/304L SST	ASME SA240	3
	1	M2E801580A007-1	18.25" DIA. DRUM LID			2
AR	X	-1	DRUM LID WELDMENT			1
M2E801580A001	-1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		QTY REQ'D NEXT ASSEMBLY	PARTS LIST			

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

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

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P THIS DRAWING PRODUCED ON PRO/ENGINEER

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE	WE	DATE	AR	CV	ST	HV	EM	FR	PD	EE	IE	M	NP
B	REPLACED HOLE WITH SLOT; ADDED TOL TO 13.75 DIM; ADDED (I); MOD WELD; GEN REV NOTE 4 WAS 5	JRP	SMM	GAB	RDA	DPS	11/03/05	GAB	2/10/05	JGA	2/10/05	DTE	2/11/05											
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03													

REVISION OR ISSUE PURPOSE — REVISION APPROVALS — SQUAD CHECK

SCALE:	NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED	
FRACTIONS	
XX DECIMALS ±.03	
XXX DECIMALS ±.010	
ANGLES ±0.5°	
BREAK SHARP EDGES .06 MAX	
FINISH 125 RMS	

DRAWING APPROVALS

		DATE
DRW	J.R. JACKAON	10/29/03
CHKR	J.S. LOWERY	10/29/03
DE	G.A. BYINGTON	10/29/03
DVR	J.L. HECK	10/29/03
DM	J.C. WALLS	10/29/03
PE	M.R. FELDMAN	10/29/03
PM	D.B. MILLER	10/29/03

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

PROJECT NAME
ES-3100 SHIPPING PACKAGE

DRUM LID WELDMENT

1	48	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	1	1	S	U

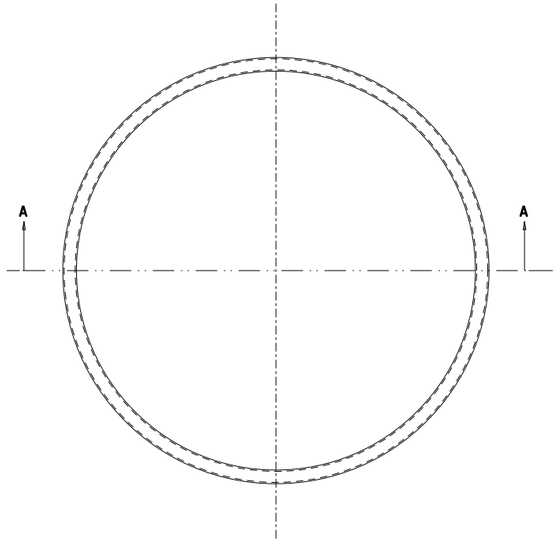
51	52	53		REV
CM	PKG	IN	M2E801580A006	B

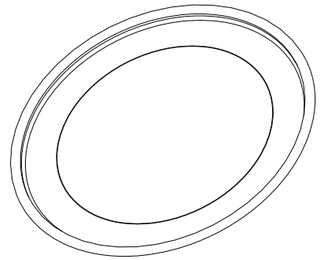
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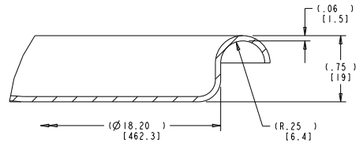
NOTES

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

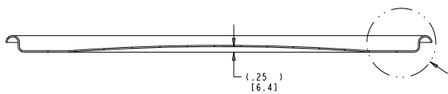




ISOMETRIC VIEW
SCALE 3/8



DETAIL Z
SCALE 2/1



SECTION A-A

-1 18.25" DIAMETER DRUM LID
SCALE 1/2

AR	-1	18.25" DIA. DRUM LID	16 GA 304/304L SST	ASME SA240	1
	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
M2E801580A004	QTY REQ'D NEXT ASSEMBLY	PARTS LIST			

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

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

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

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

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP
B	GENERAL REVISION.	JRP	SMM	GAB	RDA	DPS	11/03/05	GAB	2/10/05	JGA	2/10/05											
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03											

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

DRAWING APPROVALS

SCALE: NOTED	DRW J.R. JACKSON	10/29/03
TOLERANCES UNLESS OTHERWISE SPECIFIED	CHKR J.S. LOWERY	10/29/03
	DE G.A. BYINGTON	10/29/03
FRACTIONS	DVR J.L. HECK	10/29/03
XX DECIMALS	DM J.C. WALLS	10/29/03
XXX DECIMALS	PE M.R. FELDMAN	10/29/03
ANGLES	PM D.B. MILLER	10/29/03
BREAK SHARP EDGES MAX		
FINISH		

DATE

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

PROJECT NAME

ES-3100 SHIPPING PACKAGE

18.25" DIAMETER DRUM LID

I	48	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	I	I	S	U

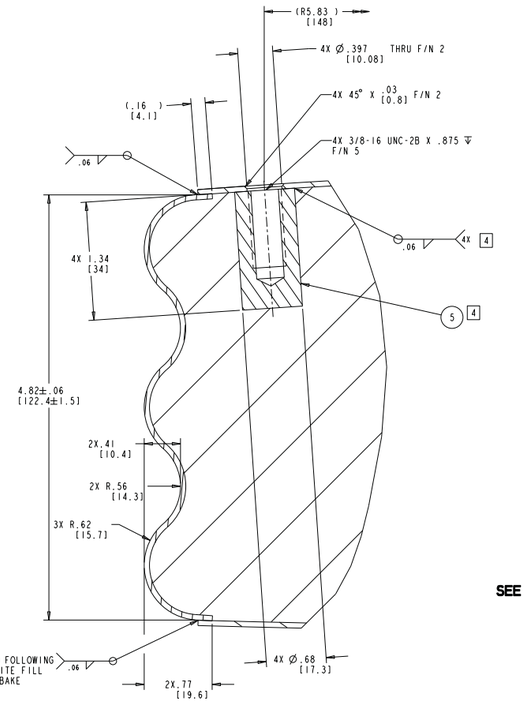
51	52	53		REV
CM	PKG	IN	M2E801580A007	B

M2E801580A007

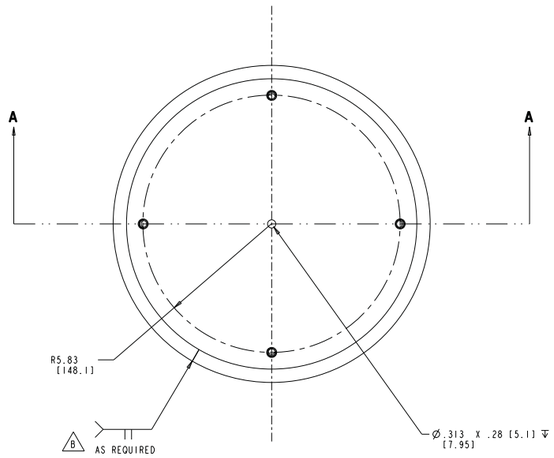
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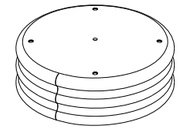
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DETAIL Z
SCALE 2/1

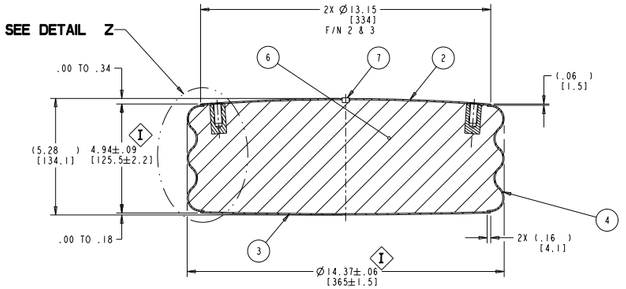




ISOMETRIC VIEW
SCALE 1/4

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. [4] WELD LIFTING INSERTS (F/N 5) IN PLACE BEFORE FILLING WITH KAOLITE (F/N 6).
5. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATIONS JS-YMN3-801580-A002 AND A003.
7. DIMENSIONS AND FEATURES FLAGGED BY A ⟨I⟩ SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
8. FOR REFERENCE ONLY:
   APPROXIMATE WEIGHT 19.6 LBS [8.8 Kg] WITH
   KAOLITE VOLUME 0.43 CU.FT.
   KAOLITE DENSITY 22.4 LBS/CU. FT.
   KAOLITE WEIGHT: 9.6 LBS [4.7 Kg]



SECTION A-A

	AR		WELD FILLER METAL	PER WELD PROCEDURES		8
	1	62MP0312 OR EQUAL	PLUG, NYLON 6/6	MICRO PLASTIC INC. FLIPPIN, AR 72634		7
	1	-6	KAOLITE 1600 TM VIBRATED CAST	THERMAL CERAMICS AUGUSTA, GA 30903-0923		6
	4	-5	LIFTING INSERT	11/16 ROUND 304/304L SST	ASME SA479	5
	1	-4	PLUG RIM	16 GA SHT 304/304L SST	ASME SA240	4
	1	-3	BOTTOM SHEET			3
	1	-2	TOP SHEET			2
AR	X	-1	TOP PLUG WELDMENT			1
M2E801580		PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
A008	--	QTY REQ'D NEXT ASSEMBLY	PARTS LIST			

-1 TOP PLUG WELDMENT
SCALE 1/2

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

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

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

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

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE	ME	DATE
B	GENERAL REVISION ADDED WELD SYMBOL	JRP	SMM	GAB	RDA	DPS	11FEB05	JGA	2/10/05	GAB	2/10/05	DJE	2/11/05
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03		

REVISION OR ISSUE PURPOSE — REVISION APPROVALS

SQUAD CHECK	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP

DRAWING APPROVALS — DATE

SCALE:	NOTED	
TOLERANCES UNLESS OTHERWISE SPECIFIED		
FRACTIONS		
XX DECIMALS ±.03		
XXX DECIMALS ±.005		
ANGLES	±0.5°	
BREAK SHARP EDGES .06 MAX		
FINISH	125 RMS	

DRW	J.R. JACKSON	10/29/03
CHKR	J.S. LOWERY	10/29/03
DE	G.A. BYINGTON	10/29/03
DVR	J.L. HECK	10/29/03
DM	J.C. WALLS	10/29/03
PE	M.R. FELDMAN	10/29/03
PM	D.B. MILLER	10/29/03

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

PROJECT NAME: ES-3100 SHIPPING PACKAGE

TOP PLUG WELDMENT

1	48	49	50	PLANT	BLDG	FL	SH. OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	1 1	S	U

51	52	53		REV
CM	PKG	IN	M2E801580A008	B

M2E801580A008

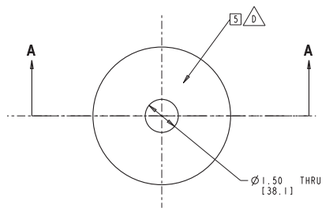
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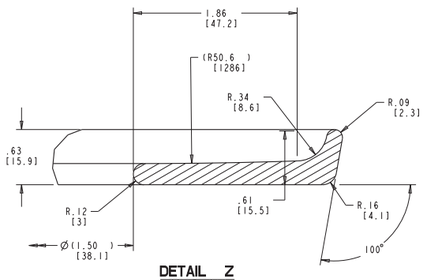
P THIS DRAWING PRODUCED ON PRO/ENGINEER

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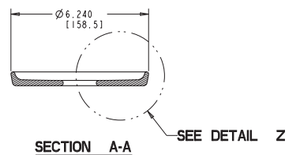
NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER "RMA" RUBBER HANDBOOK (RMA-392) CLASS "A2 PRECISION."
3. DIMENSIONS ARE IN INCHES.
4. MANUFACTURER/SUPPLIER TO PROVIDE CERTIFICATE OF COMPLIANCE FOR ALL FEATURES OF THESE ITEMS.
5. IN APPROXIMATE LOCATION SHOWN, ENGRAVE DRAWING NUMBER AND REVISION LETTER IN 1/4" HIGH CHARACTERS IN THE MOLD TO MAKE A LEGIBLE RAISED MARKINGS IN THE PART.
6. FOR ADDITIONAL INFORMATION SEE EQUIPMENT DATA SHEET DS-801580-0002.



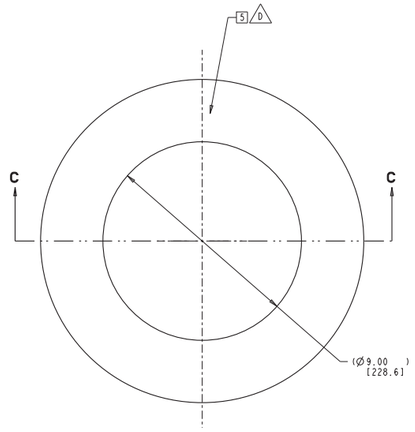


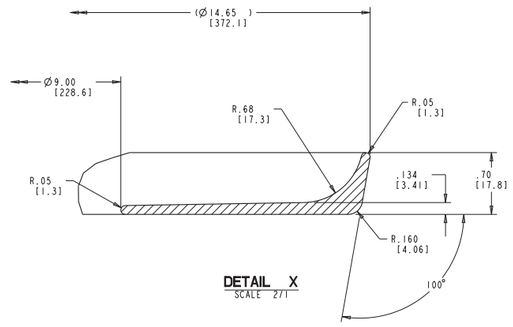
DETAIL Z
SCALE 2/1



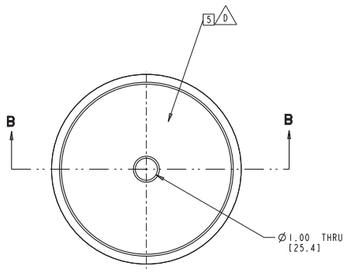
SECTION A-A

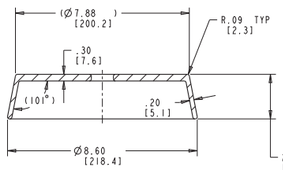
-1 CV BOTTOM PAD
SCALE 1/2
APPROXIMATE WEIGHT- 0.37 LB





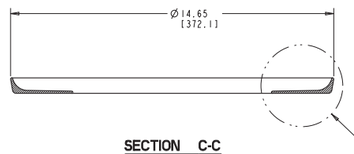
DETAIL X
SCALE 2/1





SECTION B-B

-2 CV FLANGE PAD
SCALE 1/2
APPROXIMATE WEIGHT - 1.15 LB



SECTION C-C

-3 PLUG PAD
SCALE 1/2
APPROXIMATE WEIGHT 0.77 LB

D	4	6	AR	-3	PLUG PAD	SILICONE RUBBER 22±5 SHORE A COLOR BLACK/GRAY	SEE NOTE 6	3
D	4	6	AR	-2	CV FLANGE PAD			2
D	4	6	AR	-1	CV BOTTOM PAD			1
M2E801580				PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
				QTY REQ'D NEXT ASSEMBLY	PARTS LIST			

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

REVISION	DATE	SAE APPROVAL
D	6/05/2012	J.F. DeCLUE

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

Name: DREW WINDER Date: 06/06/12

THIS DRAWING PRODUCED ON PRO/ENGINEER

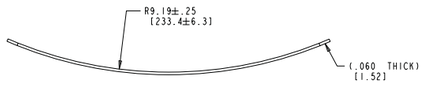
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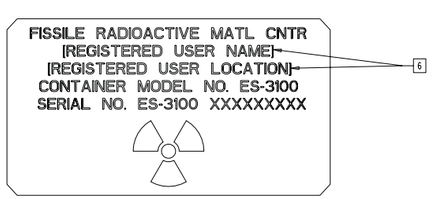
PART	REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	SE	DATE	WE	DATE	NCS	DATE	OM/SO	DATE
000	D	DELETED FIND NO 4, ADDED NOTE 6, CHANGED NOTE 5, REMOVED VENDOR FROM PARTS LIST	CDB	DEW	MLG	DEW	WIN	6/11/12	WIN	6/11/12	JGA	6/18/12						
000	C	GEN REV; REDESIGNED F/N 1; ADDED APPROXIMATE WEIGHT TO F/N 1, 2 AND 3	JRP	SMM	GAB	RDA	DPS	11/18/05	GAB	2/16/05	JGA	2/16/05						
000	B	MODIFIED DIMENSIONING ON -3	GAB	RA	GAB	JLH	JCW	11/22/04	GAB	11/22/04	JGA	11/22/04						
000	A	ISSUED FOR PROTOTYPE PROCUREMENT	JR	JSL	GAB	JLH	JCW	10/26/04	MRF	10/26/04	DES	MM	10/26/04					

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS

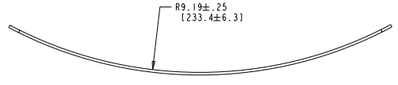
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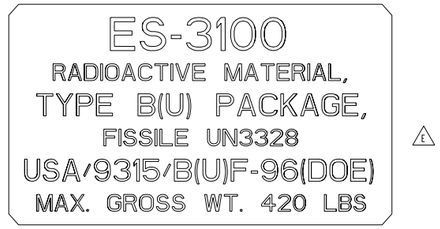
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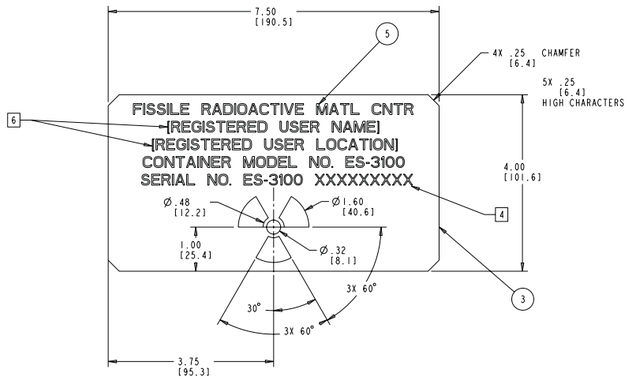


-1 ES-3100 TREFOIL DATA PLATE
FORMED

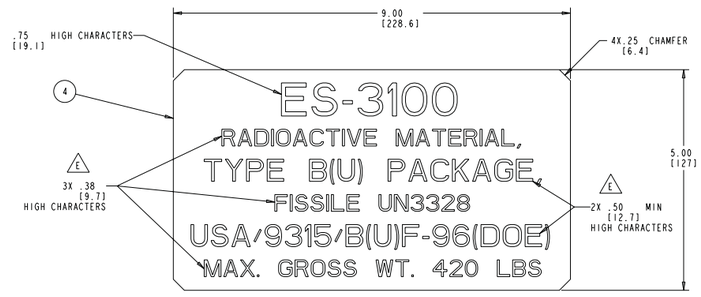




-2 ES-3100 DATA PLATE
FORMED



-1 ES-3100 TREFOIL DATA PLATE
SCALE 1/1
FLAT PATTERN



-2 ES-3100 DATA PLATE
SCALE 1/1
FLAT PATTERN

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm].
4. CONTAINER SERIAL NUMBER SHOWN "XXXXXXXXX" IS A GENERIC REPRESENTATION. ACTUAL SERIAL NUMBERS SHALL BE SPECIFIED IN PURCHASE ORDER, OR PROCUREMENT CONTRACT.
5. ALL CHARACTERS AND SYMBOLS SHALL BE ELECTROCHEMICALLY ETCHED .003-.005 DEEP AND FILLED WITH BLACK ENAMEL PAINT (F/N 5).
6. SEE PROCUREMENT DOCUMENTS FOR PROPER REGISTERED USER NAME AND LOCATION.

NEXT ASS'Y		FINAL ASS'Y	QTY REQ'D NEXT ASSEMBLY	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	AR	AR	-5	PAINT, BLACK ENAMEL			FED SPEC 595b-17038	5
		1	-4	16 GA, SHEET		304/304L SST	ASME SA240	4
	1		-3					3
AR			-2	ES-3100 DATA PLATE				2
AR			-1	ES-3100 TREFOIL DATA PLATE				1

M2E801580A010 -1 -2

PARTS LIST

E THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY ANALYSIS ENGINEERING APPROVAL.

REVISION	DATE	SAE APPROVAL
E	09/10/09	J.F. DECLUE

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

Name: R.D. AIGNER Date: 09/10/09

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP
E	REVISED DATA PLATE F/N 2 & 4, UPDATED SAE BLOCK.	MLE	JRJ	MLE	DEW	WIN	9/10/09	LR	9/10/09	JGA	9/14/09											
D	REVISED TREFOIL DATA PLATE, F/N 1, ADDED NOTE 6	JRJ	RDA	LR	GAB	WIN	9/9/08	LR	9/9/08	JGA	9/9/08											
C	REVISED TREFOIL DATA PLATE, F/N 1, AND NOTE 4	JRJ	RDA	JRJ	GAB	WIN	10/16/06	RAYer	10/17/06	JGA	10/17/06											
B	GEN REV: REMOVED RIVIT HOLES F/N 1 & 2; ADDED CHAMFERS F/N 1 & 2; ADDED NEW FLAT PATTERN VIEWS; REMOVED NOTE 5; CHANGED NOTE 6 TO NOTE 5; REMOVED NOTE 7; REMOVED INDEX NOTE BOX 5; CHANGED INDEX NOTE BOX 7 TO 4	JRP	SMM	GAB	RDA	DPS	1/11/05	GAB	2/10/05	JGA	2/10/05											
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03											

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

		DRAWING APPROVALS	DATE
SCALE: NOTED	DRW	J.R. JACKSON	10/29/03
TOLERANCES UNLESS OTHERWISE SPECIFIED	CHKR	J.S. LOWERY	10/29/03
	DE	G.A. BYINGTON	10/29/03
	DVR	J.L. HECK	10/29/03
FRACTIONS	DM	J.C. WALLS	10/29/03
XX DECIMALS ±.03	PE	M.R. FELDMAN	10/29/03
XXX DECIMALS ±.005	PM	D.B. MILLER	10/29/03
ANGLES ±0.5°			
BREAK SHARP EDGES .06 MAX			
FINISH 125 RMS			

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

PROJECT NAME
ES-3100 SHIPPING PACKAGE

DATA PLATE DETAILS

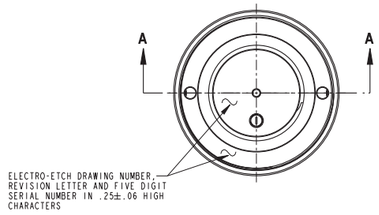
I	48	49	50	PLANT	BLDG	FL	SH. OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	1 1	S	U

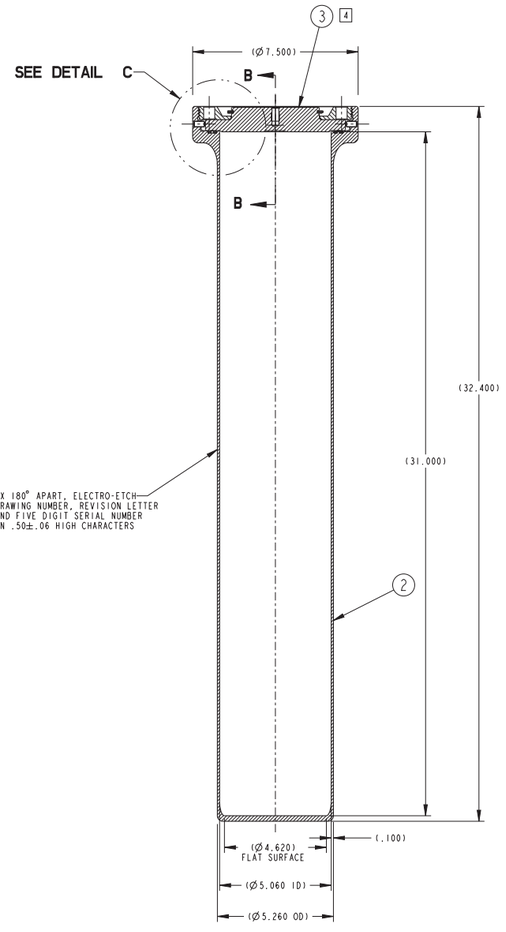
51	52	53		REV
CM	PKG	IN	M2E801580A010	E

NO REPRESENTATION OR WARRANTY, EXPRESSED OR IMPLIED, IS MADE AS TO THE ACCURACY, COMPLETENESS OR USEFULNESS OF THE INFORMATION OR STATEMENTS CONTAINED IN THESE DRAWINGS, OR THAT THE USE OR DISCLOSURE OF ANY INFORMATION, APPARATUS, METHOD, OR PROCESS DISCLOSED IN THESE DRAWINGS MAY NOT INFRINGE PRIVATELY OWNED RIGHTS. THE USER ASSUMES ENTIRE RESPONSIBILITY AND RISK FOR THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE OF ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS. DRAWINGS MADE AVAILABLE FOR INFORMATION TO BIDDERS ARE NOT TO BE USED FOR OTHER PURPOSES AND ARE TO BE RETURNED UPON REQUEST OF THE FORWARDING CONTRACTOR.

P THIS DRAWING PRODUCED ON PRO/ENGINEER

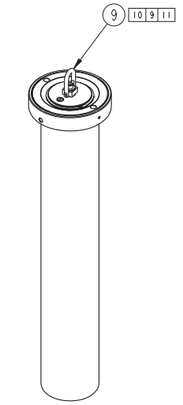
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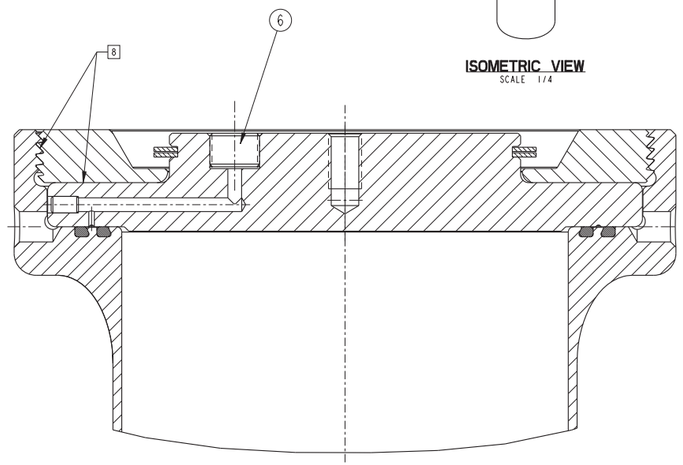


SECTION A-A

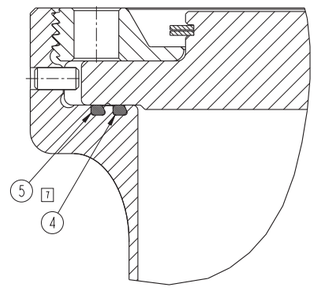
-1 CONTAINMENT VESSEL ASSEMBLY
SCALE 1/2



ISOMETRIC VIEW
SCALE 1/4



SECTION B-B
SCALE 2/1



DETAIL C
SCALE 2/1

NOTES

1. DELETED
2. DELETED
3. DELETED
4. INSTALL THE LID NUT AND TORQUE TO 120 ±5 FT-LBS AS SHOWN ON M2E801580A020-3 AND A020-4.
5. APPROXIMATE WEIGHT: 32.98 LBS. [14.96 KG].
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPEC. DS-YMN3-801580-A001.
7. DURING INSTALLATION OF O-RINGS APPLY A THIN COAT OF SUPER-O-LUBE.
8. DURING INSTALLATION OF CONTAINER VESSEL LID ASSEMBLY, APPLY A LIGHT COAT OF KRYTOX GREASE TO THE THREADS AND UNDER THE NUT.
9. SWIVEL HOIST RING FOR USE WHEN LOADING AND UNLOADING CONTAINMENT VESSEL ONLY. NOT FOR SHIPMENT.
10. TORQUE SWIVEL HOIST RING TO 12 ±1 FT.LBS. PER MFGR'S SPEC.
11. THE SWIVEL HOIST RING, THREAD LUBRICANT AND O-RING LUBRICANTS ARE REQUIRED AT EACH LOADING AND MAINTENANCE STATION.
12. DELETED

	AR	3052T56 OR EQUAL	SWIVEL HOIST RING	ALLOY STEEL	McMASTER- CARR ATLANTA, GA	9
11 10 9	AR	KRYTOX #240AC OR EQUAL	THREAD LUBRICANT	FLUORINATED GREASE	MILLER-STEPHENSON CHEMICAL CO. DANBURY, CT 06810	8
11 8	AR	SUPER-O-LUBE OR EQUAL	O-RING LUBRICANT	CLEAR DIMETHYL SILOXANE POLYMER	PARKER HANNIFIN CORP. O-RING DIV.,PO BOX 11751 LEXINGTON, KY 40512	7
11 7	1	PART # 04-2126	MODIFIED VCO THREADED PLUG	BRASS	VOLUNTEER INDUSTRIAL P. O. BOX 30371 KNOXVILLE, TN 37930 PHONE 865-660-2617	6
G	1	M2E801580A013-2	O-RING, OUTER			5
G	1	M2E801580A013-1	O-RING, INNER			4
	1	M2E801580A014-1	CONTAINMENT VESSEL LID ASSEMBLY			3
	1	M2E801580A012-1 OR A012-4	CONTAINMENT VESSEL BODY ASSEMBLY			2
AR	X	-1	CONTAINMENT VESSEL ASSEMBLY			1
M2E801580 A001	-1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		QTY REQ'D NEXT ASSEMBLY	PARTS LIST			

UNCLASSIFIED

THIS DOCUMENT HAS BEEN REVIEWED AND CONFIRMED TO BE UNCLASSIFIED.

NUCLEAR CRITICALITY SAFETY

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY.

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

NAME/DATE: This document has been reviewed and confirmed to be UNCLASSIFIED. Name: Stan Thomas Date: 07/18/2016

Stan (TSW) Thomas

TITLE: Y-12 ENGINEER

ORGANIZATION: Y-12 ENGINEERING

APPROVALS

DES	KW JOHNSON	NCS	AD WILKINSON
	Kevin W (KZH) Johnson		Alan D. (WA9) Wilkinson
DE	GA BYINGTON		
	G A (GAB) Byington		
CHKR	L ROBERSON		
	Larry (LRN) Roberson		
DVR	ML GOINS		
	Monty L (MLG) Goins		
DW/PE	JC ANDERSON		
	James C (JSA) Anderson		
PM	JG ARBITAL		
	Jeffrey G (AIJ) Arbital		

EFFECTIVE DATE: REFER TO DESIGN MANAGER APPROVAL

REVISION DESCRIPTION	NEXT ASSEMBLY/ REFERENCE DOCUMENTS
UPDATED FORMAT, DELETED VITON OPTION IN F/N's 4 & 5 AND DELETED NOTES 1-3.	N/A

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ±.01
XX DECIMALS ±.005
XXX DECIMALS ±0.5°
ANGLES .01-.06
BREAK SHARP EDGES 125 RMS MAX
FINISH
THIRD ANGLE PROJECTION

I IMPORTANT TO FORM-FIT-FUNCTION INDEPENDENT VERIFICATION REQUIRED

S IMPORTANT TO SAFETY SHALL BE 100% INSPECTED AND NOT DEVIATED WITHOUT APPROVAL

SCALE: NOTED
SHEET SIZE REPRESENTATION: 1 INCH SQUARE AT FULL SIZE
SCALE PROVIDED FOR REFERENCE ONLY DO NOT SCALE

APPROXIMATE WEIGHT: N/A
DIMENSIONING AND TOLERANCING: ASME Y14.5M - 1994
ALL DIMENSIONS ARE IN: INCHES [mm]
SOFTWARE: CREO 2.0

Y-12 NATIONAL SECURITY COMPLEX
CONSOLIDATED NUCLEAR SECURITY, LLC
P.O. BOX 2009 OAK RIDGE, TN 37831
US GOVERNMENT CONTRACT: DE-NA0001942
USERS MUST REFER TO THE TRANSMITTAL DOCUMENTS THAT ACCOMPANIED DELIVERY OF THIS DRAWING FOR ANY APPLICABLE DISCLAIMERS GOVERNING THE DRAWING.

PROJECT: ES-3100 SHIPPING PACKAGE
TITLE: CONTAINMENT VESSEL ASSEMBLY
DRAWING NUMBER: M2E801580A011 PART 000 REV G
RECORD NO: N/A STATE: IF SHEET: 1 OF 1

M2E801580A001 REV 6 SHEET 1 OF 1

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NOTES

1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.

2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.

3 DIMENSIONS ARE IN INCHES [mm].

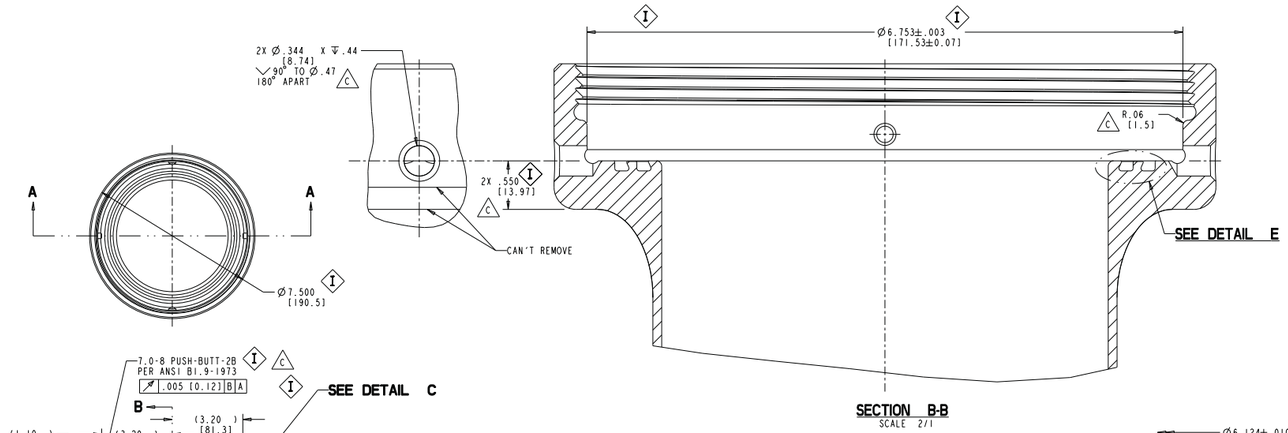
4 APPROXIMATE WEIGHT: 22.44 LBS [10.18 Kg].

5 FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.

6 DIMENSIONS AND FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.

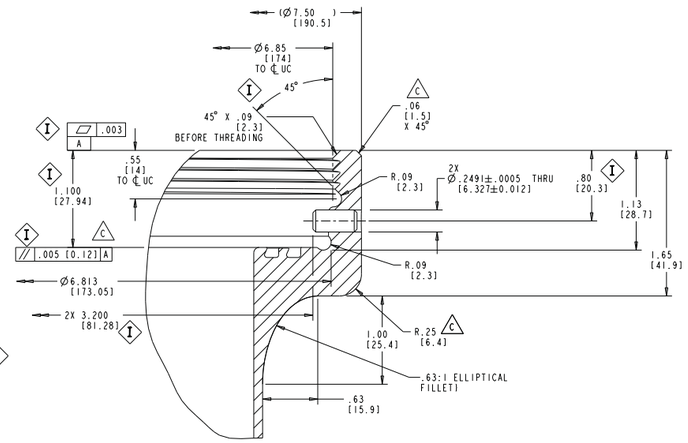
[7] VERIFY THE CONTAINMENT VESSEL INTERNAL DIAMETER BY USING THE MINIMUM CVID GAGE. THE CVID GAGE SHALL BE 10.30 +/- 0.03 LONG BY 5.020 +/- .001 EXTERNAL DIAMETER WITH A 20 DEGREE CHAMFER FROM THE CYLINDER TO A 4.52 +/- .03 DIAMETER ON THE BOTTOM. THE BOTTOM SHALL BE FINISHED WITH A .25 THICK YELLOW BRASS PLATE.

[8] THE FORMED BODY CONSTRUCTION SHOWN IN PART -2 IS PREFERED. THE ALTERNATIVE WELDED OPTION SHOWN IN PART -4 ON SHEET 2 IS ALSO ACCEPTABLE. PART -4 SHALL CONFORM TO THE PART -1 DIMENSIONS.

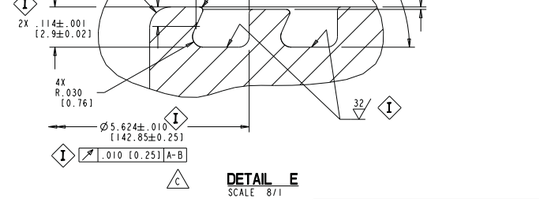


SECTION B-B
SCALE 2/1

SECTION A-A

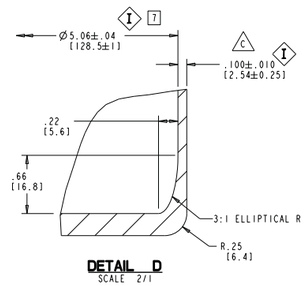


DETAIL C
SCALE 2/1



DETAIL E
SCALE 8/1

ISOMETRIC VIEW
SCALE 3/8



DETAIL D
SCALE 2/1

			I		-7	CONTAINMENT VESSEL END CAP	SST	ASME SA-182 TYPE F304L	7
			I		-6	CV PIPE BODY 5IPS SCH40		ASME SA-312 TYPE TP304L	6
			I		-5	CONTAINMENT VESSEL FLANGE		ASME SA-182 TYPE F304L	5
7 8	AR	AR		X	-4	CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION			4
C			2	2	-3	DOWEL PIN, .50 LONG Ø0.2501/0.2503 OD	18-8-SST	ANSI B18.8.2	3
			I		-2	CONTAINMENT VESSEL FORMED BODY	304L SST	SEE NOTE 5	2
7 8	AR	AR		X	-1	CONTAINMENT VESSEL BODY ASSEMBLY			1
M2E801580 A002	M2E801580 A001	-4	-1		PART OR IDENTIFYING NO ← QTY REQD NEXT ASSY	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO

PARTS LIST

-1 CONTAINMENT VESSEL BODY ASSEMBLY

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

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

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

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

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE	ME	DATE	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP
C	GEN REV; REMOVED ALL MMC & RFS SYMS FROM GEO TOLS; MODIFIED GEO TOLS TO PRIMARY & SECONDARY DATUM REF; ADDED VIEW ZONE G-6; ADDED .06 X 45° CHAM; ADDED TOL TO DIM IN DETAIL D; ADDED ANSI SPEC TO BOM; CHNG G TO U IN WELD SYM SHT 2	JRP	SMM	GAB	RDA	DPS	1/11/05	GAB	2/10/05	JGA	2/10/05	DJE	2/11/05											
B	ADDED PARTS -4,-5,-6, AND -7 ON SHEET 2 ALSO, GENERAL REVISIONS TO SHEET 1.	GAB	RA	GAB	JLH	JCW	10/22/04	GAB	10/22/04	JGA	10/22/04													
A	ISSUED FOR PROTOTYPE PROCUREMENT	DWS	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03													

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS | DATE

SCALE:	NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED	
FRACTIONS	
XX DECIMALS	±.01
XXX DECIMALS	±.005
ANGLES	±0.5°
BREAK SHARP EDGES .06 MAX	
FINISH	125 RMS

DRW	JRJ for D.W. SPARKS	10/29/03
CHKR	J.S. LOWERY	10/29/03
DE	G.A. BYINGTON	10/29/03
DVR	J.L. HECK	10/29/03
DM	J.C. WALLS	10/29/03
PE	M.R. FELDMAN	10/29/03
PM	D.B. MILLER	10/29/03

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

PROJECT NAME: ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL BODY ASSEMBLY

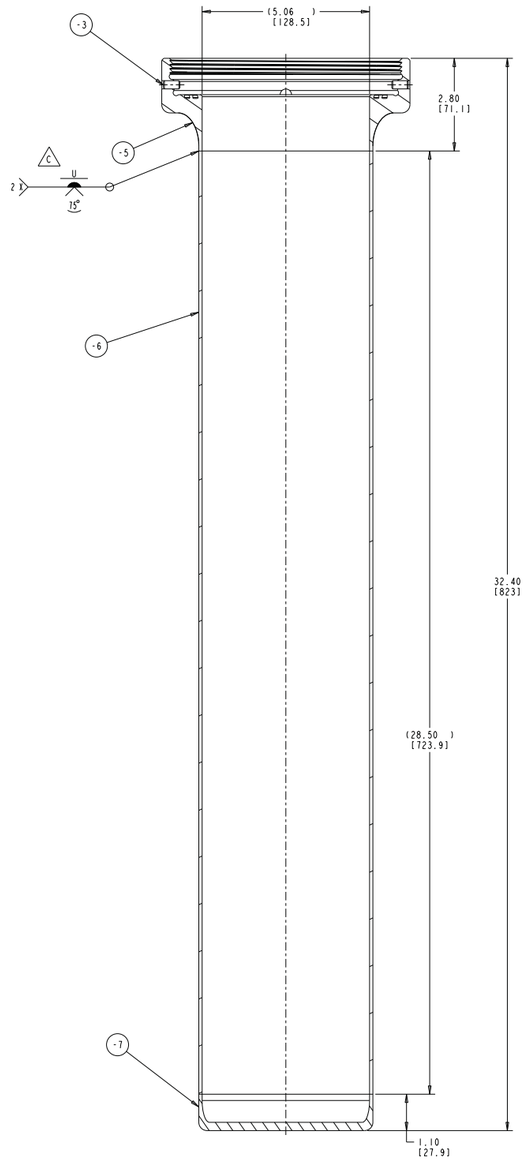
1	48	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	1	2	S	U
51		52		53						REV
CM		PKG		IN	M2E801580A012					C

M2E801580A012

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-4 CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION

SCALE 3/4

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P THIS DRAWING PRODUCED ON PRO/ENGINEER

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

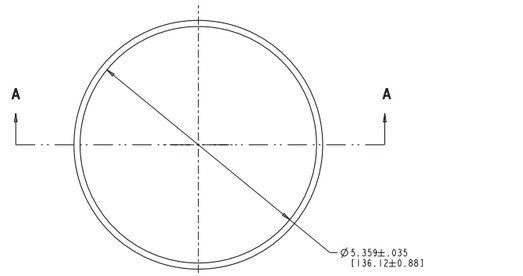
PROJECT NAME
ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL
BODY ASSEMBLY

I	AB	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	2	2	S	U

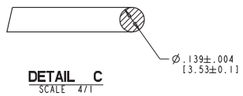
51	52	53		REV
CM	PKG	IN	M2E801580A012	C

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SECTION A-A
SCALE 1/1

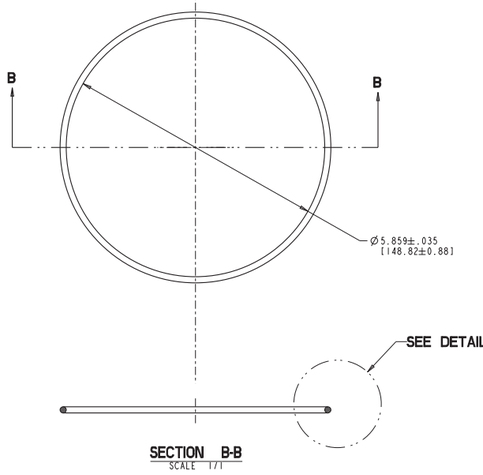
-1 INNER O-RING



DETAIL C
SCALE 4/1

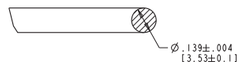
NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. (D) O-RING SHALL MEET THE REQUIREMENTS SPECIFIED IN EQUIPMENT SPECIFICATION SPC-M801580-0002.



SECTION B-B
SCALE 1/1

-2 OUTER O-RING



DETAIL D
SCALE 4/1

	AR	-2	OUTER O-RING	SEE NOTE 4	2
AR	AR	-1	INNER O-RING		1
M2E801580 A013-2 / M2E801580 A013-1		PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL / SPECIFICATION	FIND NO
	←	QTY REQ'D NEXT ASSEMBLY	PARTS LIST		

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REVISION	DATE	SAE APPROVAL
D	06/05/2012	J.F. DeCLUE

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

Name: DREW WINDER Date: 6/06/2012

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PART	REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	SE	DATE	WE	DATE	NCS	DATE	QW/SO	DATE
000	D	RESPECIFIED MATERIAL COMPOSITION AND SPECIFICATION FOR O-RINGS	CDB	DEW	MLG	DEW	WIN	6/11/12	WIN	6/11/12	JGA	6/18/12						
000	C	ADDED REFERENCE NOTE 5.	MLE	JRJ	JME		CMA	6/15/09	LR	6/15/09	CMA	6/15/09						
000	B	GEN REV; -1 WAS 2-253; -2 WAS 2-257;302"F WAS 300"F	JRP	SMM	GAB	RDA	DPS	11/18/05	GAB	2/10/05	JGA	2/10/05						
000	A	ISSUED FOR PROTOTYPE PROCUREMENT	DWS	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03						

REVISION OR ISSUE PURPOSE / REVISION APPROVALS / SQUAD CHECK

AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP																	

SCALE:	NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED	
FRACTIONS	
XX DECIMALS	±.01
XXX DECIMALS	±.005
ANGLES	±0.5°
BREAK SHARP EDGES	.06 MAX
FINISH	125 RMS

DRAWING APPROVALS

DRW	JRJ/D.W. SPARKS	10/26/03
CHKR	J.S. LOWERY	10/29/03
DE	GAB	10/29/03
DVR	J.L. HICKS	10/29/03
DM	J.C. WALLS	10/29/03
PE	M.R. FELDMAN	10/29/03
SE		
QW/SO	D.B. MILLER	10/29/03
WE	N/R	

Y-12 National Security Complex managed by B & W Technical Services Y-12, LLC for the Department of Energy under U.S. Government contract DE-AC-05-00OR22800 at Oak Ridge, Tennessee

PROJECT NAME: ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL O-RING DETAILS

USE	DISC	DT	DC	CM	SYSTEM	STA	SIZE	BLDG	FL	CLASS
6	M	L	F	CM	PKG	IN	E	NA	NA	U

SH.	OF	TYPE		PART	REV
1	1	DD	M2E801580A013	000	D

M2E801580A013

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NEXT ASS'Y: | FINAL ASS'Y: 1

NOTES

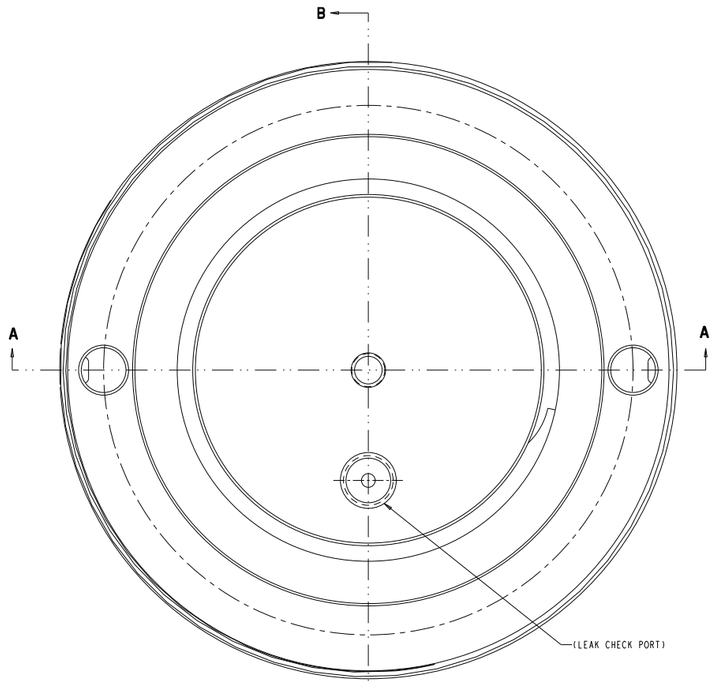
1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.

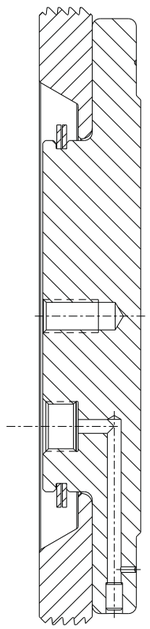
2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.

3 DIMENSIONS ARE IN INCHES [mm].

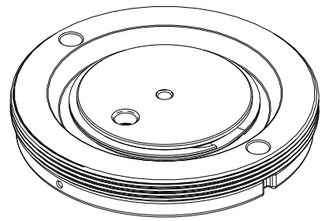
4 APPROXIMATE WEIGHT: 10.54 LBS [4.78 Kg].

5 FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.

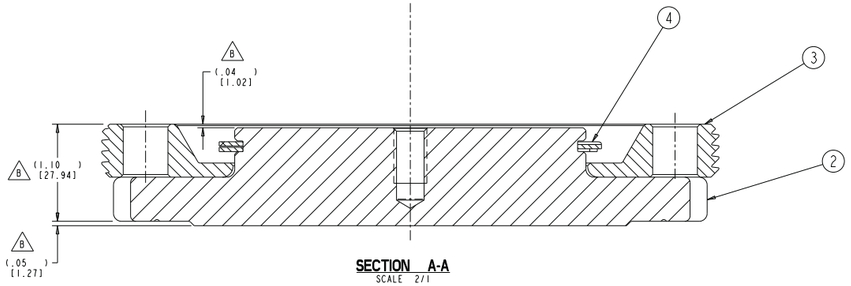




SECTION B-B



ISOMETRIC VIEW
SCALE 1/1



SECTION A-A
SCALE 2/1

-1 CONTAINMENT VESSEL LID ASSEMBLY

		1	WSM-400-S02	EXTERNAL RETAINING RING	SMALLEY STEEL RING CO. 385 GILMAN AVE. WHEELING, IL 60090	4
		1	M2E801580A016-1	CONTAINMENT VESSEL CLOSURE NUT		3
		1	M2E801580A015-1	CONTAINMENT VESSEL SEALING LID		2
AR	AR	X	-1	CONTAINMENT VESSEL LID ASSEMBLY		1
M2E801580 A013-1 M2E801580 A011-1		-1	PART OR IDENTIFYING NO / QTY REQD / NEXT ASSY	NOMENCLATURE OR DESCRIPTION	MATERIAL / SPECIFICATION	FIND NO

PARTS LIST

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

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

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

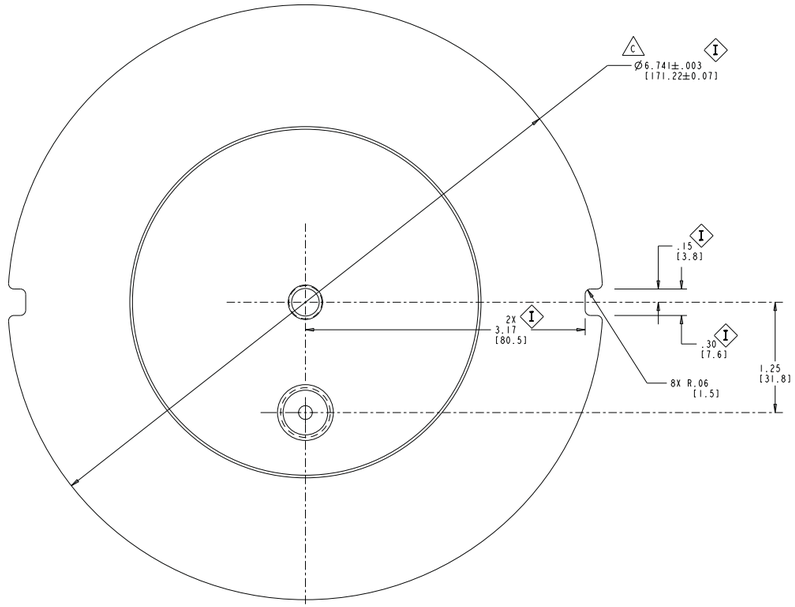
Name: ROGER D. AIGNER Date: 2/10/05

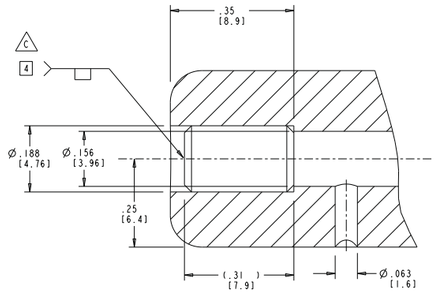
REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE
B	GEN. REV. THREAD RELIEF IN SECTION B-B; DIMS WERE 3 PLACE	JRP	SMM	GAB	RDA	DPS	11/18/05	GAB	2/10/05	JGA	2/10/05
A	ISSUED FOR PROTOTYPE PROCUREMENT	DWS	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03

REVISION OR ISSUE PURPOSE

| REVISION APPROVALS | | | | |

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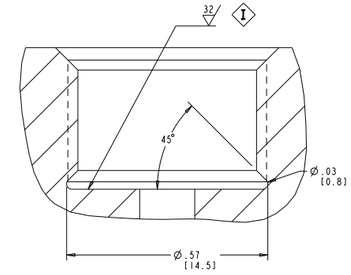




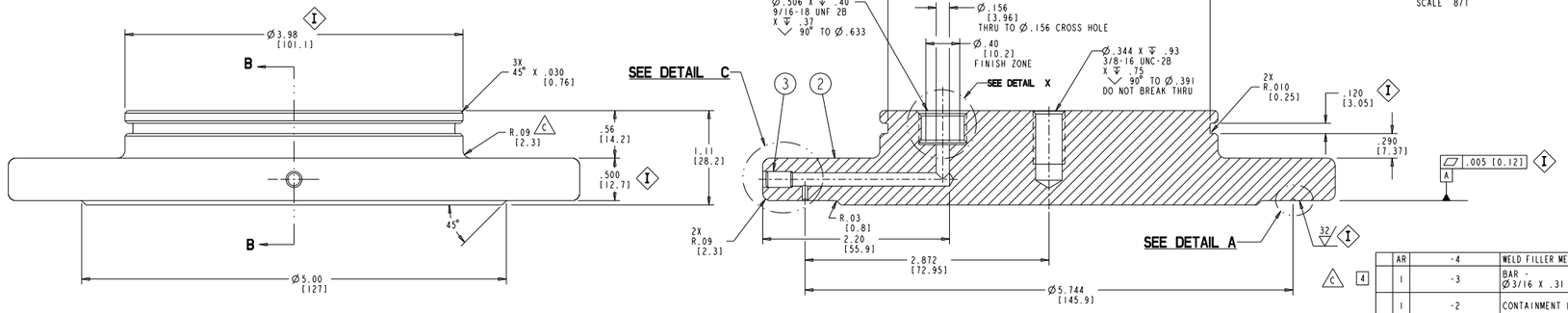
DETAIL C
SCALE 8/1

NOTES

1. INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.
3. DIMENSIONS ARE IN INCHES [mm].
4. WELD BAR (F/N 3) TO CONTAINER LID (F/N 2) BEFORE FINAL MACHINING.
5. FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.
6. DIMENSIONS OR FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.

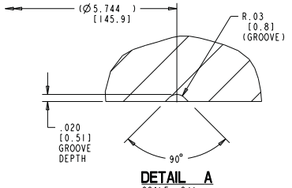


DETAIL X (C)
SCALE 8/1



-1 CONTAINMENT VESSEL SEALING LID
SCALE 2/1

SECTION B-B



DETAIL A
SCALE 8/1

	AR	-4	WELD FILLER METAL	PER WELD PROCEDURES		4
	1	-3	BAR - Ø3/16 X .31 LONG	SST 304	ASME SA-479	3
	1	-2	CONTAINMENT LID			2
	AR	-1	CONTAINMENT VESSEL SEALING LID			1
M2E801580 A001	F/N	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	← QTY REQD NEXT ASSY	PARTS LIST				

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	PM	DATE	WE	DATE	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP
C	MOVED Ø6.741 DIM TO ZONE H6; ZONE D6 ADDED DIM R.09; ZONE D5 CHANGED DIM .38 TO .37; ADDED DET. X MOVED 32 FINISH SYM & (I) FROM SEC B-B	JRP	SMM	GAB	RDA	DPS	11FEB05	GAB	2/10/05	JGA	2/10/05	DJE	2/11/05											
B	REDUCED ORING FINISH AND LEAKCHECK DEPTH	GAB	RA	GAB	JLH	JCW	01/22/04	GAB	01/22/04	JGA	01/22/04													
A	ISSUED FOR PROTOTYPE PROCUREMENT	DWS	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03													

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

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

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

SCALE: NOTED	DRW	JRJ for D.W. SPARKS 10/29/03
TOLERANCES UNLESS OTHERWISE SPECIFIED	CHKR	J.S. LOWERY 10/29/03
FRACTIONS	DE	G.A. BYINGTON 10/29/03
XX DECIMALS ±.01	DVR	J.L. HECK 10/29/03
XXX DECIMALS ±.005	DM	J.C. WALLS 10/29/03
ANGLES ±0.5°	PE	M.R. FELDMAN 10/29/03
BREAK SHARP EDGES .06 MAX	PM	D.B. MILLER 10/29/03
FINISH 125 RMS		

DRAWING APPROVALS | DATE

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

PROJECT NAME: ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL SEALING LID

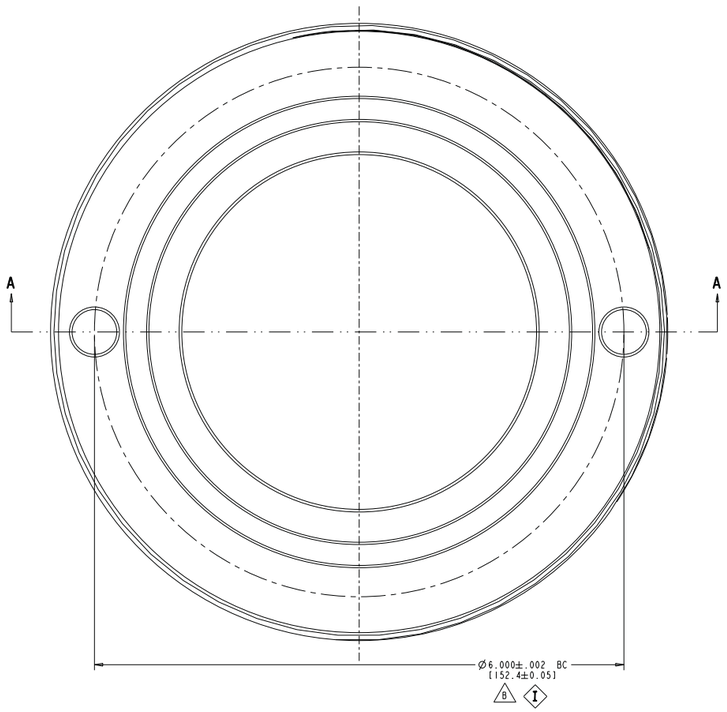
I	48	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	1	1	S	U
51 CM		52 PKG		53 IN	M2E801580A015					REV C

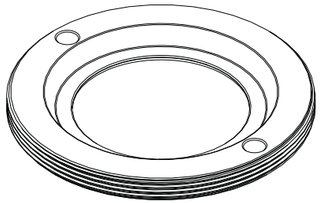
M2E801580A015

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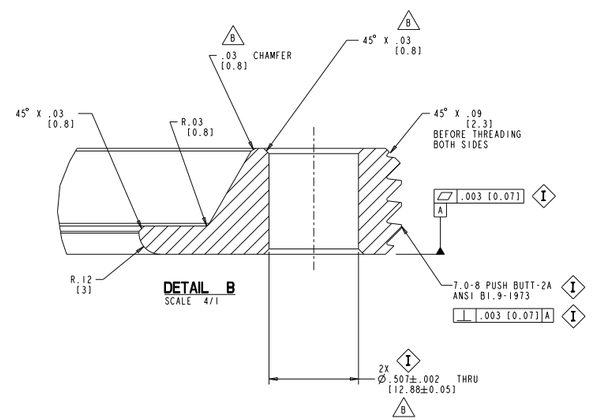


ISOMETRIC VIEW

SCALE 1/1

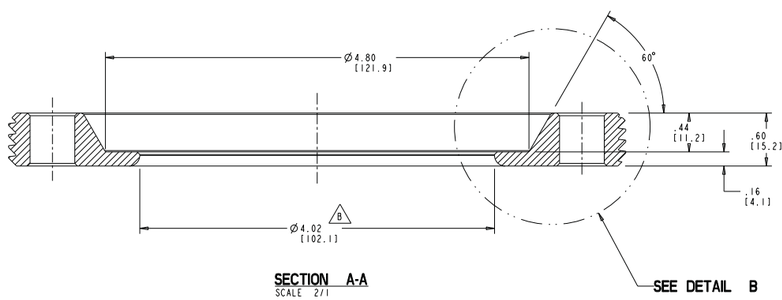
NOTES

1. INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.
3. DIMENSIONS ARE IN INCHES [mm].
4. (C) FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.
5. DIMENSIONS AND FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.]



DETAIL B

SCALE 4/1



SECTION A-A

SCALE 2/1

-1 CONTAINMENT VESSEL CLOSURE NUT

	AR	AR	-1	CONTAINMENT VESSEL CLOSURE NUT	NITRONIC 60 SST	ASME SA-479 UNS-S21800	1
M2E801580 A001-1 / M2E801580 A001-2			PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
			QTY REQD NEXT ASSY	PARTS LIST			

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

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

REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	PE	PW	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP
B	ADDED CHAMFER IN DETAIL B; MOD. HOLE TOL. REMOVED NOTE 4; RENUMBERED NOTES IN GEN NOTES	JRP 11FEB05	SMM	GAB	RDA	DPS	GAB 2/10/05	JGA 2/10/05											
A	ISSUED FOR PROTOTYPE PROCUREMENT	DWS 10/29/03	JSL	GAB	JLH	JCW	MRF 10/29/03	DBM 10/29/03											

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK | DRAWING APPROVALS | DATE

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P THIS DRAWING PRODUCED ON PRO/ENGINEER

SCALE:	NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED	
FRACTIONS	
XX DECIMALS	±.01
XXX DECIMALS	±.005
ANGLES	±0.5°
BREAK SHARP EDGES	.06 MAX
FINISH	125 RMS

DRW	JRJ for D.W. SPARKS	10/29/03
CHKR	J.S. LOWERY	10/29/03
DE	G.A. BYINGTON	10/29/03
DVR	J.L. HECK	10/29/03
DM	J.C. WALLS	10/29/03
PE	M.R. FELDMAN	10/29/03
PW	D.B. MILLER	10/29/03

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

PROJECT NAME

ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL CLOSURE NUT

I	AB	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
6	M	L	F	Y-12	NA	NA	1	1	S	U
51		52		53						REV
CM		PKG		IN	M2E801580A016					B

M2E801580A016

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NOTES

E 1 DELETED

E 2 DELETED

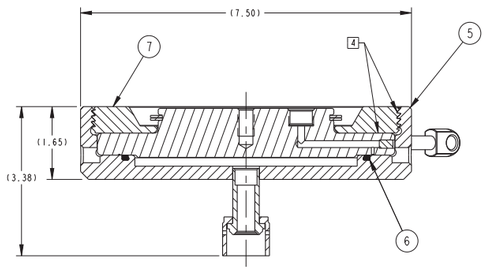
E 3 DELETED

4 APPLY A LIGHT COAT OF THREAD LUBRICANT, F/N 8, TO THREADS OF CLOSURE NUT, F/N 7; AND ON SURFACES BETWEEN CLOSURE NUT, F/N 3 AND TEST FLANGE, F/N 2.

5 APPLY A LIGHT COAT OF THREAD LUBRICANT, F/N 8, TO THREADS OF CONTAINMENT VESSEL LID ASSEMBLY, F/N 7; AND ON SURFACES BETWEEN CONTAINMENT VESSEL LID TEST FLANGE, F/N 5 AND CONTAINMENT VESSEL LID ASSEMBLY, F/N 7.

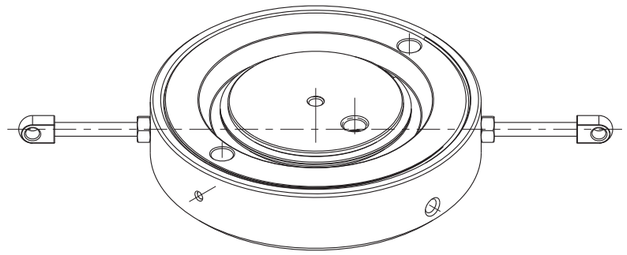
6 APPLY A LIGHT COAT OF SUPER O-LUBE, F/N 9, TO SURFACE OF INNER O-RING, F/N 6.

7 FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A001



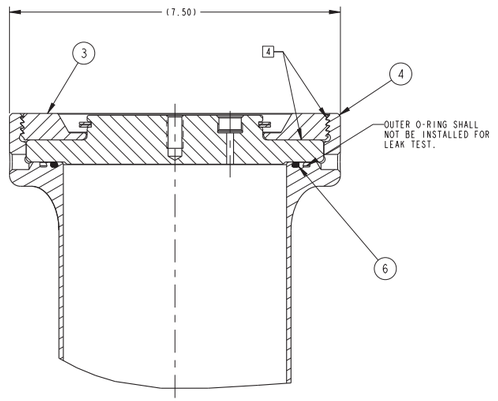
-2 CONTAINMENT VESSEL LID LEAK TEST ASSEMBLY

SCALE: 1/1



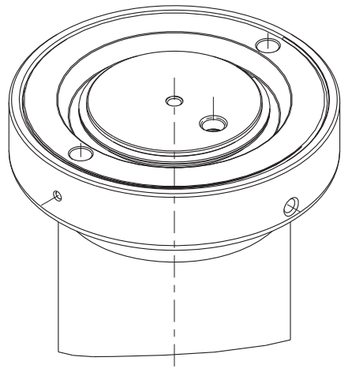
ISO VIEW

SCALE 1/1



-1 CONTAINMENT VESSEL BODY LEAK TEST ASSEMBLY

SCALE: 1/1



ISO VIEW

SCALE 1/1

	AR	AR	-9	SUPER O-LUBE	CLEAR DIMETHYL SILOXANE POLYMER	PARKER HANNIFIN O-RING DIVISION 2360 PALUMBO DR. LEXINGTON, KY	9
6	AR	AR	KRYTOX # 240 AC	THREAD LUBRICANT	FLUORINATED GREASE	MILLER-STEPHENSON CHEMICAL CO. DANBURY, CT 06810	8
4 5	I		M2E801580A014-1	CONTAINMENT VESSEL LID ASSEMBLY			7
E 6	I		M2E801580A013-1	INNER O-RING			6
	I		M2E801580A022-1	CONTAINMENT VESSEL LID TEST FLANGE			5
		I	M2E801580A012-1 OR A012-4	CONTAINMENT VESSEL BODY ASSEMBLY			4
	I		M2E801580A021-1	CONTAINMENT VESSEL BODY TEST FLANGE ASSEMBLY			3
			-2	CONTAINMENT VESSEL LID LEAK TEST ASSEMBLY			2
			-1	CONTAINMENT VESSEL BODY LEAK TEST ASSEMBLY			1
-2	-1		PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		←	QTY REQ'D NEXT ASSEMBLY	PARTS LIST			

M2E801580A023 REV E SHEET 1 OF 1

UNCLASSIFIED

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NAME/DATE: This document has been reviewed and confirmed to be UNCLASSIFIED. Digitally signed by Stan (TSW) Thomas DN: c=US, o=U.S. Government, ou=Department of Energy, cn=Stan (TSW) Thomas, 0.9.2342.19200300.100.1.1=00787 Date: 2016-07-18 10:43:30 EDT

Stan (TSW) Thomas

TITLE: Y-12 ENGINEER

ORGANIZATION: Y-12 ENGINEERING

APPROVALS

DES	KW JOHNSON	Kevin W (KZH) Johnson
DE	GA BYINGTON	G A (GAB) Byington
CHKR	L ROBERSON	Larry (LRN) Roberson
DVR	ML GOINS	Monty L (MLG) Goins
DM/PE	JC ANDERSON	James C (JSA) Anderson
PM	JG ARBITAL	Jeffrey G (AIJ) Arbital

EFFECTIVE DATE: REFER TO DESIGN MANAGER APPROVAL

REVISION DESCRIPTION	NEXT ASSEMBLY/ REFERENCE DOCUMENTS
UPDATED FORMAT, DELETED VITON OPTION IN F/N 6 AND DELETED NOTES 1-3.	N/A

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ±.01
XX DECIMALS ±.005
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .01-.06
FINISH 125 RMS MAX
THIRD ANGLE PROJECTION

1 IMPORTANT TO FORM-FIT-FUNCTION INDEPENDENT VERIFICATION REQUIRED

S IMPORTANT TO SAFETY SHALL BE 100% INSPECTED AND NOT DEVIATED WITHOUT APPROVAL

SCALE: NOTED
SHEET SIZE REPRESENTATION: 1 INCH SQUARE AT FULL SIZE
SCALE PROVIDED FOR REFERENCE ONLY DO NOT SCALE

APPROXIMATE WEIGHT: N/A
DIMENSIONING AND TOLERANCING: ASME Y14.5M - 1994
ALL DIMENSIONS ARE IN: INCHES
SOFTWARE: CREO 2.0

Y-12 NATIONAL SECURITY COMPLEX
CONSOLIDATED NUCLEAR SECURITY, LLC
P.O. BOX 2009 OAK RIDGE, TN 37831
US GOVERNMENT CONTRACT: DE-NA0001942
USERS MUST REFER TO THE TRANSMITTAL DOCUMENTS THAT ACCOMPANIED DELIVERY OF THIS DRAWING FOR ANY APPLICABLE DISCLAIMERS GOVERNING THE DRAWING.

PROJECT: ES-3100 SHIPPING CONTAINER
TITLE: CONTAINMENT VESSEL LEAK TEST ASSEMBLIES
DRAWING NUMBER: M2E801580A023 PART 000 REV E
RECORD NO: N/A STATE IF SHEET 1 OF 1

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NOTES

1 INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.

2 INTERPRET DIMENSIONS AND TOLERANCES PER "RMA" RUBBER HANDBOOK (RMA-392) CLASS "A2 PRECISION."

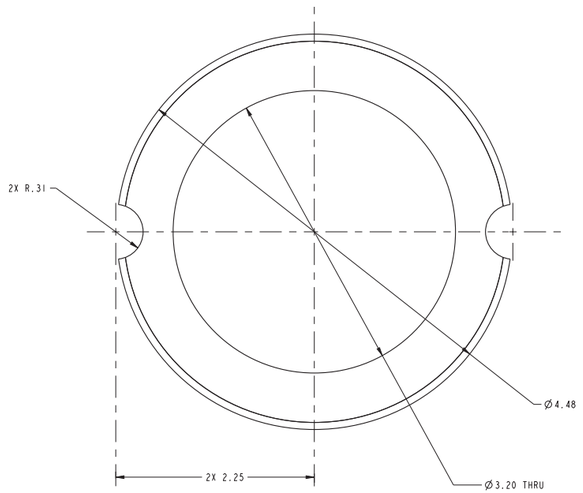
3 DIMENSIONS ARE IN INCHES.

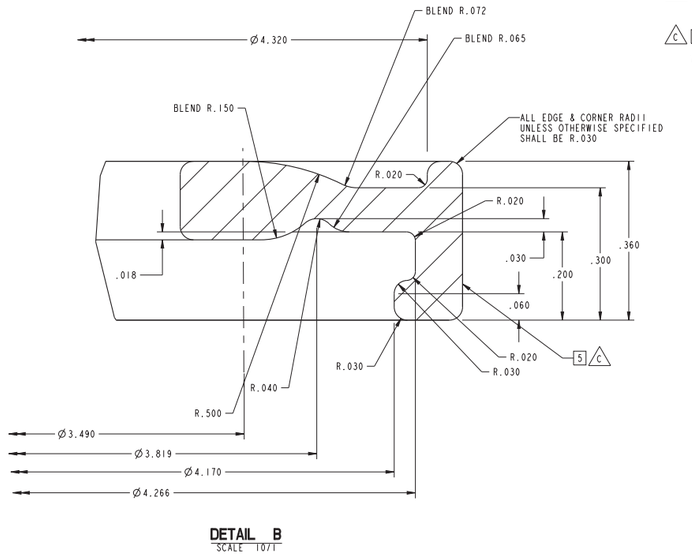
[4] MANUFACTURER/SUPPLIER TO PROVIDE CERTIFICATE OF COMPLIANCE FOR ALL FEATURES OF THESE ITEMS.

C [5] IN APPROXIMATE LOCATION SHOWN, ENGRAVE DRAWING NUMBER AND REVISION LETTER IN 1/4" HIGH CHARACTERS IN THE MOLD TO MAKE A LEGIBLE RAISED MARKING IN THE PART.

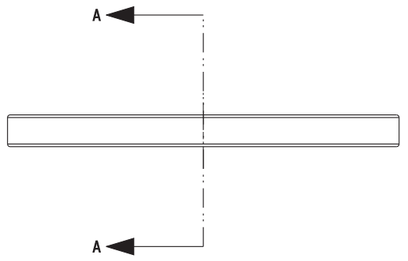
C [6] FOR ADDITIONAL INFORMATION SEE EQUIPMENT DATA SHEET DS-801580-0002.

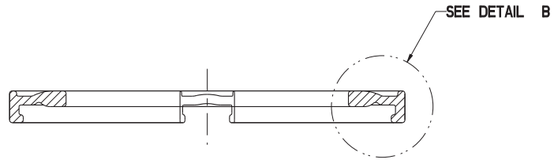
7 FOR REFERENCE ONLY:
WEIGHT: 0.0588 LBS [26.7 g]





DETAIL B
SCALE 10/1





SECTION A-A

-1 CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD
SCALE 2/1

C [4] [6]	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	QTY REQ'D NEXT ASSEMBLY				
AR	M2E801580-4025	CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD	SILICONE RUBBER A50-83B, SILICA FILLED, LOW HYDROGEN AND LOW VOLATILE VAPORS, POST CURED HARDNESS 75+/- 5 SHORE A	SEE NOTE 6	1
AR	M2E801580-4026	CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD	SILICONE RUBBER A50-83B, SILICA FILLED, LOW HYDROGEN AND LOW VOLATILE VAPORS, POST CURED HARDNESS 75+/- 5 SHORE A	SEE NOTE 6	1
AR	M2E801580-4027	CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD	SILICONE RUBBER A50-83B, SILICA FILLED, LOW HYDROGEN AND LOW VOLATILE VAPORS, POST CURED HARDNESS 75+/- 5 SHORE A	SEE NOTE 6	1
AR	M2E801580-4028	CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD	SILICONE RUBBER A50-83B, SILICA FILLED, LOW HYDROGEN AND LOW VOLATILE VAPORS, POST CURED HARDNESS 75+/- 5 SHORE A	SEE NOTE 6	1
AR	M2E801580-4029	CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25" CAN PAD	SILICONE RUBBER A50-83B, SILICA FILLED, LOW HYDROGEN AND LOW VOLATILE VAPORS, POST CURED HARDNESS 75+/- 5 SHORE A	SEE NOTE 6	1
-	M2E801580	PARTS LIST			

PARTS LIST

M2E801580A024

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REVISION	DATE	SAE APPROVAL
C	06/05/2012	J.F. DeCLUE

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Name: DREW WINDER Date: 06/06/12

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PART	REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	SE	DATE	WE	DATE	NCS	DATE	QM/SO	DATE	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP
000	C	REVISED NOTES 5 & 6	CDB	DEW	MLG	DEW	WIN	6/11/12	WIN	6/11/12	JGA	6/18/12																	
000	B	DELETED NOTE 8; ADDED NEXT ASS'Y TO BOM CHNG LOCATION OF INDEX NOTE 5 TO DET. B	JRP	SMM	GAB	RDA	DPS	11/13/03	GAB	2/10/03	JGA	2/10/03																	
000	A	ISSUED FOR DESIGN REVIEW	RDA	JSL	GAB	JLH	JCW	11/26/03	GAB	11/26/03	GBS	11/26/03																	

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

		DRAWING APPROVALS	DATE
SCALE: NOTED	DRW	R.D. AIGNER	11/26/03
TOLERANCES UNLESS OTHERWISE SPECIFIED	CHKR	J.S. LOWERY	11/26/03
	DE	G.A. BYINGTON	11/26/03
FRACTIONS	DVR	J.L. HECK	11/26/03
XX DECIMALS	DM	J.C. WALLS	11/26/03
XXX DECIMALS	PE	G.A. BYINGTON	11/26/03
ANGLES	SE		
BREAK SHARP EDGES	QM/SO	G.B. SINGLETON	11/26/03
FINISH	WE	N/R	

Y-12 National Security Complex managed by B & W Technical Services Y-12, LLC for the Department of Energy under U.S. Government contract DE-AC-05-00OR22800 at Oak Ridge, Tennessee

PROJECT NAME
ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL VIBRATION ABSORBING SILICONE 4.25 CAN PADS

USE	DISC	DT	DC	CM	SYSTEM	STA	SIZE	BLDG	FL	CLASS
6	M	L	F	CM	PKG	IN	E	NA	NA	U

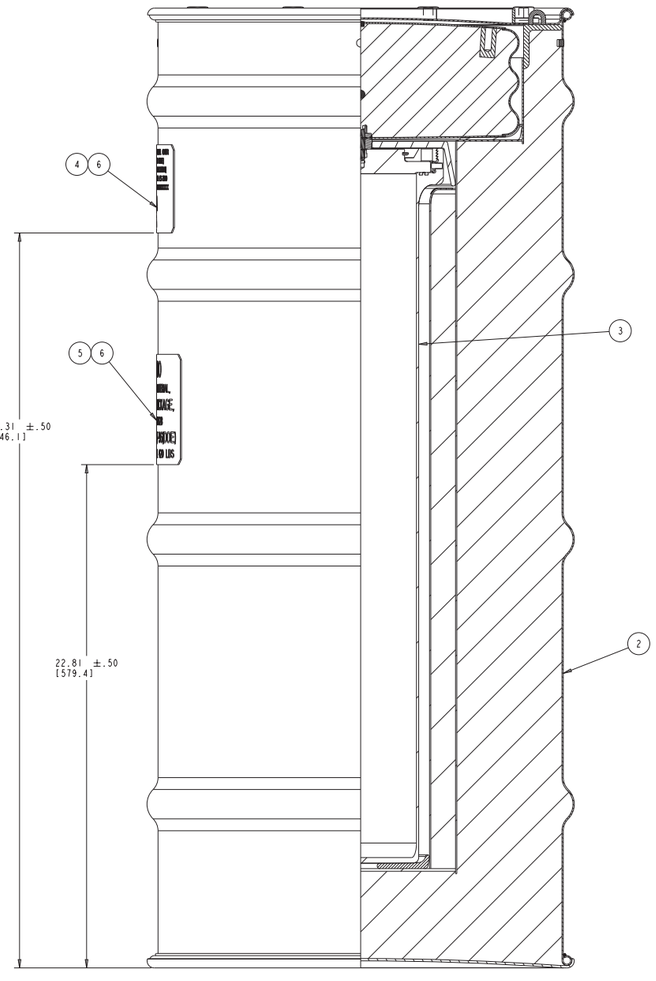
SH.	OF	TYPE		PART	REV
1	1	DD	M2E801580A024	000	C

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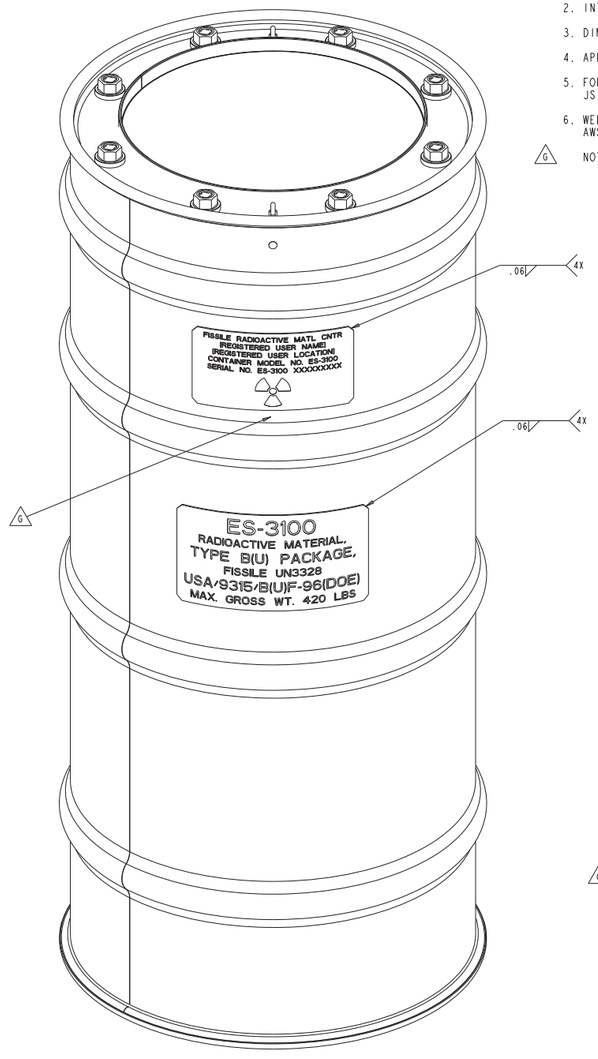
NOTES

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

G NOTE DELETED



-1 MAIN ASSEMBLY
SCALE 1/2



ISOMETRIC VIEW
SCALE 1/2

G

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

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REVISION	DATE	SAE APPROVAL
G	6/11/15	ALAN WILKINSON

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Name: STAN THOMAS Date: 06/11/15

C THIS DRAWING PRODUCED ON CREO PARAMETRIC

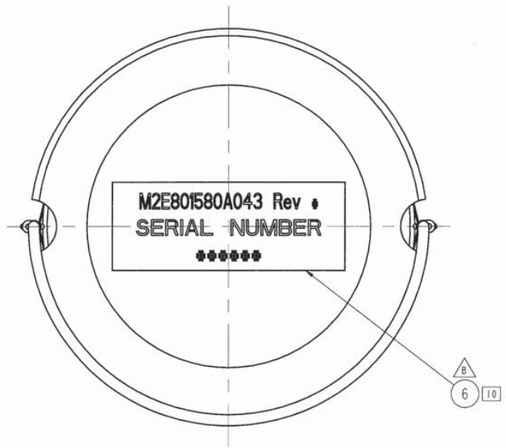
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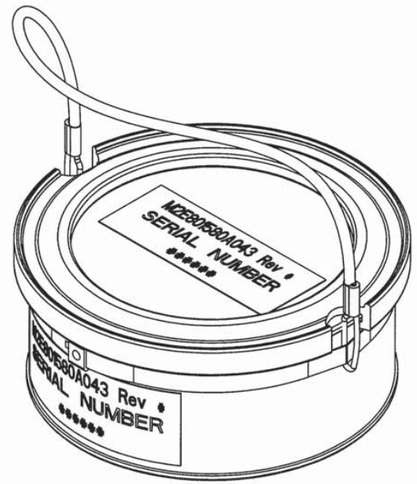
PART	REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	SE	DATE	WE	DATE	NCS	DATE	QM/SO	DATE
000	G	REMOVED TEMPERATURE LABEL F/N 7 AND DELETED NOTE 7; UPDATED FORMAT	KWJ	MLG	GAB	MLG	JCA	6/11/15	JCA	6/11/15	JGA	6/18/15						
000	F	ADDED NOTE 7 ALONG WITH F/N 7 TO PARTS LIST AND DRAWING FIELD	CDB	DEW	MLG	DEW	WIN	6/11/12	WIN	6/11/12	JGA	6/18/12						
000	E	REVISED ES-3100 DATA PLATE.	MLE	JRJ	MLE	DEW	WIN	9/10/09	LR	9/10/09	JGA	9/14/09	NA	NA				
000	D	REVISED TREFOIL DATA PLATE	JRJ	RDA	LR	GAB	WIN	9/9/08	LR	9/9/08	JGA	9/9/08	NA	NA				
000	C	REVISED TREFOIL DATA PLATE	JRJ	RDA	JRJ	GAB	WIN	10/16/06	10/16/06	LR	10/17/06	JGA	10/27/06	NA	NA			
000	B	GEN REV;CHG. NOTE 4;ADDED NOTES 5 & 6; CHG. F/N 6 WAS BLIND RIVIT;WEIGHTS & VOLS IN NOTE 10 UPDATED TO REFLECT NEW MAT'L.	JRP	SMM	GAB	RDA	DPS	11/18/05	GAB	2/10/05	JGA	2/10/05	DJE	2/11/05				
000	A		JRJ	JSL	GAB	JLH	JCW	10/29/03	MRF	10/29/03	DBM	10/29/03						

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

| | | | | | |

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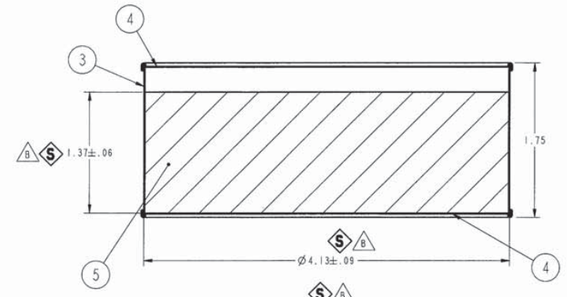




ISOMETRIC VIEW
SCALE 2/1

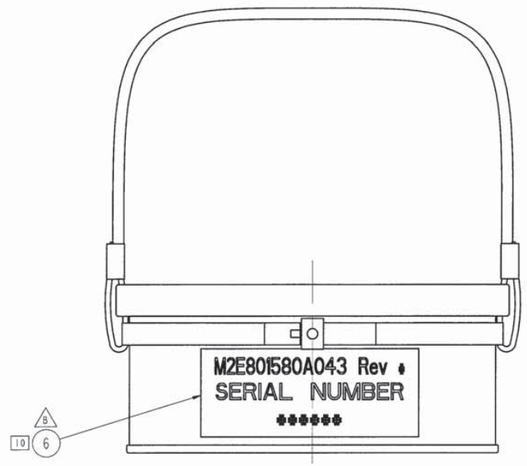
NOTES

B 1 DELETED
B 2 DELETED
B 3 DELETED
4 FOR FURTHER INFORMATION, SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A005, CASTING CATALOG NO. 277-4 NEUTRON ABSORBER.
5 FOR PURCHASE OF F/N 8, SEE DOCUMENT #DS-YMN3-801580-A001.
6 USE THE BAND-IT TIE-LOCK II HAND TOOL "A920" TO ATTACH THE STAINLESS STEEL BANDS AND CABLE ASSEMBLIES TO THE MATERIAL CANS. THE TOOL'S TENSION SETTING SHALL BE SET BETWEEN 4 AND 8.
7 REFERENCE DOCUMENT #DAC-YMN3-801580-A001.
B 8 FOR REFERENCE ONLY FIND NO 1; NOMINAL WEIGHT: 1.38 LBS [0.626 KG]
9 DELETED
10 MARK WITH PERMANENT LABELS F/N 6 DRAWING NUMBER, REVISION LETTER AND SIX DIGIT SERIAL NUMBER IN .18±.03 HIGH CHARACTERS.
11 SUPPLIED BY COMPANY.
12 FOR SHIPMENTS, THE USE OF VIBRATION PAD, FIND NO.9 WITH HEAVY CAN SPACER, IS OPTIONAL.

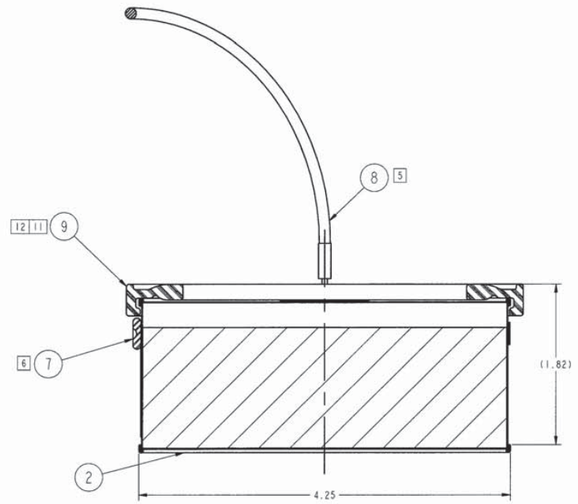


MINIMUM WEIGHT: 1.16 LB [526 G]
MAXIMUM WEIGHT: 1.56 LB [707 G]

-2 FILLED CAN
SCALE 2/1



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



12 | 11		AR	M2E801580A024-1	VIBRATION ABSORBING SILICONE 4.25" CAN PAD			9
5		1	-8	CABLE LANYARD	REFERENCE NOTE 5		8
6		1	AS213	BAND CLAMP	304 SST	BAND-IT-IDEX, INC. DENVER, CO 80216	7
B 10		2	WL-OL875WJ OR EQUAL	2.625" BY 1" VINYL COATED WEATHERPROOF WHITE PRINTER LABELS		WORLDLABEL.COM 336 CONVENT AVE,STE 2A NEW YORK NY 10031 SALES (866) 226-8669	6
4	AR		-5	277-4 FILLER		JS-YMN3-801580-A005	5
	2		-4	CAN END COVER	304/304L STAINLESS STEEL 30 GA. (0.012)	ASTM A240	4
	1		-3	CAN BODY			3
X	X	1	-2	FILLED CAN			2
	X	X	-1	HEAVY CAN SPACER ASSEMBLY (SST)			1
QTY REQ'D NEXT ASSEMBLY: 2 / 1			PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO

PARTS LIST

UNCLASSIFIED

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NAME: STAN THOMAS
DATE: 05/01/16
TITLE: PKG ENGR
ORGANIZATION: PACKAGING

NUCLEAR CRITICALITY SAFETY

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CURRENT ISSUE APPROVALS

DES	KW JOHNSON	NCS	AD WILKINSON
DC	LRA BEYINGTON		
CHK	L ROBERSON		
DVR	WL GOINS		
SE	N/A		
PE	L ROBERSON		
DM	JC ANDERSON		

REV	DATE	REVISION DESCRIPTION
B	3/31/2016	UPDATED FORMAT. MODIFIED REV LETTERS ON F/N 6 & CALL OUT ON PARTS LIST. DELETED NOTES 1-3 & 9. CHANGED DIAMOND 1 TO DIAMOND 5 ON F/N 2.
A	6/11/12	REVISED NOTES AND ADDED NOTE 12 FOR FIND NO.9
0	9/10/09	ORIGINAL ISSUE

NEXT ASSEMBLY/ REFERENCE DOCUMENTS: N/A

SCALE: NOTED — SHEET SIZE REPRESENTATION: 1 INCH SQUARE AT FULL SIZE — SCALE PROVIDED FOR REFERENCE ONLY DO NOT SCALE

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ±.01
XX DECIMALS ±.005
XXX DECIMALS ±0.5°
ANGLES
BREAK SHARP EDGES .01-.06
FINISH 125 RMS
THIRD ANGLE PROJECTION

1 IMPORTANT TO FORM-FIT-FUNCTION INDEPENDENT VERIFICATION REQUIRED
S IMPORTANT TO SAFTEY SHALL BE 100% INSPECTED AND NOT DEVIATED WITHOUT APPROVAL

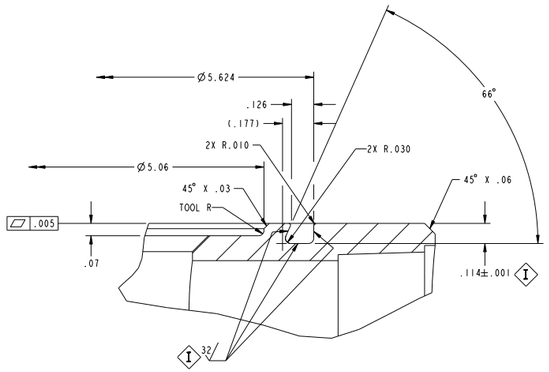
APPROXIMATE WEIGHT: N/A
DIMENSIONING AND TOLERANCING: ASME Y14.5M - 1994
ALL DIMENSIONS ARE IN: INCHES
SOFTWARE: CREO 2.0

Y-12 NATIONAL SECURITY COMPLEX
CONSOLIDATED NUCLEAR SECURITY, LLC
P.O. BOX 2009 OAK RIDGE, TN 37831
US GOVERNMENT CONTRACT: DE-NA0001942
USERS MUST REFER TO THE TRANSMITTAL DOCUMENTS THAT ACCOMPANIED DELIVERY OF THIS DRAWING FOR ANY APPLICABLE DISCLAIMERS GOVERNING THE DRAWING.

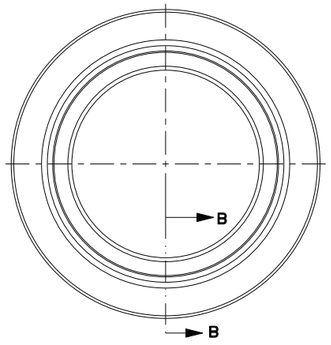
PROJECT: ES-3100 SHIPPING PACKAGE
TITLE: HEAVY CAN SPACER ASSEMBLY (SST)
DRAWING NUMBER: M2E801580A043 — PART 000 — REV B
RECORD NO: N/A — TBIS: N/A — STATE: IF — SHEET 1 OF 1

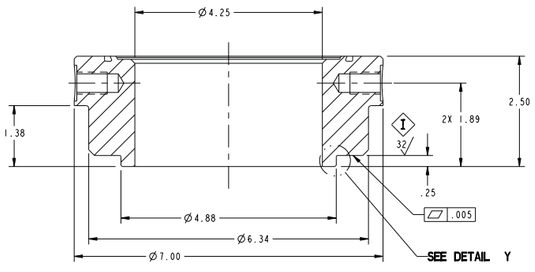
M2E801580A043 REV B SHEET 1 OF 1

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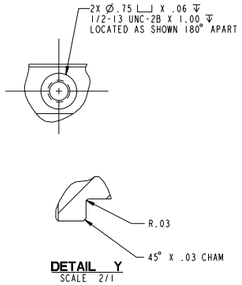


DETAIL X
SCALE 4/1

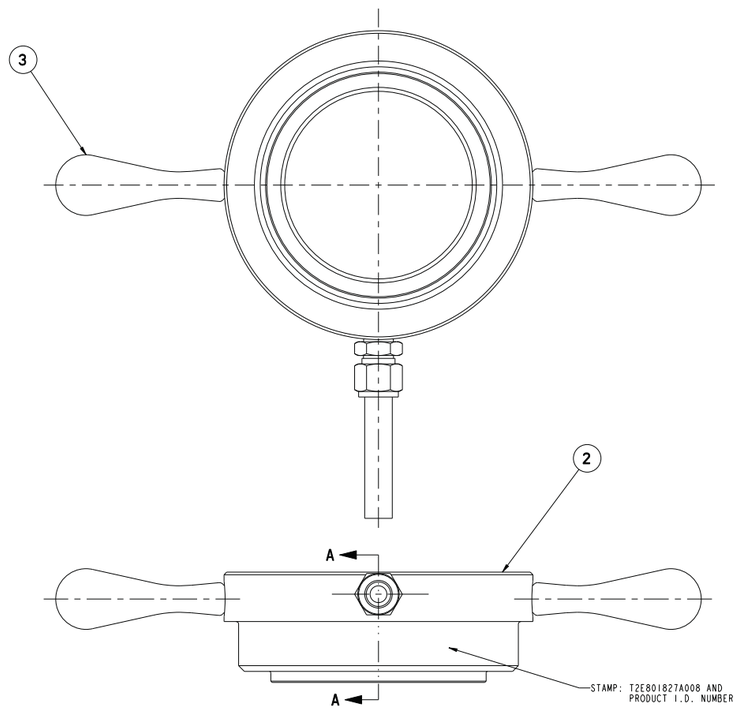




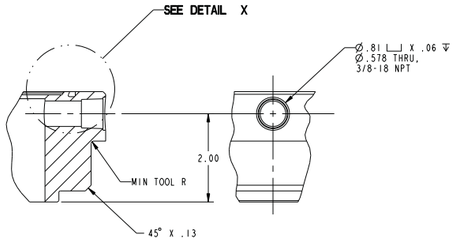
-2 LEAK CHECK FLANGE
SCALE 1/1



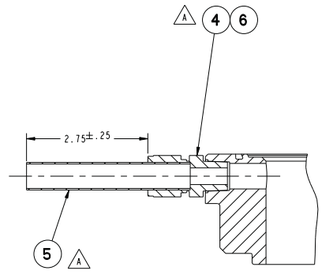
DETAIL Y
SCALE 2/1



-1 LEAK CHECK FLANGE ASSEMBLY
SCALE 1/1



SECTION B-B
SCALE 1/1



SECTION A-A
SCALE 1/1

NOTES
1 INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M - 1994.
3 DIMENSIONS ARE IN INCHES.
4 DIMENSIONS OR FEATURES FLAGGED BY ◇I SHALL BE INDEPENDENTLY VERIFIED.

A	AR	-6	TEFLON PIPE TAPE			6
A	1	-5	5/8 OD X .035 WALL OR 5/8 OD X .060 WALL TUBE	304 S.S. OR 316 S.S.	ASTM A269	5
A	1	SS-1010-1-6	MALE CONNECTOR	316 S.S.	SWAGELOK COMPANY	4
	2	TH-7	MACHINE HANDLE	STEEL	REID TOOL SUPPLY CO MUSKEGON, MI 49444	3
	1	-2	LEAK CHECK FLANGE	304 S.S.		2
AR	AR	-1	LEAK CHECK FLANGE ASSEMBLY			1
M2E801893 A028 M2E801827 A008	-1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		NEXT ASSEMBLY	PARTS LIST			

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REV	DESCRIPTION	DRW	CHKR	DE	DVR	DM	DATE	PE	DATE	SE	DATE	WE	DATE	OM/SO	DATE
A	ADDED M2E801893A028-1, ADDED F/N 4, F/N 5 AND F/N 6 TO PARTS LIST	JRJ	MLE	LR	RDA	WIN	4-18-06	WIN	5-18-06	LR	5-18-06				
0	ORIGINAL ISSUE, RN Y2003-0328	SWW	TGAB	EL	RDA	LEG	4-18-06	JL	4-18-06	MDW	4-18-06				

REVISION OR ISSUE PURPOSE | REVISION APPROVALS | SQUAD CHECK

	AR	CV	ST	HV	EM	FP	PD	EE	IE	M	NP

DRAWING APPROVALS

SCALE: NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
XX DECIMALS ±.01
XXX DECIMALS ±.005
ANGLES ±0.5°
BREAK SHARP EDGES .06 MAX
FINISH 125 RMS

DRW	McTEER/JOHNSON	4/12/06
CHKR	GA BYINGTON	4-18-06
DE	E LOZYNIAK	4-18-06
DVR	RD AIGNER	4-18-06
DM	LE GALYON	4-18-06
PE	JACK LAFFERTY	4-18-06
SE	MD WALDROP	4-18-06
OM/SO	NR	

DATE

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Name: R.D. AIGNER Date: 5/28/09

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

PROJECT NAME: TOOLING

LEAK CHECK FLANGE ASSEMBLY

1	48	49	50	PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
2	M	U	D	Y-12			I	I	S	U
51		52		53						
NC		TOOL		IN	T2E801827A008					REV A

T2E801827A008

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Appendix 1.3.8

Pyrophoricity of Uranium Metal

Prepared by: Russell W. Schmidt
BWXT Y-12
November 2006
Revised June 2007

Reviewed by: Sanford G. Bloom
BWXT Y-12
November 2006
Re-reviewed June 2007

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Appendix 1.3.8

Pyrophoricity of Uranium Metal

I. Introduction

The ES-3100 is a new shipping container designed for safe and efficient transportation of highly enriched uranium in a wide range of material forms. The ES-3100 has been certified for use with a variety of contents, including enriched uranium metal and alloy. However, the current size limitations on uranium contents in the form of broken metal are unnecessarily restrictive. The size limits exist because under certain conditions uranium metal and some uranium alloys are pyrophoric – they have the potential to spontaneously ignite. The size restrictions are intended to eliminate the possibility of spontaneous ignition during transport.

The purpose of this analysis is to evaluate the potential for uranium metal pieces to spontaneously ignite under the conditions expected for shipment in the ES-3100 shipping container, and to identify limits on the uranium metal content that will prevent spontaneous ignition during transport, while still allowing a high degree of flexibility and utility.

It is important to remember that the content limits developed for the ES-3100 must be implemented in the field. Therefore the criteria derived from this evaluation must be simple, robust, and readily applied in all of the facilities using this package.

This evaluation does not include new laboratory tests of uranium metal ignition parameters. Such tests have been performed and well documented in the past. This evaluation draws on the extensive body of existing data and proven storage and transport practice to identify the bounds within which uranium metal and alloys can be safely transported in the ES-3100 shipping container.

II. Proposed Definition of Pyrophoricity

The Certificate of Compliance (CoC), gives the definition of broken metal in Paragraph 5(b)(1)(ii), as follows:

> *For metal or alloy defined as broken metal, mass limits are specified in Table 2. Uranium metal and alloy pieces must have a surface-area-to-mass ratio of not greater than 1 cm^2/g or must have a mass not less than 50 g, whichever is most restrictive. Powders, foils, turnings, wires, and incidental small particles are not permitted, unless they are restricted to not more than 1 percent by weight of the content per convenience can, and they are either in a sealed, inerted container or are stabilized to an oxide prior to shipment.*

It is suggested that the definition of broken metal in Paragraph 5(b)(1)(ii) be revised to the following:

> *For metal and alloy defined as broken metal, mass limits are specified in Table 2. Uranium metal and alloy pieces must have a surface-area-to-mass ratio of not greater than 1 cm^2/g or must not pass freely through a 3/8-inch (0.0095 m) mesh sieve. Particles and small shapes that do not pass this size restriction, as well as powders, foils, turnings, and wires, are not permitted, unless they are either in a sealed container under an inert cover gas.*

III. Rational for Proposed Changes

The proposed text makes the following changes:

- The 50 g minimum piece size is eliminated.
- A 3/8-in. mesh limit is added.
- The phrase "whichever is most restrictive" is deleted.
- Remove oxidation as a treatment for pyrophoric uranium, in this context.
- The 1% limit on inerted material is eliminated.

The 1-cm^2/g maximum specific surface area limit is the most significant limit in the original text, and that limit is retained unchanged. Specific surface area is the most significant parameter in determining if a given piece of uranium is at risk of spontaneous ignition under a given set of conditions, and therefore it is appropriate that this restriction should control any other restrictions to the package contents. The discussion section below will demonstrate that the 1 cm^2/g maximum allowable specific surface area is adequate to prevent spontaneous ignition in the ES-3100.

The 50-g minimum piece size is overly restrictive and is inconsistent with the 1-cm^2/g upper limit on specific surface area. Smooth uranium metal pieces can have a mass of less than 0.5 g and still have a specific surface area less than 1 cm^2/g (see Example 1). This makes the 50-g limit two orders of magnitude too large. The 50-g limit is nearly an order of magnitude too large even considering metal pieces with the rough surface of broken metal instead of a smooth cast or polished surface.

Example 1.
Consider a smooth uranium metal sphere with a diameter of 0.32 cm (0.126 in.).
The radius of the sphere is 0.16 cm. The density of uranium metal is 19 g/cm^3.

The volume is	$V = (4 / 3) \times Pi \times r^3 = (4 / 3) \times Pi \times (0.16)^3 = 0.01716\ cm^3$
The mass is	$M = Density \times V = 19\ g/cm^3 \times 0.01716\ cm^3 = 0.3260\ g$
The surface area is	$A = 4 \times Pi \times r^2 = 4 \times Pi \times (0.16)^2 = 0.3217\ cm^2$
The specific surface area is	$SA = A / M = 0.3217\ cm^2 / 0.3260\ g = 0.9868\ cm^2/g$

This specific surface area is just within the 1 cm^2/g upper limit.

If instead of a smooth surface the sphere has a rough surface characteristic of broken uranium metal, a larger size is needed to ensure that the 1 cm^2/g limit is maintained. For a roughness factor of three (meaning that the rough surface has an actual surface area that is three times the surface area calculated from the radius), the radius would need to be three times the above example to give the same specific area. In this case:
$r = 3 \times 0.16\ cm = 0.48\ cm$; $V = (4 / 3) \times Pi \times (0.48)^3 = 0.463\ cm^3$;
$M = 19\ g/cm^3 \times 0.463\ cm^3 = 8.802\ g$; $A = 4 \times Pi \times (0.48)^2 \times 3$ (roughness factor) $= 8.686\ cm^2$
And so the specific surface area is $8.686\ cm^2 / 8.802\ g = 0.9868\ cm^2/g$ as above.

Depending on the surface roughness, a sphere with a mass between 0.33 and 8.8 g will meet the 1 cm^2/g specific surface area limit

The 1 cm^2/g specific surface area limit controls the parameter that is most important in terms of preventing spontaneous ignition, but it is not easy to measure or to use in the field. A mass limit (similar to the 50-g limit in the existing certificate, but more consistent with the 1-cm^2/g specific area limit) could be used, but it is very time-consuming to weigh every piece of metal in a package. An approach that is both effective at enforcing the 1-cm^2/g specific surface area limit and quick and easy to use in the field is to separate large pieces from small ones in a sieve. The recommended text stipulates a 3/8-in. mesh sieve to quickly remove small particles (with a large specific surface area) from large particles which have a small specific surface area.

As demonstrated in Example 1, rough-surfaced spheres 3/8 in. (0.95 cm) in diameter meet the 1 cm^2/g specific surface area limit (a smooth-surfaced sphere of this size has a specific surface area of 0.33 cm^2/g). Therefore, a sphere which does not pass freely through the 3/8-in. mesh sieve will meet the 1 cm^2/g specific surface area limit. Other simple shapes such as cubes and rods are also effectively controlled by the 3/8-in. sieve. Foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packed in an inert atmosphere.

The phrase "whichever is most restrictive" has been deleted from the proposed text since the sieve test has been sized to effectively enforce the 1-cm^2/g specific surface area limit.

The option of converting pyrophoric uranium to an oxide is removed, since metals need to be shipped as metals for maximum usefulness at the receiver site. In addition, if oxides are produced, packing limits for oxides have been explicitly given in the CoC.

The final change in the proposed text is to eliminate the 1% of content weight limit on inerted material. This limit is unnecessary for uranium metal sealed in a container containing an inert atmosphere. If the metal has been sealed in a container containing an inert atmosphere, there is no oxygen available to the metal and therefore no chance of combustion.

Uranium metal packaged for transport in the ES-3100 is first placed inside a convenience can or other container. These cans are then placed into the ES-3100 containment vessel (CV). The convenience cans will displace most of the oxygen from the CV, leaving only enough to react with a few grams of metal. If a sealed container containing an inert atmosphere somehow came open in transport (an unlikely scenario given the very limited amount of movement possible inside a properly loaded CV), this small amount of oxygen is not enough to support spontaneous ignition. The CV has been shown to retain its structural integrity and remain leak tight under hypothetical accident conditions (HAC), so no additional oxygen can enter.

IV. Discussion

In his 1995 review,[1] Terry Totemeier explains pyrophoricity this way: "Pyrophoricity refers to the tendency of certain metals to ignite and burn in a self-sustaining oxidation reaction. The pyrophoric nature of metals is usually defined in terms of an ignition temperature, which is the temperature at which a metal will ignite and burn in a self-sustained fashion for a given set of conditions." ASTM C-1454[2] defines pyrophoric as "capable of igniting spontaneously under temperature, chemical, or physical/mechanical conditions specific to the storage, handling, or transportation environment."

This evaluation will demonstrate that uranium metal with a specific surface area of 1 cm^2/g will not spontaneously ignite under the conditions existing in the ES-3100 during packaging and transport.

The primary factors determining if the conditions for spontaneous ignition exist are specific surface area and temperature. Totemeier explains, "Because oxidation is a surface reaction, the amount of area available for reaction is a critical factor in the determination of the heat generated in oxidation. Specific area is the best parameter to describe the effect of area, as it also accounts for the amount of material not reacting which can serve as a heat sink." Temperature is critical because the amount of heat generated by the reaction is a function of the reaction rate, which is in turn a function of the temperature. Higher temperatures give higher reaction rates.

An additional safety factor in the case of the ES-3100 is the small amount of oxygen available in the sealed inner CV. This serves to limit the total amount of uranium that can oxidize, and therefore prevents any potential heat build-up from reaching the ignition point of uranium metal.

Ignition Temperature and Transport Conditions

In Figs. 4 and 5 of his review, Totemeier plots two separate tests of uranium ignition temperatures as a function of specific surface area. For a specific surface area of 1 cm^2/g these two plots give values of 390°C (663 K)[1] and 340°C (613 K), respectively. Using the lower value and rounding down gives a conservative value of 600 K for the ignition temperature of uranium metal in the ES-3100.

The ES-3100 thermal analysis determined that the temperature at the CV wall would not exceed 190°F (361 K) for normal conditions of transport (NCT) and 255°F (397 K) for HAC. These values, particularly the HAC temperature, are very conservative. The actual results from six separate package tests showed that the CV wall temperature was typically around 210°F (372 K), with the highest recorded value of 241°F (389 K). Note that all of these temperatures are well below the 600 K ignition temperature of the uranium metal contents.

Maximum Temperature from Oxidation – Basic Equations

Uranium metal readily reacts with oxygen to form uranium dioxide (UO_2). This reaction is exothermic. The heat released by the reaction warms the uranium metal, increasing the reaction rate. Under normal conditions for storage and transport, the reaction rate is slow enough that the small amount of heat generated by the reaction is lost to the environment, and a stable steady-state is achieved. If the reaction rate is fast enough, and the metal is relatively well insulated, the temperature of the uranium metal can build, slowly at first but at an increasing rate, until the ignition temperature is reached and the metal ignites and burns.

The task at hand is to evaluate the balance between heat generation and heat loss in the ES-3100 under HAC to verify that a stable steady state is reached, and that the steady-state condition is safely below the ignition point of uranium metal. A recent paper by Epstein, Malinovic, and Plys[3] lays out a useful approach, which will be followed here without the approximations used in their paper.

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[1] The curve in Totemeier Fig. 4 is discontinuous, with a transition from a lower curve to an upper curve shown at a specific surface area of 6 cm^2/g. At a specific surface area of 1 cm^2/g, the upper curve would give an ignition temperature of 550ºC, while extrapolation of the lower curve gives 390ºC. The original reference from which Totemeier drew Fig. 4 explains that the transition from the lower curve to the upper curve is influenced by many factors, including the metallurgy of the uranium, any alloying metals or impurities, and the oxygen content of the gas involved. Therefore, this analysis uses the lower curve value of 390ºC.

For uranium metal packed in cylindrical cans, the generation of heat throughout the can and the associated transfer of heat to the can wall is mathematically identical to the generation of heat within a wire due to electrical resistance. In their text "Transport Phenomena"[4] Bird, Stewart & Lightfoot develop the desired relation (Equation 9.2-14):

$$Tcenter - Twall = (S \times R^2) / (4 \times Kth) \quad \text{(Equation 1)}$$

where

Tcenter is the temperature at the center of the can (K)
Twall is the temperature at the can wall (K)
S is the heat production per unit volume (W/cm^3)
R is the radius of the can (cm)
Kth is the thermal conductivity of the uranium contents (W/cm K)

The heat production per unit volume is a function of the reaction rate and the heat of reaction. Since the oxidation reaction occurs at the surface of the uranium, the reaction rate is typically stated as a mass reacted per second per unit area. The specific surface area, the uranium metal density, and the packing density are applied to convert the rate per unit uranium surface area to a rate per unit can volume. The result is:

$$S = Rho \times Phi \times SArea \times dHrxn \times RxnRate \quad \text{(Equation 2)}$$

where

Rho is the density of the uranium metal (g/cm^3)
Phi is the packing density of the uranium in the can (cm^3 U/cm^3 can volume)
SArea is the specific surface area of the uranium (cm^2/g)
dHrxn is the heat of reaction (J/g uranium)
RxnRate is the reaction rate [g uranium / ($s \cdot cm^2$)]

The reaction rate of uranium metal with oxygen has been evaluated by many researchers over the years. The general form of the rate equation used is:

$$RxnRate = K0 \times P^n \times e^{(-Te/T)} \quad \text{(Equation 3)}$$

where

K0 is the reaction rate coefficient [g uranium / ($s \cdot cm^2$)]
P is the partial pressure of water vapor (kPa)
n is the exponential coefficient on the partial pressure of water vapor
Te is the activation energy (K)
T is the temperature of the reactants (K)

For the case at hand, the temperature of the reactants is the highest at the can center (Tcenter) and the lowest at the can wall (Twall). The average temperature of the reactants is midway between these two values. For conservatism the reaction rate of the entire contents is evaluated at the maximum temperature, which occurs at the center of the can (Tcenter). This analysis considers heat transfer only through the can walls, and ignores heat transfer through the top and bottom of the can. This is also a conservative assumption.

Equations 1, 2, and 3 are combined to yield:

$$Tcenter - Twall = (R^2 \times Rho \times Phi \times SArea \times dHrxn \times K0 \times P^n \times e^{(-Te/Tcenter)}) / (4 \times Kth) \quad \text{(Equation 4)}$$

Note that Kth is a property of the can contents (that is, for the bed of uranium metal particles with air in between), and not a property of solid uranium metal. The thermal conductivity of uranium metal is much higher than the thermal conductivity of a bed of uranium metal pieces.

P is the partial pressure of H_2O present in the CV at the center-line temperature. This value is calculated by assuming that the ES-3100 was loaded at ambient conditions of T0 and 100% relative humidity, which yields a water vapor pressure of P0. When the temperature in the CV increases the partial pressure of water vapor increases according to the ideal gas law, which in this case reduces to:

$$P = P0 \times (Tcenter/T0) \qquad \text{(Equation 5)}$$

In this evaluation, the maximum possible rate of heat generation due to the oxidation of the uranium metal is also of interest since this heat must be carried away by the package, even at HAC. The maximum rate of heat generation is the heat generated by the oxidation of uranium metal at the highest temperature reached during HAC, assuming the maximum allowable load of uranium metal. This is:

$$Qmax = Mmax \times SArea \times dHrxn \times K0 \times P^n \times e^{(-Te/Tcenter)} \qquad \text{(Equation 6)}$$

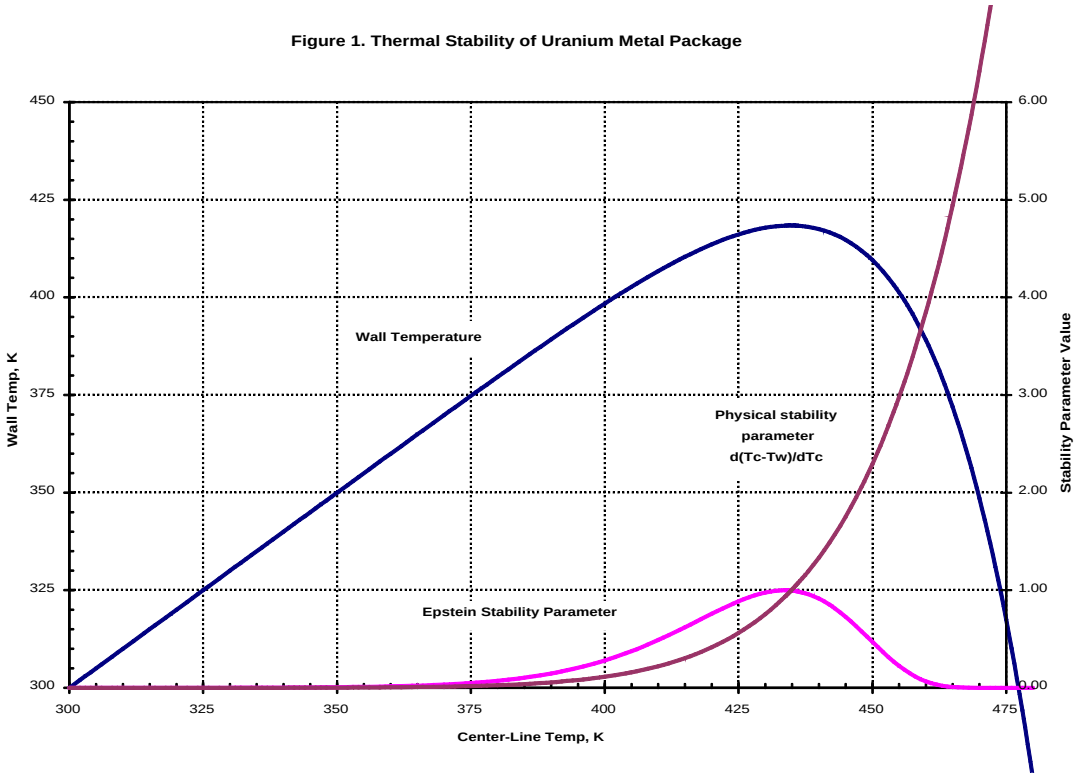
where

Qmax = the maximum rate of heat generation (W)
Mmax = the maximum uranium metal loading (g)

Evaluation of Thermal Stability

Equation 4 provides the means to evaluate the maximum temperature reached in the uranium metal. It does not by itself validate the stability of the system. This system does present a simple means to evaluate stability – both numerical stability and more importantly physical stability (meaning that the temperature cannot build to spontaneous ignition).

Solving Equation 4 for Twall over a range of Tcenter values and plotting the results produces Fig. 1:



The wall temperature calculated from Equation 4 and plotted here is the temperature needed in order to provide enough heat transfer to maintain the given center-line temperature. The wall temperature initially tracks the center-line temperature – the rate of heat generation is low, so a very small temperature difference is sufficient to remove that heat. As the center-line temperature (and therefore the amount of heat generated) increases, the temperature difference needed to keep the center-line temperature steady at the given value increases exponentially. At some point (~435 K in Fig. 1) the required temperature difference gets so large that the wall temperature would have to decrease in order to maintain a stable center-line temperature. In an actual package there is no cooling mechanism to do this, and once the center-line temperature exceeds this point the amount of heat generated will exceed the ability to carry off that heat, and the center-line temperature will increase until either the reaction runs out of oxygen or the ignition point is reached. The point at which the required wall temperature stops increasing, marks the maximum stable center-line temperature for the package. The required wall temperature stops increasing at the point where the rate of increase in the needed temperature difference [d(Tcenter−Twall)] equals the rate of increase of the center-line temperature (dTcenter). Stated mathematically, when d(Tcenter−Twall)/dTcenter is less than 1 the required Twall increases along with Tcenter, and stability is maintained. When d(Tcenter−Twall)/dTcenter is greater than 1 Twall would have to drop to maintain stability as Tcenter increases. Since this is not possible in a real package, the temperature in the package would steadily increase to either ignition or consumption of all available oxygen. The value of d(Tcenter−Twall)/dTcenter = 1 marks the maximum stable point for a given package.

Equation 4 is

$$Tcenter - Twall = (R^2 \times Rho \times Phi \times SArea \times dHrxn \times K0 \times P^n \times e^{(-Te/Tcenter)}) / (4 \times Kth)$$

Taking the first derivative of this equation with respect to Tcenter yields an equation for the stability parameter derived above:

$$d(Tcenter-Twall)/dTcenter = (Tcenter-Twall) \times Te/Tcenter^2 \quad \text{(Equation 7)}$$

The thermal stability of the system is maintained as long as $(Tcenter-Twall) \times Te/Tcenter^2 \leq 1$. This parameter is equivalent to the stability parameter "B" developed in Epstein et al., without the simplifying assumptions made in that paper. The value of d(Tcenter−Twall)/dTcenter is plotted in Fig. 1, along with the Epstein "B" parameter.

Input Parameters

The key values used to evaluate Equations 4, 5, 6, and 7 are shown in Table 1.

Table 1. Key input parameters

Parameter	Value	Units
R	5.27	cm
Rho	19	g/cm³
Phi	0.26	cm³/cm³
SArea	1	cm²/g
dHrxn	4559	J/g Uranium
K0	76086	gU/(s·cm²)
P0	3.53	kPa
T0	300	K
n	0.3	
Te	11490	K
Kth	0	W/(cm·K)

The sources of these parameters are:

R is the inside radius of a convenience can. The typical can used has an outside diameter of 4.25 in., and an inside diameter of 4.15 in. (10.54 cm).

Rho is the density of uranium metal.

Phi is the packing density of uranium metal when packed into the convenience cans. Operator experience at Y-12 is that a maximum of 5 kg U of broken metal will fit into a 4.25-in. OD by 4.875-in. high can, which has an internal volume of 1000 cm³. This yields a packing density of 0.26 cm³/cm³. The effects of variations on this value are discussed below.

SArea is the specific surface area, which is limited by the package certification to 1 cm²/g.

dHrxn is the heat of reaction, on a uranium basis. This value came from Totemeier, page 17 (1089 cal/gU = 4559 J/gU).

K0, n, and Te are parameters for the reaction rate equation. As noted above, a number of researchers have analyzed the reaction rate of uranium metal with various combinations of oxygen and water vapor. Numerous models have been developed from this data. This analysis used the published model that best fit the conditions present. Many of the published rate models are only valid up to 100 to 130°C. This evaluation requires evaluation beyond 140°C. Many of the models are for either pure oxygen or pure water vapor. McGillivray[5] notes that the reaction rate at a given temperature varies with both the oxygen concentration and the partial pressure of water vapor. The published model that best matches the conditions of this evaluation (reaction in air at temperatures exceeding 140°C, with a small water vapor partial pressure) is the Pearce model (Pearce, <100% RH, in Air, T <192°C) as reported in the Epstein paper.

P0 and T0 are used to calculate P, the partial pressure of H_2O vapor present in the CV at the center-line temperature. This value is calculated by assuming that the ES-3100 was loaded at ambient conditions of T0 = 300 K (80°F) and 100% relative humidity. P0 is therefore the vapor pressure of water at 300 K, which is P0 = 3.53 kPa. When the temperature in the CV increases, the partial pressure of water vapor increases according to equation 5.

Kth is the thermal conductivity of the uranium particle bed. The value here was taken from Epstein et al., page 6. Because of the air-filled void spaces, the bed thermal conductivity is much lower than the uranium metal value of 0.3 W/(cm·K).

Results

The set of equations (4, 5, 6, and 7) was evaluated using a commercial software package named Tk!Solver, which has the advantage of being able to automatically iterate to solutions as needed. This is necessary when solving equation 4 for a fixed wall temperature to determine Tcenter. Attachment 1 shows the rules, input and output for the TK!Solver model for the HAC and NCT cases.

The HAC evaluation gave a maximum CV temperature (Twall) of 255°F (397 K). Evaluating Equations 4–7 for these conditions yields a Tcenter of 398.4 K (257.5°F), with a maximum heat output (assuming a full load of 36 kgU) of 5.9 Watts, and a stability parameter d(Tcenter−Twall)/dTcenter of 0.102, well below the critical value of 1.0.

The 255°F HAC temperature was based on a uranium heat generation of 0.4 W. The 5.9-W maximum heat generated from the oxidation reaction under those conditions would heat the CV wall above that temperature. The thermal analysis evaluated the HAC for heat generation rates of 20 W and 30 W as well as the 0.4-W standard value. Table 3.7 in the thermal analysis shows that for an assumed 20 W heat generation in the uranium metal contents, the peak CV wall temperature is 277°F (409.3 K). Using this value ensures that the heat transfer from the uranium contents to the CV wall and to the rest of the package is conservatively addressed.

For the revised HAC wall temperature of 277°F (409.3 K), Equations 4–7 yield the following results:

Tcenter = 413.3 K (284.4°F) [well below the ignition temperature of 600 K]
MaxQ = 17.0 Watts (below the 20 W assumption)
d(Tcenter−Twall)/dTcenter = 0.272 (well below the critical value of 1.0)

At the NCT wall temperature of 190°F (360.9 K) the results are:

Tcenter = 361.0 K (190.1°F) [well below the ignition temperature of 600 K]
MaxQ = 0.289 Watts (below the 0.4 W assumption)
d(Tcenter−Twall)/dTcenter = 0.006 (well below the critical value of 1.0)

These values clearly show that uranium metal with a specific surface area of no more than 1 cm^2/g will not spontaneously ignite under any anticipated transport conditions.

Variation in Input Packing Density

The density with which uranium metal is packed into the convenience cans limits the surface area available to oxidize. Operator experience at Y-12 is that a maximum of 5 kg U of broken metal will fit into a 4.25-in.-OD by 4.875-in.-high can, which has an internal volume of 1000 cm^3. This yields a packing density of 0.26 cm^3/cm^3.

A search of the literature on packing densities reveals a lot of work on smooth spheres, and very little on anything else. Scott and Kilgour[6] experimented with packing smooth steel spheres in cylinders, and reported a maximum packing density of 0.6366 after extensive vibration to compact the steel spheres as much as possible. The steel balls used in this experiment had a coefficient of friction of 0.2, well below the value for smooth uranium metal of 1.0. Subsequent analysis by Kong and Lannutti[7] considering the effects of friction between particles gives packing fractions in the range of 0.41 to 0.46, with higher friction coefficients producing lower packing fractions.

The broken metal routinely packed at Y-12 consists of large, rough, irregular pieces. The reported packing density of 0.26 for this material is consistent with the literature reviewed, particularly Kong and Lannutti. Therefore, the value of 0.26 was used as the base value in the analyses reported above.

To bound the metal contents of the ES-3100 two additional cases have been analyzed under HAC: rough broken metal at a packing density of 0.46 (the upper end of the range reported by Kong & Lannutti); and smooth cast spheres at a packing density of 0.64 (consistent with Scott & Kilgour).

For rough broken metal at a packing density of 0.46 the maximum center temperature at HAC was 422 K, well below the ignition temperature of 600 K. For smooth cast 3/8" spheres at a packing density of 0.64 the maximum center temperature at HAC was 412 K, well below the ignition temperature of 600 K.

Oxygen Limitation in the Containment Vessel

The analysis above placed no restriction on the amount of oxygen available to react with the uranium metal contents. In reality, the ES-3100 CV has a finite volume, which restricts the amount of oxygen available for reaction.

The CV is a cylinder with inside dimensions of 31.00-in. (78.74-cm) tall and 5.06 in. (12.85 cm) in diameter. This produces a volume of 10,215 cm^3, or 10.215 liters. At ambient conditions of 300 K (80.3°F) and 100% relative humidity, 10.215 liters of humid air contains 2.78 g of oxygen from the air, and another 0.23 grams of oxygen in the H_2O. These 3.01 grams of oxygen can react with 22.40 g of uranium metal. This is 0.06% of the ES-3100's capacity.

A mass of 22.4 g of U metal when reacted with 3.01 g of oxygen will produce a maximum total heat output of 102 kJ (96.8 BTU), spread out over the time required for the reaction to take place. This total amount of oxygen could sustain the NCT maximum heat output of 0.289 W for 4.1 days, or the HAC peak heat output for 1.7 hours. If somehow released all at once, the 102 kJ would only raise the temperature of 36 kg of uranium by 24.5 K. More realistically, as shown by the calculations above, any reaction will be slow, with enough time for the heat generated to flow to the CV and the rest of the package.

The ES-3100 CV is 15.1 kg of stainless steel, with a heat capacity of 0.515 J/(g·K). The 102 kJ maximum produced by the oxidation reaction could only raise the temperature of the CV (ignoring contents) by 13.1 K. This heat sink, plus the heat sinks offered by the CV contents, ensures that the oxidation reaction will not be able to build to the 600 K ignition temperature required for spontaneous ignition.

In practice there will less than 3 g of oxygen available to react with the uranium metal inside the closed CV. A full load of uranium will, by itself, displace nearly 20% of the air in the CV. The convenience cans, spacer cans, and other packing materials will displace even more air, further reducing the amount of uranium that could possibly react. Also, the uranium metal is packed inside closed convenience cans. These cans limit the oxygen available to react with the contents to the oxygen in the convenience can itself. Finally, part of the available oxygen will react with the uranium before the peak HAC conditions are reached. Figure 22b in Sect. 3 shows that it will take ~4 hours for the CV wall to reach the maximum temperature in the HAC fire. During this four-hour temperature ramp-up 0.9 grams of oxygen would be consumed by reaction with the uranium, leaving only 2.1 grams available to react once the HAC temperature was reached. Even if the uranium surface area was uncontrolled, lack of oxygen would snuff out any increase in the uranium reaction rate before it could reach the ignition point.

Specific Surface Area Implementation via Sieve

As noted above, the 1 cm^2/g specific surface area limit is not easy to measure or to use in the field. A screening method that is simple and easy to use in the field will reduce the potential for packaging mistakes. The recommended approach is to separate large pieces from small ones in a sieve. The recommended text stipulates a 3/8-in. mesh sieve to quickly remove small particles (with a large specific surface area) from large particles which have a small specific surface area.

Example 1 above showed that the minimum size of a metal sphere meeting the 1 cm^2/g specific surface area limit varies with the degree of surface roughness. In Example 1 a smooth sphere 1/8 in. in diameter and a rough sphere 3/8 in. in diameter both had specific surface areas just below the 1 cm^2/g limit. The 3/8-in. mesh is stipulated in the recommended text in order to accommodate both smooth and rough metal.

The actual metal contents of the ES-3100 will include both smooth-surfaced and rough-surfaced metal. The smooth-surfaced items include a variety of cast and machined shapes. The rough-surfaced items are "broken metal" – large castings that have been fractured into smaller pieces. These broken metal pieces will typically have two or three cast surfaces with the remaining 3 or 4 surfaces of fractured metal.

The 3/8-in. mesh recommendation is based on a surface roughness factor of three, meaning that the rough surface has an actual surface area available to react with oxygen that is three times that of a smooth-surface of the same gross dimensions. This roughness factor of three was derived from an evaluation of fracture surfaces for cast uranium metal. Roughness factors ranged from 1.1 to 2.7, with a mean value of 2.0. A roughness factor of three was selected to bound the highest value observed. The

3/8-in. mesh screening is therefore suitable for metal that is fractured on all surfaces. Since as noted above even broken metal will have several smooth faces the 3/8-in. mesh screening should be quite conservative.

As demonstrated above, a rough-surfaced sphere which does not pass freely through the 3/8-in. mesh sieve will meet the 1 cm^2/g specific surface area limit. Other simple shapes such as cubes and rods are also effectively controlled by the 3/8-in. sieve. Foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packaged in an inert atmosphere. Attachment 2 shows the dimensions of a variety of shapes that have a specific surface area of 1 cm^2/g. All of these items will fall through a 3/8-in. sieve, demonstrating that the sieve will effectively enforce the 1 cm^2/g specific surface area limit.

Most foils and wires will not fall through a sieve of any reasonable size. The current 50 g test would likewise not reliably exclude these materials, which is why foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packed in an inert atmosphere. Operator training will be required under either the current or the proposed text to ensure that these items are properly packaged.

Operator Training

As part of the transition to using the new shipping container, training materials are being prepared to instruct the field operations personnel on the proper way to use the ES-3100. As noted above, the training for the operators packing uranium metal into the convenience cans for shipment in the ES-3100 will be important in ensuring that potentially pyrophoric materials are properly categorized and inerted as necessary. This training will cover the following points:

- All metal pieces must be evaluated to ensure that their smallest dimension is larger than the 3/8-in. mesh size.
  - Single solid-metal pieces that are clearly larger than the 3/8-in. mesh in every dimension do not require sieving.
  - Items which are obviously unacceptable, such as foils, wires, and turnings, may be removed before the sieving
  - Any item that is not obviously larger than the 3/8-in. mesh in every dimension and which has not been rejected must be sieved.
  - Any item that falls through the sieve must be rejected.
- Operators need to be alert to items which may not fall through the sieve but which are too small:
  - Long, thin shapes such as wires and turnings may not fall through the sieve when shaken. If the wire or turning could be picked up and poked through the mesh it must be rejected, even if it did not fall through unassisted.
  - Wires or turnings may form a tangled ball which will not fall through. The above criterion applies: if the wire or turning could be separated and poked through the mesh it must be rejected.

- No distinction is made between wires and rods – if the item could be picked up and poked through the mesh it must be rejected.
- Foils, thin chips or shards - any item less than 1/8-in. thick – must be rejected.
- Metal showing visible moisture or signs of having been stored in water must be rejected.

- Rejected items must be separated for proper handling:
  - Rejected items can be shipped if packed under an inert cover gas.
  - An acceptable cover gas must be an inert gas or mixture of inert gases with a high-purity (≥99%) and low moisture (≤5 ppm moisture).

V. Conclusion

The evaluations performed show that uranium metal conforming to the 1-cm^2/g limit on specific surface area will not spontaneously ignite under any anticipated transport conditions. Spontaneous ignition is independently prevented by both the 1-cm^2/g limit on the uranium metal and by the limited amount of oxygen available in the sealed ES-3100 CV.

The 3/8-in. sieve specified in the revised text effectively applies the 1-cm^2/g specific surface area limit to broken uranium metal in a manner that is quick and easy to use in the field.

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Attachment 1. TK!Solver Model and Results

Rules

Tcenter-Twall=((R^2*rho*phi*SArea*dHrxn*K0*P^n)/(4*Kth))*exp(-Te/Tcenter)
P=P0*(Tcenter/T0)
Deriv=(Tcenter-Twall)*Te/Tcenter^2
HRate=SArea*dHrxn*K0*P^n*exp(-Te/Tcenter)
MaxQ=HRate*MaxM
RRate=SArea*MaxM*K0*P^n*exp(-Te/Tcenter)
ORate=RRate*32/238
OTime=MaxO/ORate

HAC—277°F Wall Temperature

Input	Name	Output	Unit	Comment
	Tcenter	413.348	K	Temperature at the center of the can
409.3	Twall		K	Temp at the can wall
	HRate	.000472	W/gU	Rate of heat production (w/unlimited O2)
	MaxQ	16.9945	W	Maximum heat production (from max KgU)
36000	MaxM		gU	Maximum ES-3100 contents
3.01	MaxO		gO	Maximum ES-3100 Oxygen Content
	RRate	.003728	gU/s	Reaction Rate at given Conditions
	ORate	.000501	gO/s	Oxygen Use rate at given conditions
	OTime	1.66822	hr	Oxygen time to run-out
5.27	R		cm	Can radius
1	SArea		cm^2/gU	Specific Surface Area of U particles
	Deriv	.272221		d(Tcenter-Twall)/dTcenter
19	rho		gU/cm^3	Density of uranium
.26	phi			Packing density, U cm^3 / Can cm^3
4559	dHrxn		J/gU	Heat of Reaction
76086	K0		gU/(s*cm^2)	Reaction rate coefficient - Pearce <100%
11490	Te		K	Reaction rate coefficient - Pearce <100%
.3	n			Reaction rate coefficient - Pearce <100%
3.53	P0		kPa	Vapor pressure of water at T0
300	T0		K	Temperature for P0
	P	4.86373	kPa	Vapor Pressure of Water at Tcenter
.004	Kth		W/cm*K	Thermal Conductivity of U particle bed

NCT - 190℉ Wall Temperature

Input	Name	Output	Unit	Comment
	Tcenter	360.969	K	Temperature at the center of the can
360.9	Twall		K	Temp at the can wall
	HRate	8.03E-6	W/gU	Rate of heat production (w/unlimited O2)
	MaxQ	.288991	W	Maximum heat production (from max KgU)
36000	MaxM		gU	Maximum ES-3100 contents
3.01	MaxO		gO	Maximum ES-3100 Oxygen Content
	RRate	6.34E-5	gU/s	Reaction Rate at given Conditions
	ORate	8.52E-6	gO/s	Oxygen Use rate at given conditions
	OTime	98.1015	hr	Oxygen time to run-out
5.27	R		cm	Can radius
1	SArea		cm^2/gU	Specific Surface Area of U particles
	Deriv	.00607		d(Tcenter-Twall)/dTcenter
19	rho		gU/cm^3	Density of uranium
.26	phi			Packing density, U cm^3 / Can cm^3
4559	dHrxn		J/gU	Heat of Reaction
76086	K0		gU/(s*cm^2)	Reaction rate coefficient - Pearce <100%
11490	Te		K	Reaction rate coefficient - Pearce <100%
.3	n			Reaction rate coefficient - Pearce <100%
3.53	P0		kPa	Vapor pressure of water at T0
300	T0		K	Temperature for P0
	P	4.2474	kPa	Vapor Pressure of Water at Tcenter
.004	Kth		W/cm*K	Thermal Conductivity of U particle bed

Attachment 2. Pyrophoric Size Limits on Small Uranium Metal Pieces

Specific Surface Area:	1.0	cm^2/g
Uranium Metal Density:	19.0	g/cm^3
Surface Area Multiplier:	3.0	

The surface area multiplier is the ratio of the actual surface area divided by the simple geometeric surface area.

Spheres - Minimum Safe Diameter

Limiting diameter	0.9474	cm	or	0.3730	in	8.459	grams

Rods - Minimum Safe Diameter

Length	Diameter						
0.9 cm	0.9474	cm	or	0.3730	in	12.688	grams
1.0 cm	0.9231	cm	or	0.3634	in	12.715	grams
1.5 cm	0.8000	cm	or	0.3150	in	14.326	grams
2.0 cm	0.7500	cm	or	0.2953	in	16.788	grams
2.5 cm	0.7229	cm	or	0.2846	in	19.495	grams
Infinite	0.6316	cm	or	0.2487	in		

Cubes - Minimum Safe Side Length

Limiting side length	0.9474	cm	or	0.3730	in	16.155	grams

Square Cross-Section Rods - Minimum Safe Side Length

Length	Side						
0.9 cm	0.9474	cm	or	0.3730	in	16.155	grams
1.0 cm	0.9231	cm	or	0.3634	in	16.189	grams
1.5 cm	0.8000	cm	or	0.3150	in	18.240	grams
2.0 cm	0.7500	cm	or	0.2953	in	21.375	grams
2.5 cm	0.7229	cm	or	0.2846	in	24.822	grams
Infinite	0.6316	cm	or	0.2487	in		

Chips & Shards - Minimum Safe Thickness

Length	Width	Thickness					
1.0 cm	0.5 cm	6.0000	cm	or	2.3622	in	57.000 grams
1.5 cm	0.5 cm	2.0000	cm	or	0.7874	in	28.500 grams
2.0 cm	0.5 cm	1.5000	cm	or	0.5906	in	28.500 grams
2.5 cm	0.5 cm	1.3043	cm	or	0.5135	in	30.978 grams
3.0 cm	0.5 cm	1.2000	cm	or	0.4724	in	34.200 grams
Infinite	0.5 cm	0.8571	cm	or	0.3375	in	
1.0 cm	0.6 cm	2.0000	cm	or	0.7874	in	22.800 grams
1.5 cm	0.6 cm	1.2000	cm	or	0.4724	in	20.520 grams
2.0 cm	0.6 cm	1.0000	cm	or	0.3937	in	22.800 grams
2.5 cm	0.6 cm	0.9091	cm	or	0.3579	in	25.909 grams
3.0 cm	0.6 cm	0.8571	cm	or	0.3375	in	29.314 grams
Infinite	0.6 cm	0.6667	cm	or	0.2625	in	
Infinite	Infinite	0.3158	cm	or	0.1243	in	

VI. References

1. Totemeier, Terry C. ANL/ED/95-2 "A Review of the Corrosion and Pyrophoricity Behavior of Uranium and Plutonium", June 1995, Argonne National Lab-West.

2. ASTM C-1454-00, "Standard Guide for Pyrophoricity/Combustibility Testing in Support of Pyrophoricity Analyses of Metallic Uranium Spent Nuclear Fuel", January 10, 2000, ASTM International.

3. M. Epstein, B. Malinovic, M. G. Plys, SNF-6192-FP, "Uranium Pyrophoricity Phenomena and Prediction", April 2000, Fluor Hanford, Richland Washington.

4. R. Byron Bird, Warren E. Stewart, Edwin N. Lightfoot, "Transport Phenomena", 1960, John Wiley & Sons.

5. G. W. McGillivray, D. A. Geeson, R. C. Greenwood, "Studies of the Kinetics and Mechanism of the Oxidation of Uranium by Dry and Moist Air – A Model for Determining the Oxidation Rate Over a Wide Range of Temperatures and Water Vapor Pressures", June 1993, Journal of Nuclear Materials # 208 (1994) pg 81-97.

6. G. D. Scott, D. M. Kilgour, "The Density of Random Close Packing of Spheres", February 1969, British Journal of Applied Physics, Series 2, Volume 2, pp 863 - 866.

7. C. M. Kong, J. J. Lannutti, "Effect of Agglomerate Size Distributions on Loose Packing Fraction", March 2000, Journal of the American Ceramic Society, Volume 83, pp 2183 – 2188.

Appendix 1.3.9

SPC-M801580-0002,
Equipment Specification for
Ethylene Propylene Diene Monomer (EPDM)
Containment Vessel O-rings

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EQUIPMENT SPECIFICATION

DOC TYPE	DOC #	PART #	REV. #	PAGE
SPC	M801580-0002	000	02	i of v

APPROVAL / REVISION PAGE

** For Company Use Only - Do Not Provide To Supplier **

QUALITY LEVEL	PROTECTION LEVEL	BUILDING
Q	B	

PROJECT TITLE: ES-3100

JOB TITLE: O-rings

ITEM DESCRIPTION: ES-3100 Ethylene Propylene Diene Monomer (EPDM) Containment Vessel O-rings

UNID: YAREA-CMH-042

REVISIONS

REV. NO.	DESCRIPTION OF REVISION
00	Original issue
01	Made corrections and added procurement-related attachments and O-ring drawing
02	Changed inspection standard and updated requirements and format using SPC-M801794-0005 000 01 as template

REFERENCE DOCUMENTS & OTHER INFORMATION

This specification is for procurement of domestic, commercially available items; does not contain scientific, technical, or operational information (STI); and therefore does not require a review by the Information Release Office (IRO).

Recommended Suppliers:

JDS Technologies, Inc.
1299 Airport Road
Oneida, TN 37841
(423) 286-6190

OR

Rainier Rubber Co.
15660 Nelson Pl
Tukwila, WA 98188
(425) 227-4500

OR

Other Company Approved Supplier

Upon delivery, maintain Supplier's level of packaging
In-Storage Maintenance Requirements – [None], for long term storage maintain Protection Level B per Y60-015, *Integrated Quality Manual*

References for Company Use

1. Receipt Inspection Checklist: Attached
2. TE&AP: TEA 801794-0001
3. QCPI: QCPI-1317
4. QLD: CK-M801580-0010 (inner O-ring) and CK-M801580-0011 (outer O-ring)
5. This specification includes applicable requirements from OO-PP-986, QO-A-017, and QO-A-018

Quality Notes:

1. ASTM D1329 Low Temperature TR-10 test results are not to be used for acceptance criteria, but for information only
2. Procurement of O-rings must satisfy 10 CFR Part 71, Subpart H

Procurement Notes:

1. Purchasing shall include this specification and O-ring drawing M2E801580 A013, Rev. D

DC REVIEW
This document has been reviewed by a Y-12 DC / UCNIRO and has been determined to be UNCLASSIFIED and contains no UCNI.

This review does not constitute clearance for Public Release.

Name: Stan Thomas 07/19/16
Stan Thomas

APPROVALS

PRINT	SIGNATURE	DATE	PRINT	SIGNATURE	DATE
PREPARED BY / PACKAGING ENGINEER L. Roberson	L. Roberson	7/20/16	OSO ENGINEER (Q) J. E. Worthy III	J E Worthy	7/25/2016
DESIGN VERIFICATION M. L. Goins	M. L Goins	7/21/16	DESIGN AUTHORITY REP. (DAR)		
DESIGN ENGINEER G. A. Byington	G. A. Byington	7/21/16	QA ENGINEER (Q & RS) D. R. Cardwell	Donald R Cardwell	7/25/2016
DISCIPLINE MANAGER J. C. Anderson	J. C. Anderson	7/25/16			

EQUIPMENT SPECIFICATION Do Not Provide To Supplier	DOC TYPE SPC	DOC. # M801580-0002	PART # 000	REV. # 02	PAGE ii of v

RECEIPT INSPECTION CHECKLIST	DOC TYPE RP	DOC. #	PART #	REV. #	PAGE of

Form instructions – EPD Preparer should complete all spaces pertaining to the specification of the item (shown in red). The individual performing receipt inspection should complete all spaces pertaining to the inspection of the received item (shown in blue). Multiple copies of the RIC may be used for POs with multiple items. Attach comments and other documentation, as needed.

A. GENERAL INFORMATION

SPECIFIED

ITEM DESCRIPTION	UNID
Ethylene Propylene Diene Monomer (EPDM) Containment Vessel Inner O-rings	

QUALITY LEVEL	PROTECTION LEVEL	QTY TO INSPECT OR SAMPLE SIZE: If Sample is <100%, attach sampling plan and justification	PROCUREMENT QUALITY STRATEGY
Q	B	See Sampling Plan below	Evaluated or Commercial

RECEIVED

ITEM DESCRIPTION	SAT Y or N	INITIALS	DATE

PO#:	ITEM #	QTY ORDERED:	SHIPMENT COMPLETE or PARTIAL	SHIPMENT #: of	QTY REC'D/ LOT SIZE:	QTY INSPECTED/ SAMPLE SIZE:

RELATED APPROVED WAIVERS/DEVIATIONS:

B. SUPPLIER PACKAGING, HANDLING, SHIPPING, & STORAGE (INCL. MAINTENANCE)

SPECIFIED:

Supplier's normal packaging, handling, shipping and storage are adequate.

RECEIVED:	SAT Y or N	INITIALS	DATE

C. ITEM SUPPLIER/MANUFACTURER INFORMATION

	IF SPECIFIED AS A REQUIREMENT	RECEIVED
SUPPLIER		
MANUFACTURER		
MODEL #		
PART #		
		SERIAL #:

	SAT Y or N	INITIALS	DATE
Suspect/Counterfeit Item (S/CI) Inspection, Review of S/CI Notifications and Item Markings			

D. MEASUREMENT AND TEST EQUIPMENT (M&TE used for receipt inspection) *(add additional pages if needed)*

M&TE TYPE	M&TE NUMBER	CALIBRATED RANGE	TOLERANCE	CAL. DUE DATE

E. COMPANY PACKAGING, HANDLING, SHIPPING, & STORAGE (INCL. MAINTENANCE)

RECEIPT INSPECTION CHECKLIST	DOC TYPE	DOC. #	PART #	REV. #	PAGE
	RP				

SPECIFIED:

Upon delivery, maintain Supplier's level of packaging, handling, and shipping. Protection Level B required. No specific maintenance requirements are applicable to these items.

Communicated requirements to Company Material Management	Y or N	INITIALS	DATE

F. SALIENT FEATURE EVALUATION

of

CRITICAL CHARACTERISTIC	NUC PROC OR CGD METH #	INSPECTION AND/OR TEST	TO BE PERFORMED BY	REQ'D OBJ EVIDENCE	TO BE REVIEWED BY	REC'D ?
Product Identification – Product identification information and/or markings on each O-ring package (Receipt inspector – see sampling note below.)	CGD Method 1 or CGD Method 3	Inspection	PQE	Documentation of Inspection Results (CGD Method 1) or PQR(s) (CGD Method 3)	PQE	Y, N, N/A

TE&AP # IF CGD	ACCEPT. CRITERIA W/ TOLERANCE/ RANGE	ACTUAL	SAT	INITIALS	DATE
TEA-801794-0001	Y-12 PO number, markings that properly identify material such as part name, batch ID, lot ID (as applicable). Additional markings are required for sampling in the important features section.		Y or N		

CRITICAL CHARACTERISTIC	NUC PROC OR CGD METH #	INSPECTION AND/OR TEST	TO BE PERFORMED BY	REQ'D OBJ EVIDENCE	TO BE REVIEWED BY	REC'D ?
Physical Property Testing – Material Composition	CGD Method 1, CGD Method 2, or CGD Method 3	Inspection	PQE	CoC (CGD Method 2) or PQR (CGD Method 3)	PQE	Y, N, N/A

TE&AP # IF CGD	ACCEPT. CRITERIA W/ TOLERANCE/ RANGE	ACTUAL	SAT	INITIALS	DATE
TEA-801794-0001	CoC or PQR are in accordance with EPD referenced in the PO; test results are in accordance with the applicable criteria in the EPD. Additional FTIR test (Method 1) to be verified downstream per QCPI. 1. Chemical Composition FTIR per ASTM D3677, EPDM (two samples from each batch) 2. Hardness Test per ASTM D2240, 70 ± 5 Shore A 3. Low Temp. Resistance Test per ASTM D2137, Non-brittle after 3 ± 0.5 minutes at -40°C, test Method C, per Sect. 9.3.3. • None of the specimens shall fail 4. Heat Resistance Test per ASTM D573 after 70 hours at 100°C. • Increase in hardness ≤10 Shore A points per ASTM D2240 • Maximum of 25% reduction in tensile strength per ASTM D412 • Maximum of 25% reduction in ultimate elongation per ASTM D412 5. Compression Set Test per ASTM D395 after 22 hours at 70°C, test Method B • Maximum compression set ≤26%		Y or N		

CRITICAL CHARACTERISTIC	NUC PROC OR CGD METH #	INSPECTION AND/OR TEST	TO BE PERFORMED BY	REQ'D OBJ EVIDENCE	TO BE REVIEWED BY	REC'D ?
Configuration – Dimensions, Cross-sectional diameter & Inside diameter	CGD Method 2 or CGD Method 3	Inspection	PQE	CoC (CGD Method 2) or PQR(s) (CGD Method 3)	PQE	Y, N, N/A

TE&AP # IF CGD	ACCEPT. CRITERIA W/ TOLERANCE/ RANGE	ACTUAL	SAT	INITIALS	DATE
TEA-801794-0001	CoC or PQR are in accordance with EPD referenced in the PO. Supplier must certify via report of 100% dimensional inspection. 1. Record inner O-ring dim's from drawing for verification: • Cross-section diameter and		Y or N		

RECEIPT INSPECTION CHECKLIST	DOC TYPE RP	DOC. #	PART #	REV. #	PAGE

	tolerance • Inside diameter and tolerance 2. Record outer O-ring dim's from drawing (for information only): • Cross-section diameter and tolerance • Inside diameter and tolerance				

RISK ATTRIBUTES	INSPECTION AND/OR TEST	TO BE PERFORMED BY	REQ'D OBJ EVIDENCE	TO BE REVIEWED BY	REC'D ?
None	N/A	N/A	N/A	N/A	Y, N, N/A

QLD #	ACCEPT. CRITERIA W/ TOLERANCE/ RANGE	ACTUAL	SAT	INITIALS	DATE
CK-M801580-0010 CK-M801580-0011	N/A		Y or N		

IMPORTANT FEATURES	INSPECTION AND/OR TEST	TO BE PERFORMED BY	REQ'D OBJ EVIDENCE	TO BE REVIEWED BY	REC'D ?
Product identification – information and/or markings on each O-ring package (Receipt inspector – see sampling note below.)	Inspection	PQE	Documentation of Inspection Results	PQE	Y, N, N/A

	ACCEPT. CRITERIA W/ TOLERANCE/ RANGE	ACTUAL	SAT	INITIALS	DATE
	As specified in the EPD, identification for size, material compound, cure date, and expiration date.		Y or N		

IMPORTANT FEATURES	INSPECTION AND/OR TEST	TO BE PERFORMED BY	REQ'D OBJ EVIDENCE	TO BE REVIEWED BY	REC'D ?
Configuration – Visual Inspection	Inspection	PQE	CoC, test reports, or PQR(s)	PQE	Y, N, N/A

	ACCEPT. CRITERIA W/ TOLERANCE/ RANGE	ACTUAL	SAT	INITIALS	DATE
	Supplier must certify to 100% visual inspection. 1. O-ring shall be molded in one piece. O-ring shall be smooth, non-porous, and free of skin defects per ISO-3601-3, Grade CS. Imperfection limits per Table 3 of ISO 3601-3.		Y or N		

IMPORTANT FEATURES	INSPECTION AND/OR TEST	TO BE PERFORMED BY	REQ'D OBJ EVIDENCE	TO BE REVIEWED BY	REC'D ?
Mechanical Property Testing	Inspection	PQE	CoC, test reports, or PQR(s)	PQE	Y, N, N/A

	ACCEPT. CRITERIA W/ TOLERANCE/ RANGE	ACTUAL	SAT	INITIALS	DATE
	Test results are in accordance with the applicable criteria in the EPD. 1. Tensile strength test in accordance with ASTM D412, 12 MPa (1740 psi) minimum 2. Elongation test in accordance with ASTM D412, 100% minimum 3. Density (specific gravity) test in accordance with ASTM D297 on a representative cured sample from the batch of material, 1.13–1.19 g/cc (two samples from each batch) 4. Low temperature TR-10 test in accordance with ASTM D1329, performed on a representative cured test specimen from each batch of material. (See Quality Note #1 on page I.)		Y or N		

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G. DISPOSITION

APPLICABLE PQR # AND/OR NCR #: ATTACH COMMENTS & OTHER DOCUMENTATION AS NEEDED	QUANTITY APPROVED:	QUANTITY REJECTED:

H. AUTHORIZATION

EVALUATOR SIGNATURE	ORGANIZATION	BADGE	DATE

Sampling Plan:

Critical characteristics for product identification/marking will be verified in accordance with a normal sampling plan as defined for non-destructive testing in Y17-69-316, *Engineering Procurement Document Manual*, Chapter 6, Attachment 6-E, "Sampling Plan Guidance and Justification," based on the total quantity procured per the purchase order (PO). Based upon supplier performance and compliance data accumulated from receiving, the sampling plan may be relaxed or tightened accordingly per Table 6.G.1 in Attachment 6-E. This sampling plan is acceptable based on the leak-testing performed on each O-ring after its installation in the containment vessel. As noted in the safety function, these O-rings are used to provide a containment function verified after the O-ring installation by the performance of a pre-shipment leak-test between the inner and outer O-rings. Any issues with a specific O-ring would be identified during this leak testing.

According to the requirements of this specification, the Supplier places a label on each O-ring package, performs dimensional verification and visual configuration inspections on 100% of the O-rings before shipment to Y-12. Y-12 personnel will, at a minimum, witness these verification activities at the Supplier's facility during the First Article Evaluation (FAE) process if warranted per the EPD. Depending upon supplier quality program deficiencies, oversight sampling could be enforced on every order.

For material of composition, one FTIR test will be performed in accordance with Option 1 (destructive testing with production traceability) on a sample size of one for each batch of O-rings as defined in Y17-69-316, Chapter 6, "Augmented Quality Requirements," and Attachment 6-E. O-rings and a 6 in. x 6 in. minimum piece of material are supplied directly to Y-12 from the Supplier with material identified by PO number, batch number, and lot number. Based on this lot identification, material composition is verified either on a 6 in. x 6 in. minimum piece of material from the same batch, which has been cured with the lot or on a specific O-ring. Option 1, according to Attachment 6E, is an acceptable approach based on the rationale provided in the previous paragraphs.

NOTE: Receipt Inspector will confirm receipt of Supplier Certificate of Conformance (CoC) or verify with the Procurement Quality Report (PQR) that O-rings are in accordance with the specification requirements to address critical characteristics specified in the Technical Evaluation & Acceptance Plan (TE&AP) **and** for important features specified in the Receiving Inspection Checklist (RIC). If Method 3 Commercial Grade Dedication (CGD) is used for acceptance, the Receipt Inspector will verify the items inspected and documentation of this inspection at the Supplier's facility is tied to the items shipped and received at Y-12. If Method 3 was not performed at the Supplier's facility for the critical characteristics and important features of product identification/marking and the supporting sampling plan, the Receipt Inspector will perform this verification, document the results of these inspections in the RIC, and include the results in the receipt inspection package. After this acceptance, PQE will green tag (i.e., UCN-4804) the O-rings. O-rings will then be transferred to the user organization for implementation of the Quality Certification Procurement Instructions (QCPI) requirements and final acceptance as certified O-rings (i.e., UCN-14850). An identification label with product number, MC number, expiration date, and lot number will be added to each O-ring package.

EQUIPMENT SPECIFICATION FOR ETHYLENE PROPYLENE DIENE MONOMER (EPDM) CONTAINMENT VESSEL O-RINGS

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1. SCOPE

This specification and design drawing specify the requirements for O-rings used in Type B Shipping Packages. The design drawing M2E801580 A013, Rev. D specifies the dimensional requirements and refers to this specification for the non-dimensional requirements.

If conflicting requirements appear in these documents, the Supplier shall immediately notify the Company for resolution.

The Supplier shall not deviate from the requirements of this specification without prior written consent from the Company. Requests for changes or deviations shall be submitted on the Request for Waiver or Deviation (RFWD) form; an example is shown in Attachment B.

1.1 General Description of the Item

This specification is applicable to inner and outer Containment Vessel (CV) O-rings used in fissile hazardous material shipping containers. The O-rings will be used for a static face seal application. The O-ring material shall be Ethylene Propylene Diene Monomer (EPDM). The O-ring service temperature range is -40˚F to 302˚F. The O-ring material must properly seal at these extreme temperatures. CV O-rings must comply with strict manufacturing, testing, and quality standards.

1.2 Background

Failure or malfunction of these O-rings will directly result in an unacceptable condition of containment. Proper O-ring sealing is crucial for package containment during storage, shipping, and testing for normal conditions of transport (NCT) and hypothetical accident conditions (HACs). Shipping containers are regulated and certified by the Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), the U.S. Department of Transportation (DOT), and the National Nuclear Security Administration (NNSA).

2. REFERENCES

2.1 Definitions

Company – The Company (i.e., Y-12 National Security Complex), as referenced in this specification, is the buyer of the Supplier's final product.

Supplier – The Organization or person(s) entering into a subcontract with the Company to provide the product(s) described in this specification.

Subcontract Administrator (SA) – An individual, generally called the Buyer, who is responsible for the overall subcontract administration and has authority to act officially for the Company. This person may also assign a Subcontract Technical Representative (STR) to have authority to represent the Company in technical matters.

First Article – Product submitted to the Company for evaluation before the Seller being released to manufacture the remaining quantities in the PO. This product must be representative of production items by virtue of having been produced and inspected using the same facilities, testing, processes, and type of personnel planned for use in production.

First Article Evaluation (FAE) – An evaluation by the Company of the first article manufactured and the facilities, tooling, processes, etc., concerned with manufacture, test, and inspection.

Request for Waiver or Deviation (RFWD) – A formal request by the supplier for a waiver or deviation to the equipment specification, drawing, or PO using the Company form, which can be provided by the SA. The form must be approved by the Company in writing before the Supplier being granted authorization to proceed.

- **Deviation** – A specific written authorization, granted by the Company before the manufacture of an item, to depart from a subcontract requirement for a specific piece or pieces of product, or a specified period of time.
- **Waiver** – A specific written authorization, granted by the Company, to accept a configuration item or other designated items which, during production or after having been submitted for inspection, are found to depart from the specified requirements, but are considered suitable for use as-is or after rework by an approved method.

Batch – A batch of material is defined as a homogeneous mixture of material compound mixed at one time.

Lot – A lot shall be a quantity of product of the same identity, cured in the same production run, and from the same batch.

2.2 Codes/Standards/Orders/Regulations

The EPDM O-rings shall be fabricated, tested, and inspected according to the design drawings, this specification, and the applicable referenced documents.

- ASTM D297, *Standard Test Methods for Rubber Products – Chemical Analysis*
- ASTM D395, *Standard Test Methods for Rubber Properties – Compression Set*
- ASTM D412, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension*
- ASTM D573, *Standard Test Methods for Rubber – Deterioration in an Air Oven* (high temperature test)
- ASTM D1329, *Standard Test Method for Evaluating Rubber Property Retraction at Lower Temperatures* (TR Test)
- ASTM D1349, *Standard Practice for Rubber – Standard Conditions for Testing*
- ASTM D2000, *Standard Classification System for Rubber Products in Automotive Applications*
- ASTM D2084, *Standard Test Methods for Rubber Property – Vulcanization Using Oscillating Disc Cure Meter for Equivalent Such As ISO 3417*
- ASTM D2137, Standard *Test Methods for Rubber Property – Brittleness Point of Flexible Polymers and Coated Fabrics* (low temperature test)
- ASTM D2240, *Standard Test Method for Rubber Property – Durometer Hardness*
- ASTM D3182, *Standard Practice for Rubber – Materials, Equipment, and Procedure for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets*
- ASTM D3677, *Standard Test Methods for Rubber – Identification by Infrared*

Spectrophotometry

- ISO 3601-3, *Fluid Power Systems – O-rings, Part 3: Quality Acceptance Criteria*

2.3 Applicable Documents

A Company-provided O-ring drawing will be supplied with the PO.

3. ITEM REQUIREMENTS

3.1 Performance Requirements

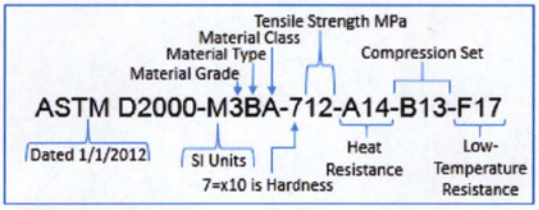
See Sect. 3.2

3.2 Design Requirements

O-rings shall meet the requirements specified in ASTM D2000. The "line call-out" or specification for these O-rings shall be as follows: ASTM-D2000-M3BA-712-A14-B13-F17.

NOTE: O-ring application is for a static face seal.

1. Below is a summary of the requirements in this line call-out.



- ASTM-D2000 is the required consensus standard.
- M3BA
  - M – prefix letter meaning requirements are in SI units (see Sect. 4.1 in ASTM D2000)
  - 3 – grade number (see Sect. 5 in ASTM D2000)
  - B – material type (see Sect. 4.3 and Table 1 in ASTM D2000), testing temperature 100˚C
  - A – material class based on volume swell in oil (see Sect. 4.4 and Table 2 in ASTM D2000), no requirement for these O-rings
- 712
  - 7 – 70 Shore A hardness (see Sect. 9.1 in ASTM D2000)
    - Test per ASTM D2240 (see Table 5 in ASTM D2000)
  - 12 – 12 MPa tensile strength minimum (see Sect. 9.1 in ASTM D2000)
    - Test per ASTM D412 (see Table 5 in ASTM D2000)
- A14 (see Table 6, page 11, BA materials, grade 3 in ASTM D2000)
  - A – heat resistance (see Table 3 in ASTM D2000)
  - 1 – test per ASTM D573 for 70 hr. (see Table 5 in ASTM D2000)

  - 4 – test @ 100˚C (see Table 4 in ASTM D2000)
  - Change in hardness +10 max
  - Change in tensile strength -25% max
  - Change in ultimate elongation -25% max
- B13 (see Table 6, page 11, BA materials, grade 3 in ASTM D2000)
  - B – compression set (see Table 3 in ASTM D2000)
  - 1 – test per ASTM D395 Method B for 22 hr. (see Table 5 in ASTM D2000)
  - 3 – test @ 70˚C (see Table 4 in ASTM D2000)
  - 25% max compression set
- F17 (see Table 6, page 11, BA materials, grade 3 in ASTM D2000)
  - F – low temperature resistance (see Table 3 in ASTM D2000)
  - 1 – test per ASTM D2137 Method C, 9.3.3, 3 minutes (see Table 5 in ASTM D2000)
  - 7 – test @ -40˚C (see Table 4 in ASTM D2000)

2. Material shall be Ethylene Propylene Diene Monomer (EPDM).
3. Color shall be black.
4. Specific Gravity/Density shall be 1.13–1.19 g/cc.
5. Minimum elongation shall be 100%.
6. Normal service temperature range shall be -40°F to 302°F.
7. Each O-ring shall be molded as a single piece.
8. O-ring surface imperfection limits shall be in accordance with ISO 3601-3, Sect. 5 and Table 3, Quality Acceptance Criteria for Grade CS – critical service. A visual inspection report shall be submitted in the certified data package and a procedure per the submittal checklist, Attachment A.
9. O-ring dimensions shall comply with the requirements on the Company drawing specified in the procurement PO or attachment to this specification. A dimensional inspection report shall be submitted in the certified data package and a procedure per the submittal checklist, Attachment A.
10. Each "lot" of O-rings associated with this procurement shall be molded from the same "batch" of material unless prior Company approval is obtained. A "batch" of material is defined as a homogeneous mixture of material compound mixed at one time. Each "lot" shall be cured in the same production run.
11. Each "lot" of O-rings shall be cured according to the temperature and time schedule specified in the Supplier's Company-approved manufacturing plan (see Sect. 3.6.2). The Supplier shall provide a copy of the curing time-temperature charts to the Company in the Certified Data Package (see Sect. 4.6.1).

12. For each "batch" of material used to mold O-rings, the Supplier shall supply to the Company one molded "slab" sample at least 6 in. x 6 in. square meeting the ASTM D3182 requirement. The sample shall be identified with the PO, the batch number of the material compound used and the O-ring lot number that it represents. The sample shall be provided to the Company with the first shipment of O-rings.

3.3 Service Conditions

See Sect. 3.2

3.4 Fabrication and Assembly Requirements

N/A

3.5 Installation Requirements

N/A

3.6 Requirements

3.6.1 Property Testing

1. Hardness test in accordance with ASTM D2240, the acceptance criteria is 70 ± 5 shore A, record median values from five determinations taken at least 6.0 mm apart and 12.0 mm from any edge, the specimen shall be ≥ 6.0 mm in thickness and may be composed of plied pieces
2. Tensile strength test a minimum of three pieces with two spares in accordance with ASTM D412, the acceptance criteria is 12 MPa minimum, dumbbell specimens per Die C dimensions with thickness requirement of 2.0 mm ± 0.2mm, the median of three measurements on each specimen shall be used to calculate thickness for cross sectional area, the test speed shall be 500 mm ± 50 mm/min, record median values from test specimens
3. High temperature test a minimum of three pieces with two spares in accordance with ASTM D573, 70 hours @ 100°C, the acceptance criteria is ≤10 max Shore A hardness, -25% max reduction in tensile strength, -25% max reduction in elongation, final testing to be performed following ≥ 16 hour cooling period (conditioning time) after removed from the oven, hardness / tensile / elongation test performed as described in 3.6.1.1 / 3.6.1.2 / 3.6.1.7, record median values from test specimens.
4. Compression set test three samples in accordance with ASTM D395 test method B, after 22 hours @ 70°C, the acceptance criteria is ≤25% max compression set, final measurements to be performed following ≥ 30 minutes cooling period after removal from the oven and fixture, button diameter and thickness per 5.2.1 – 1A, record median values expressed as a percentage.
5. Low temperature test five specimens in accordance with ASTM D2137 test method C, 3.0 ± 0.5 minutes @ -40°C, acceptance criteria is non-brittle after three minutes, failure is defined as any crack, fissure, or hole in the test samples visible to the naked eye, or complete separation into two or more pieces, none of the specimens shall fail this test per 9.3.3, die cut specimens per Fig. 2 dimensions with thickness requirement of 2.0 mm ± 0.2mm, prior to testing condition specimens ≥ 16 hours,

the striker speed shall be ≥ 1.8 m/s and be maintained for ≥ 6.0 mm of travel following impact.

6. Low temperature TR-10 test three specimens in accordance with ASTM D1329, performed on a representative cured test specimens from the batch of material, die cut specimens per Fig. 2 dimensions with thickness requirement of 2.0 mm ± 0.2mm, following ASTM procedure, stretch specimen 250%, soak 10 minutes minimum @ -70˚C to -73˚C, release stretched specimen with a controlled temperature rise of 1˚C per minute, first recorded reading at -70˚C, specimen length measured every two minutes until 75% retraction is completed. Acceptance criteria is a retraction of 10% expressed as median values prior to reaching -40˚C.
7. Elongation test a minimum of three pieces with two spares in accordance with ASTM D412, the acceptance criteria is 100% minimum, dumbbell specimens per Die C dimensions with thickness requirement of 2.0 mm ± 0.2mm, the median of three measurements on each specimen shall be used to calculate thickness for cross sectional area, the test speed shall be 500 mm ± 50 mm/min, record median values from test specimens.
8. Composition test in accordance with ASTM D3677 using Fourier Transform Infrared Spectroscopy (FTIR) on two representative cured samples from each batch – The purpose of this test is to verify that the material is EPDM. The result shall be consistent with that of "known" infrared spectra of EPDM recorded over the 4000 to 666 cm-1 region and compared to standard reference spectra and by reference to a table of diagnostic absorptions - the Pyrolysis Method shall be acceptable to the significant absorption frequency graph shown in Fig. 16 (EPM pyrolyzate from a vulcanizate) and the Film Method shall be acceptable to the significant absorption frequency graph shown in Fig. 32 (EPM film from a vulcanizate).
9. Density (specific gravity) test in accordance with ASTM D297 on two representative cured samples from each batch, the acceptance criteria is 1.13–1.19 g/cc using the hydrostatic method, to eliminate air bubbles dip specimens in alcohol and blot prior to suspending in water.
10. Supplier's procedures for conducting all of these tests shall be provided to the Company in accordance with section 3.9 requirements.
11. Rubber sheets for test specimens shall conform to the requirements of ASTM D3182.
12. Test specimen preparation and testing shall be conducted at 23˚C ± 2˚C (73.4˚F ± 3.6˚F) and 50% ± 10% relative humidity per ASTM D1349 *standard laboratory atmosphere* requirements. Materials shall be conditioned for no less than 12 hours at this controlled atmosphere prior to testing unless specified otherwise.

3.6.2 Manufacturing Requirements

1. The Manufacturer shall be responsible for supplying all materials, services, facilities, and equipment to meet the requirements of this specification and Company drawings unless otherwise noted.

2. The Supplier shall submit manufacturing plans (i.e., routings, written procedures, follow sheets, data forms, and processing records) for FAE and production orders as required to document and control the manufacturing processes to ensure consistency of all operations for Company approval. At a minimum, the plan should include materials to be procured, suppliers to be used, quality program used to buy or manufacture product, sequence of operations, equipment to be used, hold point TBD with company approval. These submittals shall be provided in accordance with the Submittal checklist, Attachment A.
3. The Supplier shall prepare and submit to the Company an inspection procedure as specified in the Quality Assurance section for review and approval. These procedures shall be submitted with the Submittal checklist, Attachment A.

3.7 Government-Furnished Material, Equipment, Services

N/A

3.8 Schedule

Proposed contract performance schedule (i.e., raw material procurement, fabrication, testing, inspection, and delivery) shall be submitted with the Proposal. This proposal shall be approved by the company before start of fabrication. **Hold/witness points shall be included, as applicable.**

3.9 Deliverables (Including Submittals)

The documentation required with the Proposal as indicated in the Submittal Checklist, Attachment A, shall be submitted to the Company in the quantities listed with the Supplier's offer. Submittals shall be emailed to the Company's SA.

Additional documentation listed in Submittal Checklist, Attachment A shall be submitted at the times requested.

The Company will review the submittals required before fabrication, as indicated in the Submittal Data attachment and respond with one of the following:

- Work may proceed.
- Revise and resubmit. Work may proceed subject to incorporation of changes indicated.
- Revise and resubmit. Work may not proceed.
- Review not required. Work may proceed.

The Company shall review the submittals required per Attachment A. Shipping shall not commence without documented permission from the Company. Submittals apply to both FAE work and production work.

3.10 Packaging, Handling, Shipping, and Storage Requirements

3.10.1. Packaging Requirements

1. Each O-ring will be thoroughly cleaned after the completion of all processing and before inspection and individual packaging. The Supplier will clean the O-rings in accordance with industry standard cleaning procedures for O-rings to ensure they are free of foreign materials (including dirt, grease, curing compound, etc.) on the surface. After cleaning, O-rings will be handled with clean nitrile gloves. Supplier

shall submit a cleaning procedure for Company approval per Submittal Checklist, Attachment A.

2. O-ring packaging will be accomplished under conditions which will ensure no contamination by dust, oil, grease, and other extraneous matter. Packaging will be carried out in an atmosphere in which the relative humidity (RH) is <65%.
3. Each O-ring shall be packaged in an individual sealed package providing adequate protection against ultra-violet rays.
4. Packaging material shall be a heat-sealable, greaseproof, water-proof, flexible barrier made of laminated paper or film in accordance with MIL-PRF-121G, Type I (medium duty) and identified on each bag. Supplier shall submit certificate of conformance for packaging material per Submittal Checklist, Attachment A.
5. Packaging method shall be in accordance with MIL-DTL-117H, Type II (medium duty), Class C (waterproof, greaseproof), Style I (opaque) and identified on each bag. Supplier shall submit CoC for packaging material per Submittal Checklist, Attachment A.

3.10.2. Shipping Requirements

O-rings shall be shipped in containers that will protect the O-rings during shipment and storage. The O-rings shall be protected against exposure to weather or any other NCTs and storage. Unless otherwise specified in the Company's PO, as a minimum, the box shall be marked with the following information:

- Supplier's company name and return "ship to" address
- Supplier's part number
- Suppliers part name
- Company's ship to address
- Company's PO number
- Date of shipment
- Number of O-rings inside

3.11 Marking and Identification Requirements

Each individual O-ring package shall be marked with the following information:

- MIL-DTL-117H, Type 2, Class C, Style 1
- MIL-PRF-121G, Type 1
- O-ring Supplier company name
- O-ring PO number
- O-ring batch number
- O-ring lot number (if applicable)
- O-ring supplier part number or part name
- O-ring compound number
- O-ring size (inside diameter and cross section, as stated per drawing)
- O-ring cure date, quarter, and year (i.e., 4Q15)
- O-ring expiration date, 4 years from cure date (i.e., 4Q19)

3.12 Request for Waiver or Deviation (RFWD)

1. The Supplier must comply with all requirements specified in this specification, the design drawing, and the applicable documents referenced herein unless approved otherwise in writing by the Company.
2. Any requested exceptions, deviations, or proposed changes to the requirements of a procurement specification by the Supplier after award or before acceptance shall be submitted using UCN-13816B, *Request for Waiver or Deviation (RFWD)*. See Attachment B for sample and instructions.
3. The Supplier shall contact the SA to obtain a UCN-13816B and submit a request for waiver and deviation to the SA when a nonconforming condition is identified including:
   - Requirements in Supplier documents approved by the Company are violated.
   - Non-conformances cannot be corrected by continuing the original manufacturing process except by reworking or repairing the item.
   - The item does not meet original requirements, even though it can be restored to a fully functional condition.
4. The Supplier shall not ship non-conforming O-rings to the Company without a Company-approved RFWD to justify such action.
5. Any non-conforming O-ring approved for shipment shall be documented on the CoC, with a reference to the approved RFWD number.
6. Certified data packages for the applicable O-rings being shipped shall include all applicable Company-approved RFWDs per Sect. 4.6.

4. QUALITY ASSURANCE REQUIREMENTS

4.1 Final Acceptance Method

1. Final acceptance of a shipment of O-rings will be based on receipt inspection performed by the Company at the Supplier's facility or upon receipt.
2. Any O-ring not meeting the requirements set forth in this document will be cause for rejection of the entire lot.
3. No O-rings shall be shipped with unapproved RFWDs.

4.1.1. General Requirements

The Supplier shall ensure the quality of the O-rings by fully complying with all drawings, requirements, testing, inspections, reports, documentation, and approvals required by this specification.

1. Before the start of production, the Supplier shall submit a Quality Assurance Program meeting 10 CFR 71, Subpart H requirements. This shall include a copy of the cover page with signatures, date, and revision number of their current Quality Manual with the Proposal. The Company reserves the right to evaluate and approve the Quality Assurance Plan of the Supplier. The Company reserves the right to perform oversight activities if there are deficiencies in the Supplier's quality program.
2. The Supplier shall notify the Company a minimum of 14 calendar days before the fabrication start date. The Company reserves the right to inspect the fabrication before, during, and after completion. Hold/witness points will be identified by the Company in the Supplier's manufacturing schedule after it is submitted to the Company for review.
3. The Supplier shall document the results of each inspection and/or test on quality record forms.
4. Where inspection or test equipment yields quantitative readings, actual measurements or deviation from nominal readings shall be submitted. Test results from the chemical analysis and physical properties test results from the batch shall be provided to the Company per the certified data package requirements and the submittal schedule, Attachment A.
5. The quality requirements shall be applicable and implemented by the Supplier and flowed down to all sub-tier supplier and subcontractors.
6. Y-12 shall be notified in advance of any subcontracting work and provided a copy of the sub-tier supplier or subcontractor project specific QA plan(s) addressing the quality requirements.
7. The supplier shall provide evidence of an acceptable assessment/oversight plan for ensuring implementation of sub-tier supplier QA requirements.
8. For requirements governing Suspect/Counterfeit Items (S/CI), reference the section regarding S/CI in the General Terms and Conditions. The General Terms and Conditions can be found in the Request for Solicitation.
9. The Supplier shall ensure the packaged O-rings are traceable from the marking on the individual packaging (Sect. 3.11) to the raw material supplier quality records accepted by the Supplier. The Supplier shall ensure the Company has full access to all records validating this traceability, including all lower-tier raw material certifications. The Supplier shall ensure only raw material meeting the applicable specifications are used in the fabrication of the O-rings.
10. Documentation of all final inspection, traceability, and testing results shall be maintained by the Supplier for a minimum of 5 years after acceptance by the Company. The Company shall have the option to retrieve and review this data during this period, if and when deemed necessary to ensure compliance with all product requirements.

4.1.2. Dimensional Inspections

1. Cross-sectional width/diameter shall be measured and documented on 100% of the O-rings. This width/diameter shall be measured with an optical/vision system, micrometer or other method via a Company-approved procedure. This diameter shall be measured at a minimum of eight locations equally spaced around the O-rings. All eight locations shall meet the width/diameter tolerance specified on the Company's drawing.
2. Per ASME Y14.5, all dimensions are applicable at 20°C (68°F). The Company's (Y-12's) dimensional lab is maintained at 68° ± 2°F. Caution: If samples are measured or verified at the Company, and the Supplier's dimensional lab is not controlled to this level, the Company's measurements may be used as the official records to determine dimensional accept/reject.
3. Inside diameter shall be measured and recorded on 100% of the O-rings. This diameter shall be measured with an optical/vision system, Pi tape or other method via a Company-approved procedure. Diameter shall meet the specified tolerance on the Company's drawing.
4. Supplier's procedures for dimensional inspection shall be provided to the Company in accordance with Sect. 3.9 requirements.
5. Dimensional inspection reports shall be prepared and submitted to the Company for approval in the Certified Data Package according to Sect. 4.6.1.

4.1.3. Visual Inspections

1. All 100% of the O-rings shall be visually inspected per ISO 3601-3, Grade Level CS. O-ring surfaces shall be free from foreign material (including dirt, grease, curing compound, etc.) and cracks, ruptures, blisters, or other imperfections greater than the limits given in Table 3 of ISO 3601-3 when the unstretched O-ring is viewed under a 2X magnifier with adequate illumination.
2. Supplier's procedure for visual inspection shall be provided to the Company in accordance with Sect. 3.9 requirements.
3. Visual inspection reports shall be prepared and submitted to the Company for approval in the Certified Data Package per Sect. 4.6.1.

4.2 Inspection/Testing Requirements

See Sect. 4.4 (Quality Requirements)

4.3 Surveillance and Audits

See Sect. 4.5 (FAE)

4.4 Quality Requirements

PROGRAM/PLAN QUALITY ASSURANCE REQUIREMENTS

The Supplier's specific QA plan shall, as a minimum, address the requirements listed in this section. The specific QA plan shall be submitted for approval.

4.4.1 Quality Assurance Organization

Responsibilities for the establishment and implementation of the QA program shall be defined. The organizational structure, functional responsibilities, levels of authority, and lines of communications for activities affecting quality shall be documented.

4.4.2 Quality Assurance Program

A QA program shall be based upon 10 CFR 71, Subpart H, "Requirements." The program shall provide control over activities affecting quality to an extent consistent with their importance. The program shall include monitoring activities against acceptance criteria in a manner sufficient to provide assurance that the activities affecting quality are performed satisfactory and shall be established at the earliest time consistent with the schedule for accomplishing the activities.

The program shall provide for planning and accomplishment of activities affecting quality under suitable controlled conditions. The controlled conditions shall include the use of appropriate equipment, suitable environmental conditions for accomplishing the activity and assurance that prerequisites for the given activity have been satisfied.

The program shall provide for any special controls, processes, test equipment, tools, and skills to attain the required quality of activities and items and for verification of that quality. The organization shall establish and implement processes to detect and correct quality problems.

The program shall provide for indoctrination and training, and qualification as necessary of personnel performing or managing activities affecting quality to assure suitable proficiency is achieved and maintained.

Management shall regularly assess the adequacy and effective implementation of the QA program.

4.4.3 Design Control

N/A

4.4.4 Procurement Document Control

Applicable design bases and other requirements necessary to assure adequate quality shall be included or referenced in documents for procurement of items and services.

4.4.5 Instructions, Procedures and Drawings

Activities affecting quality and services shall be prescribed by and performed in accordance with documented instructions, procedures, or drawings including or referencing appropriate quantitative or qualitative acceptance criteria for determining prescribed results have been satisfactorily attained.

4.4.6 Document Control

The preparation, issue, and change of documents that specify quality requirements, or prescribe activities affecting quality (e.g., instructions, procedures, and drawings) shall be controlled to assure correct documents are being employed.

Such documents, including changes thereto, shall be reviewed for adequacy and approved for release by authorized personnel.

4.4.7 Control of Purchased Items and Services

The procurement of items and services shall be controlled to ensure conformance with specified requirements.

4.4.8 Identification and Control of Items

Controls shall be established to assure only correct and accepted items are used or installed. Identification shall be maintained on the items or in documents traceable to the items, or in a manner which assures identification is established and maintained.

4.4.9 Special Processes

N/A

4.4.10 Inspection

Inspections requiring verifying conformance of an item or activity to specified requirements or continued acceptability of items in service shall be planned and executed. Characteristics subject to inspection and inspection methods shall be specified and inspection results shall be documented.

Inspection for acceptance shall be performed by qualified persons other than those who performed or directly supervised the work being inspected.

4.4.11 Test Control

Tests requiring collecting data for design input, to verify conformance of an item or computer program to specified requirements, or to demonstrate satisfactory performance for service shall be planned and executed. Characteristics to be tested and test methods to be employed shall be specified. Test results shall be documented and their conformance with test requirements and acceptance criteria evaluated.

4.4.12 Control of Measuring and Test Equipment

Tools, gages, instruments, and other measuring and test equipment used for activities affecting quality shall be controlled, adjusted, and maintained to required accuracy limits. Measuring & Test Equipment shall be calibrated and certified by an organization with ISO 17025 accreditation, or Y-12-approved equal, and traceable to the National Institute of Standards. Documentation shall be submitted in accordance with the Submittal Checklist, Attachment A.

4.4.13 Handling, Storage, and Shipping

Handling, storage, cleaning, packaging, shipping, and preservation of items shall be controlled to prevent damage or loss and to minimize deterioration. These activities shall be conducted in accordance with established work and inspection instructions, drawings, specifications, shipment instructions, or other pertinent documents or procedures specified for use in conducting the activity.

4.4.14 Inspection, Test, and Operating Status

The status of inspection and test activities shall be identified either on the item or in documents traceable to the items where it is necessary to assure required inspections and tests are performed and to assure items which have not passed the required inspections and tests are not inadvertently installed, used, or operated.

Status shall be maintained through indicators (e.g., physical location and tags, markings, shop travelers, stamps, inspection records) or other suitable means.

The authority for application and removal of tags, markings, labels, and stamps shall be specified.

4.4.15 Control of Nonconforming Items

Items that do not conform to specified requirements shall be controlled to prevent inadvertent installation or use. Controls shall provide for identification, documentation, evaluation, segregation when practical, and disposition of nonconforming items, and for notification to affected organizations.

4.4.16 Corrective Action

Conditions adverse to quality shall be promptly identified and corrected as soon as practicable. In the case of a significant condition adverse to quality, the cause of the condition shall be determined and corrective action taken to preclude recurrence. The identification, cause, and corrective action for significant conditions adverse to quality shall be documented and reported to appropriate levels of management. Completion of corrective actions shall be verified.

4.4.17 Quality Assurance Records

QA records shall furnish documentary evidence that items or activities meet specified quality requirements. QA records shall be identified, generated, authenticated, and maintained, and their final disposition specified. Requirements and responsibilities for these activities shall be documented.

4.4.18 Audits

N/A

4.4.19 Software Quality Assurance (SQA)

If applicable, the SQA process shall be established to provide assurance that software will satisfy customer requirements. The process shall apply to acquisition, development, operation, maintenance, and retirement.

4.4.20 Suspect/Counterfeit Items

A suspect item is one in which visual inspection or testing indicates it may not conform to established government or industry-accepted specifications or national consensus standards, or whose documentation, appearance, performance, material, or other characteristics may have been misrepresented by the Supplier or manufacturer. A counterfeit item is one that has been copied or substituted without legal right or authority, or whose material, performance, or characteristics have been misrepresented by the Supplier or manufacturer. Items that do not conform to established requirements are not normally considered S/CIs if nonconformity results from identifiable causes. These items should be treated as nonconforming items.

4.5 Acceptance Criteria

First Article Evaluation (FAE)/Surveillance and Audits

NOTE: Follow-on orders will not require additional FAEs unless warranted by changes at the Supplier.

The primary objective of a FAE is to verify the O-ring conforms to its requirements and the facilities, tooling, processes, controls, personnel, acceptance methods, etc., can consistently furnish O-rings of the required quality and quantity. The FAE is conducted in two phases: The first phase is an evaluation at the Supplier's site of all critical manufacturing, inspection, and testing operations and equipment. The second phase is an independent evaluation by the Company of the FAE O-rings received by the Company.

FAE O-rings must be submitted to the Company for evaluation before the Supplier is released to manufacture the remaining quantities in the PO. The O-rings must be representative of production items by virtue of having been produced and inspected using the same facilities, testing, processes, compounds, and type of personnel planned for use in production.

The total number of O-rings to be manufactured for the FAE and production shall be specified in the Company's PO.

1. Supplier shall notify the Company approximately 14 calendar days in advance of initiating fabrication of FAE O-rings.
2. Supplier shall provide the Company a Certified Data Package for the FAE O-rings, same as required for production O-rings (Sect. 4.6.1).
3. The Supplier shall not proceed to manufacture O-rings beyond the initial FAE quantities until a successful FAE has been completed and notification to proceed has been received from the Company. The Company will notify the Supplier in writing with the results of the FAE. The FAE results will be reported in one of the following three categories:
   - ***Acceptable:*** Supplier is released to initiate manufacture of production quantities.
   - ***Conditionally Acceptable:*** The Company will specify actions which the Supplier must complete before being released for production quantities.
   - ***Not Acceptable:*** The first article units have serious deficiencies, or the ability of the Supplier to consistently furnish product of the required quality and quantity is subject to major uncertainty. The Company will specify the required action.

After the Company has approved an FAE, the Supplier shall notify the Company of any proposed changes to manufacturing and acceptance procedures, facilities, personnel, testing, tooling, compounds, etc., which could conceivably impact product quality. The Company will determine if a new FAE is warranted.

The Company may periodically perform quality surveys of the Supplier's operations for assurance that the evaluated facilities, procedures, personnel, processes, testing, tooling, etc., are being used in fulfilling the subcontract.

4.6 Certificate of Conformance

A CoC shall be submitted to the Company with each shipment of O-rings.

- The CoC shall identify the purchased material or equipment by the PO number.
- The CoC shall identify the specific procurement requirements met by the purchased material or equipment (e.g., codes, standards, and other specifications). This may be accomplished by including a list of the specific requirements or by providing to the

Company a copy of the PO and the procurement specifications or drawings, together with a suitable CoC.

- The CoC shall identify any approved changes, waivers, or deviations applicable to the subject material or equipment.
- The CoC shall identify any procurement requirements that have not been met, together with an explanation and the means for resolving the RFWD.
- The CoC shall be signed or otherwise authenticated by a person responsible for this quality assurance function and whose function and position are described in the quality assurance program of the Supplier.
- The Supplier's certification system, including the procedures to be followed in filling out a CoC and the administrative procedures for review and approval of the certificates, shall be described in their quality assurance program.
- If the CoC is for Commercial Grade Survey (CGS), the certificate shall identify the programs, process, and controls, including revision level evaluated and approved by the company, and attest to the implementation thereof. The specific documents and revision level that the Supplier shall attest to are specified in the PO.

4.6.1 Certified Data Package Requirements

The following Certified Data Package shall be forwarded to the Company with each shipment of O-rings. One copy shall be forwarded to the SA **before** shipment via PDF files (email is preferred). One copy shall be included with the shipment of O-rings. **Failure to supply the required data may be cause for rejection.**

- Certificate of Conformance (Sect. 4.6)
- Raw material supplier evidence that raw material is EPDM and meets specification requirements
- Oscillating Disc Rheometer (ODR) curve for vulcanization characteristics in accordance with ASTM D2084, ISO 3417 or approved equal for each batch of material, to be supplied for information purposes only
- Testing agency CoC evidence that physical and/or chemical testing meets specification requirements
- Curing time-temperature charts, the supplier shall certify each lot was cured according to the temperature and time parameters specified in the Seller's approved manufacturing plan.
- ASTM D2000 Physical Properties
  - ASTM D573 high temperature test report (A14)
  - ASTM D395 compression set test report (B13)
  - ASTM D2137 low temperature test report (F17)
  - ASTM D2240 hardness test report (7)
  - ASTM D412 tensile strength test report (12)
- ASTM D412 elongation test report

- ASTM D1329 low temperature TR-10 test report
- ISO 3601-3 Grade CS visual inspection report
- ASTM D3677 Fourier Transform Infrared Spectroscopy (FTIR) report (**two samples from each batch**)
- ASTM D297 Density test report (**two samples from each batch**)
- Dimensional inspection report
- 6 in. x 6 in. batch test sample (in box with shipment of O-rings only)
- Applicable RFWDs

4.7 Factory Acceptance Testing or Inspection

N/A

4.8 Personnel Qualifications/Certification

The Supplier shall provide for the training and qualification of personnel, as necessary, to ensure their competence in the use of process, test and inspection procedures, and specifications.

Attachment A: Submittal Checklist

Preparation of Submittals

Note 1 – All correspondence from the Seller shall include the contract number and a unique chronological number. All correspondence shall be addressed to the subcontract administrator identified by the Company. The Seller shall forward submittals via transmittal letter to the Company at the address specified in the contract.

Note 2 – The submittal must have adequate detail so full compliance with the requirements may be determined. For example, a simple off-the-shelf item to be used in an assembly may only need a manufacturer's cut-sheet to show compliance, but a factory acceptance test developed and submitted by the Supplier must have each test step detailed with acceptance criteria consistent with the requirements.

a. Do NOT use highlight marker or color coding on submittals.
b. Review submittal before transmittal to the Company to verify conformance of submittal with requirements of the contract documents (e.g., field measurements, field construction criteria, or manufacturer's catalog numbers).
c. Coordinate submittals with the work requirements and the contract documents.
d. AFTER written approval is obtained, THEN proceed with work requiring approved submittals.
e. Submit legible data for approval and certified data in the format specified in the submittal checklist (Y17-69-316, Attachment 8-A, "Examples of Supplier Data").
f. Place the PDF file for each submittal on a Company-provided URL or via email to a Company-provided address. The URL to be used for electronic file submittals will be made available upon award.
g. WHEN data are placed on the URL, THEN notify the Company via email.
h. If certified data are required, THEN provide one copy for record after the Company has approved the product data submittal.
i. Label submittals with the applicable item number, reference, and requirement description, as summarized in the Submittal Checklist. Unlabeled submittals will be returned to the Supplier without review.
j. IF a submittal is being resubmitted, THEN reference the Company revision number and Company classification/Official Use Only markings. Example of a resubmittal: "This is a resubmittal of 015050-1.05B, Rev. A."
k. Include with submittals a transmittal letter identifying individual documents by specification section/paragraph number and purpose(s) of submittal (i.e., for substitution, review, information, approval, etc.), and related questions. Embedded comments or questions not included on the transmittal may not be addressed/resolved by the Company.
l. Mark specific options provided for the work and cross-out options not provided.
m. Maintain a copy of the Company-approved submittal and status page on file.

Attachment A
Submittal Checklist

SUBMITTAL SCHEDULE				FORMAT		SUBMITTAL PURPOSE	
AA	After Award	PTM	Prior to Mobilization	CD	Compact Disk	FI	For Information
AI	After Issue	PTS	Prior to Shipment	DVD	Digital Video Disk	FA	For Action
AIT	After Inspection/Test	PTT	Prior to Test	EM	E-Mail		
AM	After Mobilization	PTW	Prior to Weld	EN	Electronic (Native)		
AP	After Proposal/Bid	Q	As Required	EP	Electronic (Pdf)		
ATS	At Time of Shipment (Separately)	R	As Requested	O	Original		
B	Before Balance of Payment	WP	With Proposal/Bid	P	Prints/Photocopies		
NTP	Notice to Proceed			PH	Photographs		
PTC	Prior to Construction/Commencing Work			S	Sample		
PTD	Prior to Delivery			X	X-rays		
PTF	Prior to Fabrication						
PTFA	Prior to Final Acceptance/At Completion						
PTL	Prior to Lift						

EPDM O-ring Submittal Check List

Item No.	Reference	Requirement Description	Schedule	Format [a]	No. of Copies	Submittal Purpose
1	4.1.1.1, 4.4, 4.6	An uncontrolled copy of the Quality Assurance Program under which the Supplier will perform the work. Shall include document number, revision, approval signatures, and issuance date	WP	EP	1	FA, FI
2	3.12	RFWD's if necessary	Q	EP	1	FA, FI
3	3.6.2.2	Manufacturing Plan	PTF	EP	1	FA, FI
4	3.6.2.2, 3.8, 4.1.1.2, 4.4, 4.5	Proposed schedule for manufacturing, inspection, and test activities that will be used for determining hold/witness point for Company oversight	WP	EP	1	FA, FI
5	3.6.1	Procedure for hardness test in accordance with ASTM D2240	PTF	EP	1	FA
6	3.6.1	Procedure for tensile test in accordance with ASTM D412	PTF	EP	1	FA
7	3.6.1	Procedure for high temperature test in accordance with ASTM D573	PTF	EP	1	FA
8	3.6.1	Procedure for compression set test in accordance with ASTM D395	PTF	EP	1	FA
9	3.6.1	Procedure for low temperature test in accordance with ASTM D2137	PTF	EP	1	FA
10	3.6.1	Procedure for TR-10 test in accordance with ASTM D1329	PTF	EP	1	FA
11	3.6.1	Procedure for elongation test in	PTF	EP	1	FA

Item No.	Reference	Requirement Description	Schedule	Format [a]	No. of Copies	Submittal Purpose
		accordance with ASTM D412				
12	3.6.1	Procedure for FTIR test in accordance with ASTM D3677	PTF	EP	1	FA
13	3.6.1	Procedure for density test in accordance with ASTM D297	PTF	EP	1	FA
14	4.1.2.1	Procedure for dimensional inspection of O-ring cross section	PTF	EP	1	FA
15	4.1.2.3	Procedure for dimensional inspection of O-ring inside diameter	PTF	EP	1	FA
16	4.1.3.1	Procedure for visual inspection in accordance with ISO 3601-3 grade CS	PTF	EP	1	FA
17	4.5	Approval data documents for FAE	PTF	EP	1	FA
18	4.6	Certificate of Conformance	PTS, ATS	EP, P	2	FA
19	4.6.1	Certified data package	PTS, ATS	EP, P	2	FA
20	4.4.12	M&TE calibration reports per ISO 17025	PTF	EP	1	FA
21	3.10.1.1	Cleaning procedure	PTF	EP	1	FA
22	3.10.1.4, 3.10.1.5	Certificate of Conformance for packaging material	PTF	EP	1	FA

NOTE Procedures for property testing (Item No. 5-13) are not required if testing agency follows ASTM guidance and initial tests have been witnessed and approved by Company oversight.

Attachment B
Sample RFWD Form (UCN-13816B)

CLICK HERE FOR INSTRUCTIONS

REQUEST FOR WAIVER OR DEVIATION (RFWD)

1. REQUEST TYPE
☐ DEVIATION (Supplier initiated)
☐ WAIVER (Supplier Initiated)
☐ Change (CNS Initiated)

2. SHEET 1 OF
3a. NUMBER
3b. SAP DMS NUMBER

4. SUPPLIER	5. P.O. NO. / ITEM NO.	6. PROGRAM / PROJECT	7. DOCUMENT NO. / REV.
8. COMPONENT NAME	9. PART OR IDENTIFY	10. ☐ SERIAL or ☐ LOT NO.	11. LOT SIZE

	12. SPEC. REF. NO.	13. SPECIFIC ITB	14. DESCRIPTION OF WAIVER/DEVIATION/CHANGE	15. SUPPLIER PLAN FOR CORRECTIVE ACTION
1)				
2)				
3)				
4)				

16. INITIATING ENTITY REPRESENTATIVE (print /sign) | 17. TITLE | COMPANY | 18. DATE

RESPONDING ENTITY EVALUATION (TO BE COMPLETED BY RESPONDING ENTITY EVALUATOR)

	20. SPEC. REF. NO.	21. EVALUATION COMMENTS	22. EVALUATOR (print/sign) / DATE	23. RECOMMENDED DISPOSITION
1)				☐ ACCEPT ☐ REJECT
2)				☐ ACCEPT ☐ REJECT
3)				☐ ACCEPT ☐ REJECT
4)				☐ ACCEPT ☐ REJECT

24. ARE DESIGN DRAWING(S), SPECIFICATION(S), DATA SHEET(S), INSPECTION PLANS(S), OR SURVEILLANCE PLAN(S), ETC. CHANGES REQUIRED? ☐ YES ☐ NO
IF YES, LIST DOCUMENTS REQUIRING CHANGES (TO BE COMPLETED BY CNS REPRESENTATIVE)

SAMPLE

Y60-075, 42,43,47,48 & 411
UCN-13816B (01-15)

CLICK HERE FOR AN ADDITIONAL PAGE

SHEET ____ OF ____

APPPOVALS (CNS Approvals Require Same Affected Functions/Organizations Approval As Original Document)				
25. ENTITY	26. NAME (print/ sign)	27. DATE	28. APPROVE/REJECT RECOMMENDED DISPOSITIONS	
CNS Customer/Program Manager:			☐ APPROVED	☐ REJECTED
CNS Technical Representative:			☐ APPROVED	☐ REJECTED
CNS Design Authority Representative:			☐ APPROVED	☐ REJECTED
CNS Project Representative:			☐ APPROVED	☐ REJECTED
CNS Quality Engineer:			☐ APPROVED	☐ REJECTED
Design Engineering:			☐ APPROVED	☐ REJECTED
Product/Packaging Engineering:			☐ APPROVED	☐ REJECTED
Procurement Representative:			☐ APPROVED	☐ REJECTED
CNS Other (List):			☐ APPROVED	☐ REJECTED
Supplier Representative:			☐ APPROVED	☐ REJECTED

SAMPLE

Y80-015, 4.2,4.3,4.7,4.8 & 4.11
UCN-13816B (01-16)

SECTION 1 REFERENCES

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2. STRUCTURAL EVALUATION

The ES-3100 package is used to ship highly enriched uranium (HEU) in the following forms: oxide; bulk and broken metal shapes; uranyl nitrate crystals (UNX); and unirradiated research reactor fuel elements and components, and uranium compounds. Content will be packed in various size convenience cans made of stainless, tin-plated carbon steel, aluminum, or nickel alloy, and polyethylene, glass, or Teflon fluorinated ethylene propylene (FEP) bottles. The cans shall have a diameter of ≤ 12.7 cm (5 in.) and heights of ≤ 25.4 cm (10 in.). Two or more cans having a diameter of ≤ 12.7 cm (5 in.) and a maximum height of ≤ 25.4 cm (10.0 in.) may be brazed together to form a can assembly of up to 76.2 cm (30 in.) in height (Fig. 1.4). 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. Containment vessel arrangements that utilize closed metal cans with diameters >10.8 cm (4.25 in.) will provide for at least 55 $in.^3$ of free or void volume for gas expansion and offgassing of material at temperatures associated with Normal Conditions of Transport (NCT) or Hypothetical Accident Conditions (HAC). The contents that cannot be packaged in the proposed cans due to the contents' overall dimensions, such as the unirradiated research reactor fuel elements and components, will be bundled together and protected on each end with an open-ended can (Fig. 1.4). When space is available inside the containment vessel, stainless-steel metal scrubbers will be placed on the top and bottom of this partially canned assembly, or an empty convenience can will be placed on the top or bottom of this assembly inside the containment vessel. Solid form HEU contents that will not fit in a convenience can may be bagged only with no convenience can required around the content. However, the usage of convenience cans for these contents is not prohibited. Stainless-steel metal scrubbers may be placed on the top and bottom of this assembly inside the containment vessel. Additionally, glass bottles with enriched uranium oxide may be packed inside metal convenience cans. These glass bottles with enriched uranium oxide containing UO_2-Mg will be treated as pyrophoric material and packaged in a sealed and inerted container. Polyethylene bags may be used inside or outside any convenience can as long as the loading restrictions in Sect. 1.2.2.8 are met. If Teflon bottles are used as convenience containers, the total amount of offgassing material (including Teflon bottles, polyethylene bagging, and lifting slings) is limited to 1490 g per package. If metal cans, polyethylene bagging or polyethylene bottles are used as convenience containers, the total amount of offgassing material (including polyethylene bottles, polyethylene bagging, and lifting slings) is limited to 500 g per package (see Item 7 in Sect. 6.2.4). 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 U_3O_8-Al, UO_2-Mg, UO_2-ZrO_2, UO_2, UO_3, or U_3O_8; (3) 24 kg of UNX crystals; (4) 35.2 kg of uranium metal and alloy (up to 100% enrichment in ^{235}U); (5) HEU metal and alloy may be in the form of broken pieces, ingots, buttons, small castings, or fuel elements (rods, plates, or tubes); and (6) the maximum weight of all contents, including nuclear material, convenience containers, polyethylene bags, spacers, slings, etc., shall not exceed 40.82 kg (90 lb). Uranium and transuranic isotopic allowances are defined in Sect. 4. Mass limits and total weights for each shipping arrangement are defined and described in Sect. 2.1.3. The 40.82-kg (90-lb) maximum containment vessel content weight and 35.2-kg (77.60-lb) HEU content weight limits have been established as a bounding case for the maximum structural, thermal, and containment limit for the shipping package. There is no minimum content weight requirement. The content masses and forms used for the proposed content do not take into consideration limits based on shielding and subcriticality.

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	U_3O_8-Al, UO_2-Mg, UO_2-ZrO_2, 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, rods, plates, or tubes	35.2 (77.60)

As described in the following sections, design analysis, similarity, drop simulations, and the full-scale testing documented herein demonstrates that the ES-3100 package is in compliance with the requirements of Title 10 Code of Federal Regulations (CFR) 71 and Title 49 CFR 100–178 when it is used to ship contents described above. The maximum bounding activity of the contents (35.2 kg of HEU) is 7.2554×10^{-1} TBq (19.6092 Ci) and occurs 10 years after initial fabrication. When the maximum activity-to-A_2 value is reached at ~70 years from material fabrication, the corresponding activity is 7.2456×10^{-1} TBq (19.5827 Ci). The corresponding maximum number of A_2s carried is 4.7528×10^{3}. This information is further discussed in Sect. 4.

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 vessel, 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 vessel. Preserving the location of the containment vessel within the packaging prevents reduction of the shielding and subcriticality effectiveness. The drum assembly for the ES-3100 consists of an internally flanged Type 304 or 304L stainless-steel 30-gal modified drum with two Type 304 or 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 1.3.7). 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. All other dimensions are controlled by Drawing M2E801580A004 (Appendix 1.3.7). Modifications to the drum from MS27683 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 1.3.7). Four 0.795-cm (0.313-in.)–diam 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 NCT. The cavity created by the inner liner for placement of a containment vessel is a three-tiered volume. The uppermost tier accommodates the top plug and has an inside diameter of

37.52-cm (14.77-in.) and is 13.26-cm (5.22-in.) deep. The second tier has an inside diameter of 21.84-cm (8.60-in.) that is 5.59-cm (2.20-in.) deep. The third tier has a 15.85-cm (6.24-in.) inside diameter that is 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 Y/DW-1661, ORNL-TM-2003/49, Y/DW-1890, and Y/DW-1972. The volume inside the center liner tube is filled with a noncombustible cast neutron poison (absorber) material called Cat 277-4, which is created by mixing Cat 277-0 material from Shieldwerx (SWX-277-0) and boron carbide (B_4C). The material is composed of aluminum, magnesium, calcium, boron, carbon, silicon, sulfur, sodium, iron, and water. The final mixture will have an average density of 110 lb/ft^3. Cat 277-4 properties, such as thermophysical, mechanical, and neutron activation, are presented in ORNL/TM-2004/290, Y/DW-1987, Y/DZ-2585, COR-NDA-04-93, and Y/DV-1914. 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 or 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. All other dimensions are controlled by Drawings M2E801580A006 and M2E801580A007, Appendix 1.3.7. The stiffener ring (Find Number 3 on Drawing M2E801580A006, Appendix 1.3.7) provides the lid with an inner flange. The stiffener 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 stiffener ring helps position drum tie-down adapters that are used for tie-down of a single unit configuration in Safeguards Transporters (SGTs) in accordance with the National Nuclear Security Administration (NNSA) Technical Manual. 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 1.3.7), respectively. Painting and marking requirements for the drum are shown on Drawing M2E801580A001 (Appendix 1.3.7). 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.)–diam 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 1.3.4), is referenced on Drawings M2E801580A002 and M2E801580A008 (Appendix 1.3.7) 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 inward 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 1.3.5), is referenced on Drawing M2E801580A002 (Appendix 1.3.7). 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 or 304L stainless-steel sheet per American Society of Mechanical Engineers (ASME) SA-240. 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 1.3.4.

Three silicone rubber pads complete the drum assembly. One pad is placed on the bottom of the most inward 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 pad is placed over the top of the containment vessel during transport. The pads are molded to the shapes as defined on Drawing M2E801580A009 (Appendix 1.3.7). 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). The O-ring material is ethylene propylene diene monomer (EPDM) [see Tables 2.7 and 2.15]. Two methods of fabrication may be used to fabricate the containment vessel body of the ES-3100 package as shown on Drawing M2E801580A012 (Appendix 1.3.7). 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 1.3.7). The top flange is machined to match the schedule 5-in. pipe, to provide two concentric half-dovetailed 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 flow forming 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 1.3.7). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.3.7) 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 1.3.7) 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 an external retaining ring made from Type 302 stainless steel. A weld is used to seal around a plug that is inserted inside the hole used for machining the pathway for leak testing between the O-rings. Since this plug and weld are outside the containment boundary, the weld is not important to safety. However, it is important to operation because its sealing capability is needed to properly conduct the preshipment leak test. This weld is addressed in Paragraph 3.4 of the containment vessel equipment specification (JS-YMN3-801580-A001, Appendix 1.3.3). In this specification, the weld is inspected visually and using dye penetrant. The requirements of Subsections NB-5110 and NB-5350 of the *ASME Boiler and Pressure Vessel Code* (ASME Code) also apply. The sealing lid is further machined to accept a ⅜-16 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. A leak-check 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 HAC as described in 10 CFR 71.

2.1.1.3 Packaging materials

Contents may be packed in four ways: first, various size convenience cans made of stainless steel, tin-plated carbon steel, aluminum, or nickel-alloy, and polyethylene bottles or Teflon FEP bottles may be used (including bottles inside metal cans); second, contents that cannot be packaged in the proposed cans due to the contents' overall dimensions, such as the unirradiated research reactor fuel elements, will be bundled together and protected on each end with an open-ended can (Fig. 1.4); third, solid form contents that will not fit in a convenience can may be bagged only with no convenience can required around content (however, usage of convenience can is allowed); fourth, glass bottles with enriched uranium oxide (UO_2-Mg) will be packed inside a sealed and inerted container and treated as pyrophoric contents.

The convenience cans shall have a diameter of ≤ 12.7 cm (5 in.) and a height of ≤ 76.2 cm (30 in.). Any combination of these cans shall be allowed in a single package, as long as the total length of the can stack (with spacers and pads as required) does not exceed the inside working height of the containment vessel (~31 in.). Any closure on the convenience can is allowed. Multiple short cans may be brazed together. Containment vessel arrangements that utilize closed metal cans with diameters >10.8 cm (4.25 in.) will provide for at least 55 $in.^3$ of free or void volume for gas expansion and offgassing of material at temperatures associated with NCT or HAC. The polyethylene bottles have a diameter of ~12.54 cm (4.94 in.) and a height of ~22.1 cm (8.7 in.). A total of three polyethylene bottles may be loaded into the containment vessel. The Teflon FEP bottles have a diameter of ~11.91 cm (4.69 in.) and a height of ~23.88 cm (9.4 in.). A total of three Teflon FEP bottles may be loaded into the containment vessel. Polyethylene bags may be used inside or outside any convenience can or bottle. In some packing arrangements, silicone rubber pads may be used between convenience cans. Also, some arrangements will require can spacers between cans (see Table 1.3). 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 ~10.49 cm (4.13 in.) in diameter by 4.45 cm (1.75 in.) in height and have a maximum weight of ~0.71 kg (1.56 lb). In order to minimize displacement of convenience containers during transport, stainless-steel scrubbers or polyethylene bags may be added on the top or bottom of the last can or bottle in the containment vessel.

When bundling fuel elements, stainless-steel metal scrubbers will be placed on the top and bottom of this partially canned assembly, or an empty convenience can will be placed on the top or bottom of this assembly inside the containment vessel.

If partial loading configurations are employed and empty cans or bottles are used, these empty cans or bottles will require a minimum 0.32-cm (⅛-in.)–diam hole to be placed through the lid.

2.1.2 Design Criteria

The ES-3100 packaging/content combination addressed in this safety analysis report for packaging (SARP) is intended to ship contents with a maximum activity of 7.2554×10^{-1} TBq (19.6092 Ci) at 10 years from initial fabrication; the maximum number of A_2s carried is 4.7528×10^3 at 70 years following initial fabrication (Table 4.4). Based on the guidance from U.S. Nuclear Regulatory

Commission (NRC) 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) and Table 2.2 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 ASME Code, Sect. III, Div. 1, Subsection NB. The design and subsequent verification comply with the requirements of 10 CFR 71. The structural requirements for the packaging under NCT are addressed in Sect. 2.6. The structural requirements for the packaging under HAC are addressed in Sect. 2.7.

Table 2.2. Category designations for Type B packages

Contents form	Category I	Category II	Category III
Special form	>3000 A_1 or >1.11 PBq (30,000 Ci)	Between 3000 A_1 and 30 A_1, and not >1.11 PBq (30,000 Ci)	<30 A_1 and <1.11 PBq (30,000 Ci)
Normal form	>3000 A_2 or >1.11 PBq (30,000 Ci)	Between 3000 A_2 and 30 A_2, and not >1.11 PBq (30,000 Ci)	<30 A_2 and <1.11 PBq (30,000 Ci)

The drum assembly of the shipping package is defined as the structure that maintains the position of and provides protection to the impact barrier, thermal barrier, and neutron poison surrounding the containment vessel. Because the location of the containment vessel in the packaging is stable, the shielding and subcriticality effectiveness of the package is not reduced. The drum assembly for the ES-3100 consists of an internally flanged Type 304 or 304L stainless-steel 30-gal modified drum with two Type 304 or 304L stainless-steel inner liners, one filled with noncombustible cast refractory insulation and impact limiter and one filled with noncombustible cast neutron absorber; a stainless-steel top plug with cast refractory insulation, silicone rubber pads, silicon bronze hex-head nuts, and a stainless-steel lid and bottom (Drawing M2E801580A001, Appendix 1.3.7). The drum assembly is maintained when there are no breaches in the drum surface, the lid remains attached, the relative position of the containment vessel is not altered significantly, and no substantial amount of insulation is exposed following testing stipulated in 10 CFR 71.71 and 73. The drum assembly's design requirements for compliance testing are as follows:

1. The drum lid shall remain attached to the drum under all loading conditions.

2. No opening in the drum shall occur large enough to pass a 10-cm cube [10 CFR 71.43(a)].

3. The outer drum's effective diameter shall exceed requirements to maintain subcriticality and shielding effectiveness.

4. The drum assembly shall provide the structural and thermal protection needed to ensure the containment vessel meets the test leakage criteria for both NCT and HAC of $\leq 1.0 \times 10^{-7}$ ref-cm^3/s.

5. Neutron poison remains in place and retains the amount of water needed to maintain subcriticality.

In accordance with NUREG/CR-3854, Part 4.2 for a Category I shipping package, an acceptable specification for a drum used in any of the component safety groups is U.S. Department of Transportation (DOT) Specification 17C or better. It should be noted that the Specification 17C package is no longer included in the DOT regulations (49 CFR 178). The drum used in the ES-3100 is fabricated in accordance with the dimensional requirements of MS27683 and modified as shown on Drawing M2E801580A004 (Appendix 1.3.7). The fabrication requirements for the ES-3100 drum assembly are shown in JS-YMN3-801580-A002 (Appendix 1.3.2). Material, fabrication, and quality control criteria are generally equivalent to those imposed for a DOT Specification 17C drum. The drum weld seam is pressure tested to 68.95 kPa (10 psi) gauge and a rough handling test in accordance with MIL-D-6054F is conducted. As

discussed in Sect. 1.2.1.1, the drum used for the ES-3100 is equivalent to or better than that stipulated by NUREG/CR-3854 for a Category I shipping package. In accordance with DOE, a performance-based package is an approved, quality-controlled, hazardous material container that has been tested or analyzed to demonstrate its ability to maintain confinement and/or containment of its contents under both normal use and credible accident conditions as stipulated in 10 CFR 71. The drum assembly and containment vessel have been maintained for the ES-3100 shipping package as demonstrated by test results documented in the test report (ORNL/NTRC-013) and the analytical comparisons discussed in Sects. 2.6 and 2.7.

The codes and standards used for design, analysis, and fabrication of the containment vessel's components are satisfied by complying with the appropriate paragraphs in Sect. III, Div. 1, Subsection NB, and Sect. IX of the ASME Code. Nominal dimensions, not minimum dimensions, were used in the design analysis of the containment vessel components. Though not explicitly expressed, the load combinations and tests stated in NRC Regulatory Guide 7.8, *Load Combinations for the Structural Analysis of Shipping Casks*, are used in the structural evaluation of the containment vessel for both NCT and HAC as depicted in Table 2.3. Acceptance criteria for the containment vessel stresses are shown in Table 2.4 and locations are depicted in Fig. 2.1.

The design internal pressure of 699.82 kPa (101.5 psi) gauge for the containment vessel was determined based on its stress capability before the ASME Code evaluation shown in DAC-M900000-0003 was started. The containment vessel is tested with an internal pressure of 1034.21 kPa (150 psi) gauge or 1.48 times the design pressure, which exceeds the requirement stipulated in Sect. III, Paragraph NB-6221 (a minimum hydrostatic test pressure of 1.25 times the design pressure) and the regulatory requirement of 10 CFR 71.85(b) (1.5 times the maximum normal operating pressure). As shown in Table 2.6, the containment vessel design stresses are well below the allowable stresses (see Fig. 2.1 for stress locations). Therefore, this ES-3100 containment vessel is capable of shipping at a higher internal pressure. The external pressure requirement from 10 CFR 71.73(c)(6) is 150 kPa (21.7 psi) gauge. These design and operating pressures were used to calculate the stresses (DAC-M900000-0003) in all components of the containment vessel, which are well below the allowable limits at all operating conditions. The maximum normal operating pressure calculated for NCT in accordance with 10 CFR 71.4 and 10 CFR 71.71(c)(1) for the bounding load case is 215.24 kPa (31.218 psia). For conservatism and for use in subsequent analyses in Sects. 2 and 4 during NCT, the maximum gas temperature and the maximum normal operating pressure in the containment vessel are rounded up to 93.33°C (200.0°F) and 215.46 kPa (31.25 psia), respectively. The maximum internal gauge pressure calculated for NCT is 190.46 kPa (27.63 psi), which is the maximum normal operating pressure minus the reduced external pressure condition of 10 CFR 71.71(c)(3) [215.46–25.00 kPa] (Sect. 2.6.3). A summary of the package's design, NCT, and HAC pressures and temperatures is presented in Appendices 3.5.1 and 3.5.2. Allowable stress intensity limits and calculated stresses at the design evaluation conditions for the containment vessel are summarized in Tables 2.4–2.6. The stresses used in the design of all metal containment vessel components are in the elastic range of the material properties. For conditions addressed by analysis, the margin of safety (M.S.) is calculated and defined as:

$$\text{Margin of Safety} = \text{Allowable Stress} / \text{Actual Stress} - 1.$$

Table 2.3. Summary of load combinations for normal and hypothetical accident conditions of transport

Normal or accident condition	Applicable initial condition								Fabrication stresses	SARP reference
	Ambient temperature		Insolation		Decay heat		Internal pressure			
	38°C	-29°C	Max	0	Max	0	Max	Min		
Normal conditions (analyze separately)										
Hot environment (38°C ambient temperature)			X		X		X		X	Sect. 2.6.1
Cold environment (−40°C ambient temperature)				X		X		X	X	Sect. 2.6.2
Increased external pressure (20 psia)		X		X		X		X	X	Sect. 2.6.4
Minimum external pressure (3.5 psia)	X		X		X		X		X	Sect. 2.6.3
Vibration and shock:	X		X		X		X		X	Sect. 2.6.5 [a]
Normally incident to the mode of transport		X		X		X		X	X	
Free drop	X		X		X		X		X	Sect. 2.6.7[b]
1.2-m drop		X		X		X		X	X	
Compression test	X		X		X		X		X	Sect. 2.6.9 [a]
		X		X		X		X	X	
Penetration test	X		X		X		X		X	Sect. 2.6.10 [a]
		X		X		X		X	X	
Accident conditions (apply sequentially)										
Free drop: 9-m drop	X		X		X		X		X	Sect. 2.7.1 [c]
		X		X		X		X	X	
Crush: 9-m drop	X		X		X		X		X	Sect. 2.7.2 [c]
		X		X		X		X	X	
Puncture: 1-m drop onto bar	X		X		X		X		X	Sect. 2.7.3 [c]
		X		X		X		X	X	
Thermal: fire accident	X		X		X		X		X	Sect. 2.7.4

[a] This condition was conducted at room temperature with atmospheric pressure inside the containment vessel.

[b] This condition was conducted at ambient temperature at the time of the test except for Test Unit-2 (TU-2). The containment vessel was at atmospheric pressure except for TU-2. Justification for compliance with the environmental requirements of NRC Regulatory Guide 7.8 is provided in Sect. 2.6.

[c] This condition was conducted at ambient temperature at the time of the test except for TU-2. The containment vessel was at atmospheric pressure except for TU-2. Justification for compliance with the environmental requirements of NRC Regulatory Guide 7.8 is provided in Sect. 2.7.

Table 2.4. Containment vessel allowable stress

Stress category	Maximum allowable stress	
	Level A (NCT)	**Level D (HAC)**
Primary membrane stress intensity	S_m	Lesser of 2.4 S_m and 0.7 S_u
Primary membrane + primary bending stress intensity	1.5 S_m	Lesser of 3.6 S_m and S_u
Range of primary + secondary stress intensity	3.0 S_m	Not applicable
Fatigue stress range	S_a @ 10^6 cycles	< 2 S_a @ 10 cycles
Buckling	No buckling	No buckling

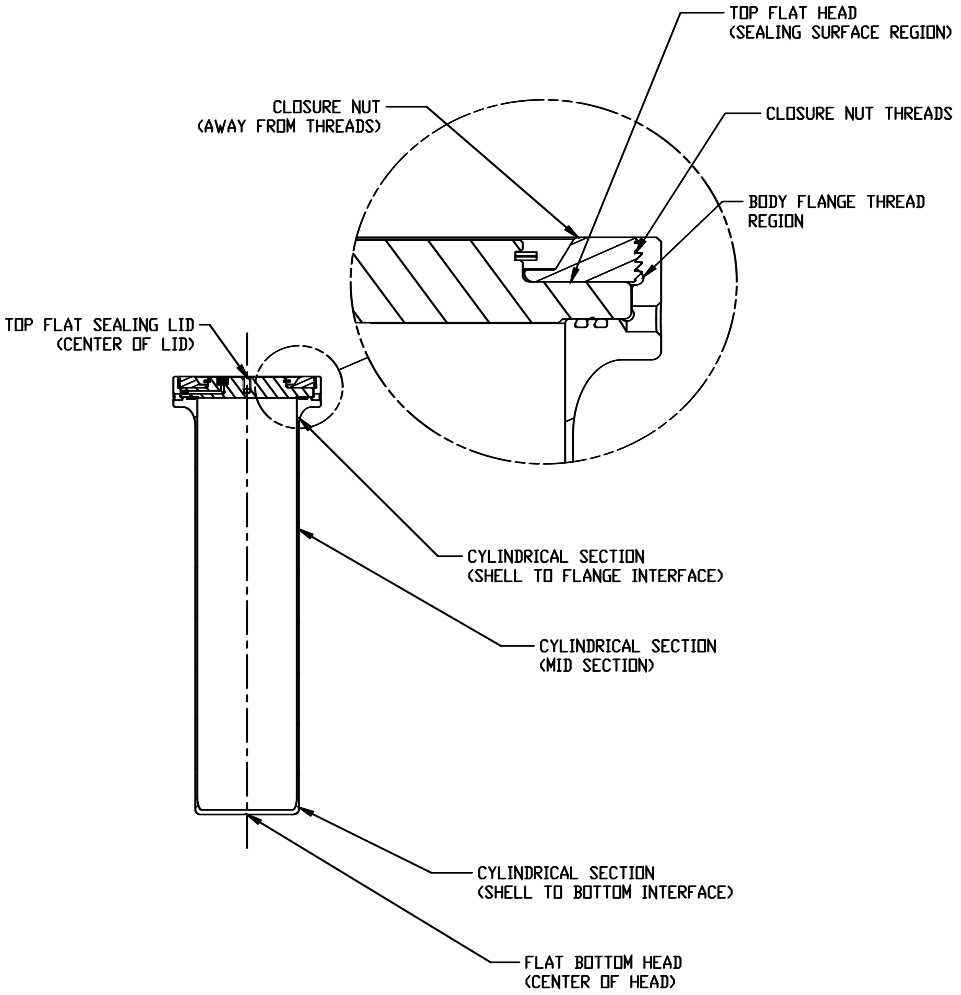


Fig. 2.1. Containment vessel calculated stress locations.

Table 2.5. Allowable stress intensity (S_m) for the containment vessel materials of construction [a]

Description	Specification	S_m (up to 148.9°C)	S_m [b] (up to 176.7°C)
Pipe body (Method 1)	ASME SA-312 seamless pipe, Type TP304L stainless steel	1.151 × 105 kPa (16,700 psi)	1.120 × 105 kPa (16,250 psi)
Formed body, end cap, and flange (Method 2)	ASME SA-182, Type F304L stainless steel	1.151 × 105 kPa (16,700 psi)	1.120 × 105 kPa (16,250 psi)
Flange and end cap (Method 1)	ASME SA-182 forging, Type F304L stainless steel	1.151 × 105 kPa (16,700 psi)	1.120 × 105 kPa (16,250 psi)
Containment vessel sealing lid	ASME SA-479, Type 304 stainless steel	1.379 × 105 kPa (20,000 psi)	1.331 × 105 kPa (19,300 psi)
Containment vessel closure nut (as ASME SA-193 bolting)	ASME SA-479, UNS-S21800, Nitronic 60 stainless steel	7.584 × 104 kPa (11,000 psi)	7.205 × 104 kPa (10,450 psi)

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 4 at 148.9°C (300°F) and 176.7°C (350°F).
[b] The values shown at 176.7°C (350°F) have been interpolated.

Table 2.6. ES-3100 containment vessel design evaluation allowable stress comparisons [a]

Stress locations shown in Fig. 2.1	Internal pressure design evaluation containment boundary stress @ 699.82 kPa (101.5 psi) gauge		External pressure design evaluation containment boundary stress @ −149.62 kPa (−21.7 psi) gauge		Allowable pressure, stress, or shear capacity
	kPa (psi) or kg (lb)	M.S. [b]	kPa (psi) or kg (lb)	M.S. [b]	kPa (psi) or kg (lb)
Top flat portion of sealing lid (center of lid)	1.142×10^4 (1656)	18	2.441×10^3 (354)	82	1.999×10^5 (29,000) [c]
Closure nut ring (away from threaded portion)	3.420×10^4 (4960)	4.2	1.902×10^4 (2759) [d]	7.6	1.441×10^5 (20,900)
Top flat head (sealing surface region)	2.897×10^4 (4202)	6.9	7.087×10^3 (1028) [d]	28	1.999×10^5 (29,000) [c]
Cylindrical section (middle) internal pressure	1.948×10^4 (2825)	5.8			1.120×10^5 (16,250) [e]
Cylindrical section (middle) external pressure			1.496×10^2 (21.7)	5.1	7.584×10^2 (110) [f]
Cylindrical section (shell-to-flange interface)	2.697×10^4 (3912)	6.2	5.766×10^3 (836)	29	1.682×10^5 (24,400) [c]
Cylindrical section (shell-to-bottom interface)	5.856×10^4 (8493)	2.9	1.252×10^4 (1816)	13	1.682×10^5 (24,400) [c]
Body flange thread load, kg (lb)	1.696×10^3 (3740)	15	9.072×10^2 (2000) [d]	29	2.608×10^4 (57,500) [g]
Body flange thread region (under cut region)	5.689×10^4 (8251)	3.0	2.839×10^4 (4117) [d]	5.9	1.682×10^5 (24,400) [c]
Flat bottom head (center)	4.895×10^4 (7100)	3.4	1.047×10^4 (1518)	16	1.682×10^5 (24,400) [c]
Closure nut thread load, kg (lb)	1.696×10^3 (3740)	20	9.072×10^2 (2000) [d]	37	3.353×10^4 (73,911) [g]

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment vessel components (DAC-M900000-0003). Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure plus the contribution from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas is dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload. Pressure ignored.

[e] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.

[f] Allowable external pressure [kPa (psi)].

[g] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 cm^2 (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

In NRC Regulatory Guide 7.11, below Table 1, the following quote is found: "Although NUREG/CR-1815 (Ref. 2) addresses the use of ferritic steels only, it does not preclude the use of austenitic stainless steels. Since austenitic stainless steels are not susceptible to brittle failure at temperatures encountered in transport, their use in containment vessels is acceptable to the staff and no tests are needed to demonstrate resistance to brittle failure." According to NRC Regulatory Guide 7.11, because the containment vessel is manufactured from Type 304L stainless steel (which is an austenitic stainless steel), "no tests are needed to demonstrate resistance to brittle failure." Therefore, brittle or fatigue failures are not anticipated under any design, transport, accident, or storage condition (Sects. 2.6 and 2.7). Material specifications for the ES-3100 packaging components are listed in Table 2.7.

Table 2.7. 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 long, ARC FT, Type 304 or 304L stainless-steel studs
Drum hex nuts	⅝-11 UNC-2B, silicon bronze C65100
Drum lid weldment	Modified 30-gal, 16-gauge (MS27683) lid, Type 304 or 304L stainless steel; and an 11-gauge-thick sheet, Type 304 or 304L stainless steel, ASME SA-240
Drum weldment	Modified 30-gal, 16-gauge (MS27683), Type 304 or 304L stainless steel, ASME SA-240, manufactured per Drawing M2E801580A004 (Appendix 1.3.7)
Drum plugs	Nylon plastic plug, Micro Plastic, Inc.
	Impact limiter, insulation enclosure, neutron absorber, and drum packing material
Insulation and impact limiter (not removable)	Lightweight cast refractory insulation, Kaolite 1600, 358.8 ±48.1 kg/m^3 (22.4 ±3 lb/ft^3) density, cast in stainless-steel shells in the drum and top plug
Neutron absorber	Cat 277-4, 1681.9 + 240.3/−80.1 kg/m^3 (105 + 15/−5 lb/ft^3) density
Top plug (removable)	Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (lifting inserts)
Inner liners	Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (modified angle)
Silicone pads	Silicone rubber, 22 ±5 Shore A, color black/gray
Aluminum foil duct tape	McMaster Carr Part # 7616A21, temperature range −40 to 121°C (−40 to 250°F)
	Containment vessel
Containment vessel plug	Part # 04-2126, Modified VCO threaded plug with O-ring, 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 (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 stainless steel per ASME SA-479, UNS-S21800 (closure nut) Method 2: Type F304L stainless-steel ASME SA-182 (body, flange, and end cap); Type 304, stainless steel, ASME SA-479 (sealing lid), Nitronic 60 stainless steel per ASME SA-479, UNS-S21800 (closure nut) All components per *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 2A

Table 2.7. ES-3100 packaging material specifications

Component	Specifications
Containment vessel O-rings	Elastomer, ethylene propylene diene monomer, Specification M3BA712A14B13F17 in ASTM D 2000 per SPC-M801580-0002 (Appendix 1.3.9)
Containment vessel lid assembly retaining ring	Smalley Steel Ring Co., Part #WSM-400-S02, Type 302 stainless steel
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-in. OD × 0.50-in. long, 18-8 stainless steel
Containment vessel packing material	
Convenience cans	Stainless steel, aluminum, 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, glass, or Teflon FEP
Silicone rubber pads	Silicone rubber, 22 ±5 Shore A, color black/gray
Can spacers	Stainless-steel can filled with Cat 277-4
Bagging	Polyethylene
Metal scouring scrubbers	Stainless steel, McMaster Carr Part #7361T13

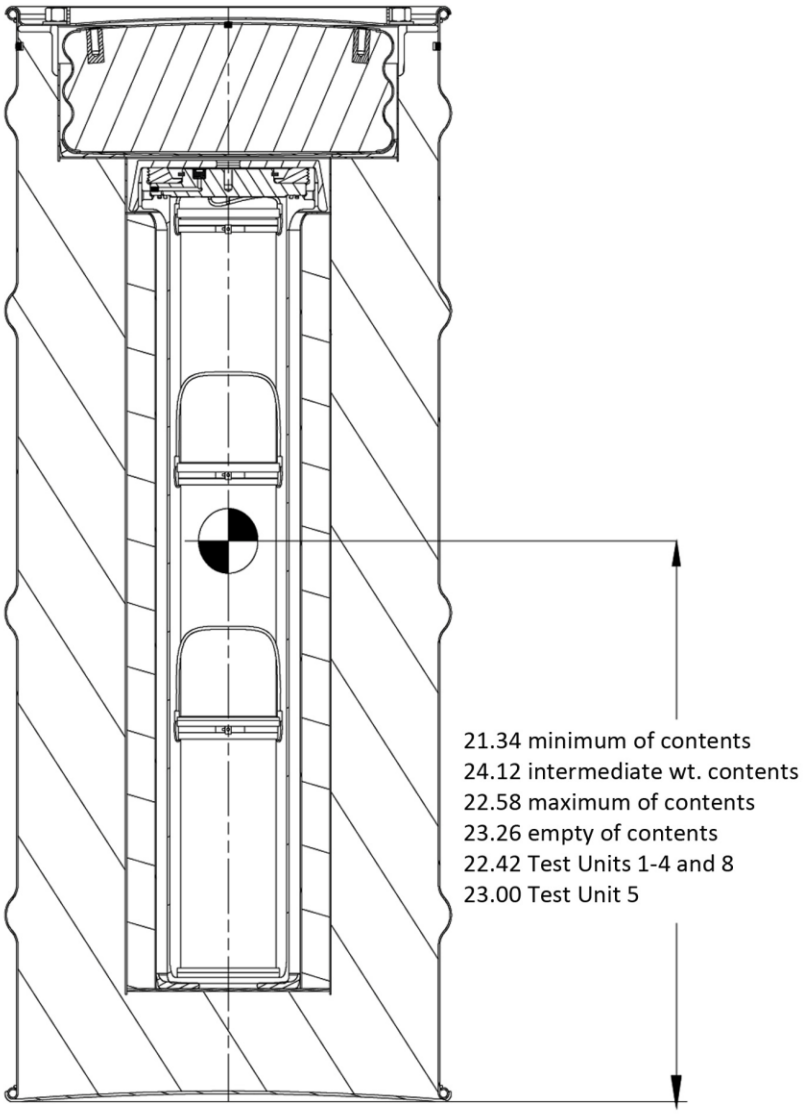
2.1.3 Weights and Centers of Gravity

The weights of the packaging components for the actual proposed contents ready for shipment and the test units are provided in Tables 2.8 and 2.9. The values listed for the test weights are the actual data recorded during compliance testing. The remaining weights listed for the shipping package are calculated weights. Nominal dimensions and densities were used in the calculations. Miscellaneous parts (nuts and washers) are included.

The range of the centers of gravity for the ES-3100 shipping package with the various HEU arrangements and the test packages is shown in Fig. 2.2. A summary of the calculations is 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, the shipping package has been designed and 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, b]

Item	Three 10-in. tall can configuration [kg (lb)] [c, d]	Six 4.875-in. tall can configuration [kg (lb)]	Five 4.875-in. tall can configuration [kg (lb)]	Six 4.75-in. tall can configuration [kg (lb)]	Three 8.75-in. tall can configuration [kg (lb)] [e]	Three 8.7-in. tall bottle configuration [kg (lb)]	Three 9.4-in. tall bottle configuration [kg (lb)]	Empty containment vessel 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) [f]	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)	121.84 (268.61)	121.96 (268.87)
Top plug	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)
Silicone support pads	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)
Total drum assembly weight	**131.89 (290.76)**	**131.89 (290.76)**	**131.89 (290.76)**	**131.89 (290.76)**	**131.89 (290.76)**	**131.89 (290.76)**	**131.89 (290.76)**	**131.78 (290.50)**	**131.89 (290.76)**
Containment vessel									
Containment vessel (flange, dowel pins, cylindrical body, and end cap)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)
Lid assembly (sealing lid, VCO plug, retaining ring, closure nut and O-rings)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)
Total containment vessel weight	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**

Table 2.8. Packaging weights for various ES-3100 shipping package arrangements [a, b]

Item	Three 10-in. tall can configuration [kg (lb)] [c, d]	Six 4.875-in. tall can configuration [kg (lb)]	Five 4.875-in. tall can configuration [kg (lb)]	Six 4.75-in. tall can configuration [kg (lb)]	Three 8.75-in. tall can configuration [kg (lb)] [e]	Three 8.7-in. tall bottle configuration [kg (lb)]	Three 9.4-in. tall bottle configuration [kg (lb)]	Empty containment vessel configuration [kg (lb)]	ES-3100 with maximum weight contents [kg (lb)]
Contents									
Convenience cans with handles	0.72 (1.59)	1.0 (2.22)	0.84 (1.85)	--	0.67 (1.47)	--	--	--	--
Silicone vibration pads	0.11 (0.23)	0.l8 (0.41)	0.16 (0.353)	--	0.11 (0.23)	--	--	--	--
Nickel cans	--	--	--	1.84 (4.07)	--	--	--	--	--
Polyethylene bottles	--	--	--	--	--	0.345 (0.76)	--	--	--
Teflon FEP bottles	--	--	--	--	--	--	0.99 (2.18)	--	--
Spacers with handles	--	--	1.88 (4.14)	--	1.25 (2.76)	--	--	--	--
Polyethylene bagging or lifting sling	0.5 (1.10)	0.5 (1.10)	0.5 (1.10)	0.5 (1.10)	0.5 (1.10)	0.155 (0.34)	0.50 (1.10)	--	--
Metal scouring pads	--	--	--	--	0.14 (0.30)	--	--	--	--
HEU or HEU/Alloy content	35.2 (77.60)	35.2 (77.60)	35.2 (77.60)	24 (52.91)	35.2 (77.60)	24.0 (52.91)	24.0 (52.91)	--	--
Total proposed content weight	**36.52 (80.52)**	**36.89 (81.33)**	**38.57 (85.04)**	**26.34 (58.08)**	**37.86 (83.46)**	**24.50 (54.01)**	**25.49 (56.19)**	**0**	**40.82 (90)**
Total shipping package weight	**183.51 (404.57)**	**183.88 (405.38)**	**185.56 (409.09)**	**173.33 (382.13)**	**184.84 (407.51)**	**171.49 (378.07)**	**172.47 (380.24)**	**146.88 (323.79)**	**187.81 (414.05)**

[a] Calculated weight using Pro/ENGINEER software with nominal dimensions and densities.
[b] Shipping weight increases by ~2.5 lb if a radio-frequency identification tag is included.
[c] The weight of this configuration bounds the weight of the bundled fuel rods, tubes, or plates with open-ended cans on either end.
[d] The weight of this configuration bounds the weight of the three 25.4-cm (10-in.)–high cans brazed together containing fuel rods, tubes, or plates.
[e] The weight of this configuration bounds the weight of the two 22.2-cm (8.75-in.)–high cans that are brazed together containing the TRIGA fuel elements.
[f] Weight excluding tamper indicating device.

Table 2.9. Compliance test unit weights [a]

Item	Test Unit [kg (lb)]						
	1	**2**	**3**	**4**	**5**	**6**	**8**
Drum body assembly [b]	126.6 (279)	127.9 (282)	127.9 (282)	127.9 (282)	128.8 (284)	--	128.4 (283)
Top plug	9.5 (21)	9.5 (21)	9.53 (21)	8.6 (19)	9.5 (21)	--	10.9 (24)
Drum silicone support pads	0.9 (2)	0.9 (2)	0.9 (2)	0.5 (1)	0.9 (2)	--	1.3 (2.8)
Containment vessel [c]	15.4 (34)	15.0 (33)	15.0 (33)	14.5 (32)	15.0 (33)	15.0 (33)	14.5 (32)
Mock-up test contents [d]	49.9 (110)	49.9 (110)	50.3 (111)	49.9 (110)	3.6 (8)		49.9 (110)
Contents						6.3 (14) [e]	
Total test unit weight	**202.3 (446)**	**202.8 (447)**	**203.7 (449)**	**201.8 (445)**	**157.4 (347)**	**21.3 (47)**	**204.6 (451)**

[a] Total weight may be different from sum of individual component weights due to scale tolerance of ±0.45 kg (1 lb).
[b] This weight includes the drum, mid liner, inner liner, cast refractory, cast neutron absorber, bottom, lid, washers and nuts.
[c] This weight includes containment vessel cylindrical body, end cap, flanged top, and lid assembly.
[d] This weight includes convenience cans, silicone rubber pads, can handles, spacers (if required), and HEU mockup.
[e] This weight was added to reduce buoyancy of containment vessel during 15-m (50-ft) immersion test.

2.2 MATERIALS

2.2.1 Material Properties and Specifications

The mechanical properties and specifications of the packaging materials are presented in Tables 2.12–2.17. See the drawings in Appendix 1.3.7 for details of all components. Design temperature ranges are listed where they are required to establish the allowable stresses used in the design calculations for the containment vessel (DAC-M900000-0003). Service temperature ranges for the remaining shipping container components were obtained from the references shown in Tables 2.12–2.17.

Kaolite 1600 property values are presented in Table 2.14, and additional Kaolite property and source information is presented in the Kaolite material safety data sheet, ORNL-TM-2003/49, Y/DW-1890, Y/LF-565, and the e-mail communication from Moody to Bales (Moody 2004). ORNL/TM-2004/290, Y/DW-1987, Y/DZ-2585, COR-NDA-04-93, and Y/DV-1914 contain the Cat 277-4 property and source information. Y/DW-1968 contains detailed technical data on strength and thermal expansion of BoroBond4. (BoroBond4 was used in the prototype test units, but it is not used in the package to be certified.)

2.2.2 Chemical, Galvanic, or Other Reactions

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

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

Content description	Distance from drum's bottom (in.)
Cylinders, bars, slugs, broken metal—35,200 g (77.60 lb) maximum—no can spacers	
3 full 4.88-in. cans + 3 empty 4.88-in. cans	21.139
2 full 4.88-in. cans + 4 empty 4.88-in. cans	21.405
1 full 4.88-in. can + 5 empty 4.88-in. cans	22.066
3 full 10-in. cans	22.071
2 full 10-in. cans + 1 empty 10-in. can	21.762
1 full 10-in. can + 2 empty 10-in. cans	22.075
3 full 8.75-in. cans	21.875
2 full 8.75-in. cans + 1 empty 8.75-in. can	21.662
1 full 8.75-in. can + 2 empty 8.75-in. cans	22.060
Cylinders, bars, slugs, broken metal—35,200 g (77.60 lb) maximum—with can spacers	
3 full 8.75-in. cans + 2 spacers	22.245
2 full 8.75-in. cans + 1 empty 8.75-in. can + 2 spacers	21.802
1 full 8.75-in. can + 2 empty 8.75-in. cans + 2 spacers	22.072
3 full 4.88-in. cans + 2 empty 4.88-in. cans + 3 spacers	21.471
2 full 4.88-in. cans + 3 empty 4.88-in. cans + 3 spacers	21.500
1 full 4.88-in. can + 4 empty 4.88-in. cans + 3 spacers	22.028
UNX crystals 24,000 g (52.91 lb) maximum—with no spacers	
3 full 8.94-in.–high Teflon FEP bottles + bagging	22.674
2 full 8.94-in.–high Teflon FEP bottles + 1 empty 8.94-in.–high Teflon FEP bottle + bagging	22.383
1 full 8.94-in.–high Teflon FEP bottle + 2 empty 8.94-in.–high Teflon FEP bottles + bagging	22.543
Oxide—24,000 g (52.91 lb) maximum—with no spacers	
6 full 4.75-in.–high nickel cans + bagging	22.631
5 full 4.75-in.–high nickel cans + 1 empty 4.75-in.–high nickel can + bagging	22.434
4 full 4.75-in.–high nickel cans + 2 empty 4.75-in.–high nickel cans + bagging	22.343
3 full 4.75-in.–high nickel cans + 3 empty 4.75-in.–high nickel cans + bagging	22.366
2 full 4.75-in.–high nickel cans + 4 empty 4.75-in.–high nickel cans + bagging	22.511
1 full 4.75-in.–high nickel can + 5 empty 4.75-in.–high nickel cans + bagging	22.787
Oxide—24,000 g (52.91 lb) maximum—with no spacers	
3 full 8.7-in.–high polyethylene bottles + bagging	22.372
2 full 8.7-in.–high polyethylene bottles + 1 empty 8.7-in.–high polyethylene bottle + bagging	22.210
1 full 8.7-in.–high polyethylene bottle + 2 empty 8.7-in.–high polyethylene bottles + bagging	22.480

Table 2.11. Applicable codes and standards for Category I packaging

	Containment *ASME Boiler and Pressure Vessel Code*, Sect. III, Subsection NB	Criticality [a]
Materials		Cat 277-4 [a]
Base materials	NB-2000 (except NB-2300) and NB-4100	
Welding materials	NB-2400	
Fabrication		
Forming, fitting, aligning, and joint preparation	NB-4200	
Welding	NB-4400	
Qualification of procedures and personnel	NB-4300	
Examination	NB-5000	[b]
Acceptance testing	NB-6000	[c]
Quality assurance	Subpart H in Title 10, CFR, Part 71	

[a] NUREG/CR-3854 states, "The designer may specify a neutron-absorber material by a commercial trade name or as a mixture of elements or common compounds. When appropriate, qualification data should be included to demonstrate that the material functions as specified. When special absorber materials are used to control criticality, an acceptance test should be performed for each container to ensure that the absorber material has been properly installed."

[b] NUREG/CR-3854 states, "Packages designed to transport fissile material which contain neutron-absorber material should be tested to demonstrate the presence of the neutron-absorber material. The test description should include information similar to that requested for gamma shield testing 3.2.1. Fabrication records of the absorber material and its installation and testing should be maintained."

[c] NUREG/CR-3854 states, "Gamma scanning or probing may be used to demonstrate the soundness of the neutron absorber. Alternatively, ultrasonic testing may be used. Whatever method is used, the following information should be provided in the test procedure:

(1) Description of the measuring technique including the electronics;
(2) The source type and strength used to measure the neutron absorber effectiveness;
(3) The standards and methods used to calibrate the source, sensors, and other pertinent equipment;
(4) The grid pattern used to check the neutron absorber;
(5) The type of gamma sensor used to measure the neutron absorber effectiveness;
(6) The specific test requirements and measurements;
(7) The acceptance criteria."

Table 2.12. Mechanical properties of the metallic components of the drum assembly [a]

Drum, bottom cover, and lid	ASME SA-240 Type 304 or 304L, stainless-steel plate	
Inner liners	ASME SA-240 Type 304 or 304L, stainless-steel plate	
Top plug weldment	ASME SA-240 Type 304 or 304L, stainless-steel plate	
Materials of construction	ASME SA-240 Type 304	ASME SA-240 Type 304L
Design stress intensity, MPa (ksi) at:		
−40°C (−40°F)	137.9 (20)	115.1 (16.7)
37.78°C (100°F)	137.9 (20)	115.1 (16.7)
93.33°C (200°F)	137.9 (20)	115.1 (16.7)
148.89°C (300°F)	137.9 (20)	115.1 (16.7)
Ultimate strength, MPa (ksi) at:		
−40°C (−40°F)	517.1 (75)	482.6 (70)
37.78°C (100°F)	517.1 (75)	482.6 (70)
93.33°C (200°F)	489.5 (71)	455.7 (66.1)
148.89°C (300°F)	456.4 (66.2)	422.0 (61.2)
Yield strength, MPa (ksi) at:		
−40°C (−40°F)	206.8 (30)	172.4 (25)
37.78°C (100°F)	206.8 (30)	172.4 (25)
93.33°C (200°F)	172.4 (25)	147.5 (21.4)
148.89°C (300°F)	154.4 (22.4)	132.4 (19.2)
Elongation in 5.08 cm (2 in.) (%)	40 [b]	40 [b]
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at:		
−40°C (−40°F)[c]	0.00001476 (0.0000082)[c]	0.00001476 (0.0000082)[c]
37.78°C (100°F)	0.00001548 (0.0000086)	0.00001548 (0.0000086)
93.33°C (200°F)	0.00001602 (0.0000089)	0.00001602 (0.0000089)
148.89°C (300°F)	0.00001656 (0.0000092)	0.00001656 (0.0000092)
Modulus of elasticity, GPa (Mpsi) at:		
−40°C (−40°F)	197.2 (28.6)	197.2 (28.6)
37.78°C (100°F)	194.0 (28.14)	194.0 (28.14)
93.33°C (200°F)	190.3 (27.6)	190.3 (27.6)
148.89°C (300°F)	186.2 (27.0)	186.2 (27.0)

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 1, Tables 2A, U, and Y-1; and Subpart 2, Tables TE-1, Column B, and TM-1.
[b] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part A, for ASME SA-240 material.
[c] MIL-HDBK-5H.

Table 2.13. Mechanical properties of the lid fastening components for the drum assembly

Drum weld studs	Specification
Material	ASTM A 493 Type 304/304L stainless steel
Fabrication standard	ASTM F 593
Service temperature range, °C (°F)	−40 to 816 (−40 to 1500) [a]
Maximum allowable stress, S, MPa (ksi) at temperatures [a]	
−29°C to 38°C (−20 to 100°F)	129.6 (18.8)
93.3°C (200°F)	115.1 (16.7)
148.9°C (300°F)	103.4 (15.0)
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) [a]	
21.1°C (70°F)	1.53×10^{-5} (8.5×10^{-6})
93.3°C (200°F)	1.60×10^{-5} (8.9×10^{-6})
148.9°C (300°F)	1.66×10^{-5} (9.2×10^{-6})
Drum hex-head nuts	**Specification**
Material	silicon bronze
Fabrication standard	ASTM F 467
UNS designation	C65100 [b]
Minimum proof stress, MPa (ksi)	485 (70) [b]
Drum washer	**Specification**
Drum	1.375-in. OD × 0.812-in. ID × 0.25 in. thick, Series 300 stainless steel

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 1, Table 3; and Subpart 2, Table TE-1, Group 3, B value.
[b] ASTM F 467.

Table 2.14. Mechanical properties of the cast refractory insulation

Material composition	Cast refractory, Kaolite 1600
Flexural tensile strength, kPa (psi)	133 (19.4) [a]
Standard deviation	32 (4.7)
Average coefficient of thermal expansion, cm/cm/°C (in./in./°F)	9.07×10^{-6} (5.04×10^{-6}) [b]
Average modulus of rupture per ASTM C 133, kPa (psi)	258.6 (37.5) [c]
Normal operating temperature, °C (°F)	−40 to 871 (−40 to 1600) [c]
Density after curing, kg/m^3 (lb/ft^3)	358.8 (22.4) [c]
Force/deflection curves	Y/DW-1972 [d]

[a] Y/DW-1661.
[b] Moody 2004.
[c] Kaolite product data sheet.
[d] Y/DW-1972.

Table 2.15. Mechanical properties of containment vessel O-rings

Ethylene propylene diene monomer	
Specification	ASTM D 2000, M3BA712A14B13F17 [a, b]
Normal service temperature range, °C (°F)	−40 to 150 (−40 to 302) [b, c]
Permissible exposure time at 150°C (302°F), h	1000 [c]
Hardness durometer, Shore A	70 ± 5 [b]
Minimum elongation, %	100 [b]
Fabrication method	Molded [b]

[a] ASTM D 2000.
[b] SPC-M801580-0002 (Appendix 1.3.9).
[c] *Parker O-Ring Handbook*, Sect. 2.13.2 and Fig. 2-28, p. 2-27.

Table 2.16. Mechanical properties of the metallic components of the containment vessel

Containment vessel: body, flange, and seal lid	Specification
Material of construction: stainless steel, Type 304L	ASME SA-312 (pipe); ASME SA-182 (flange, formed body, or end cap); ASME SA-479 (seal lid)
Design temperature range, °C (°F)	−40 to 176.67 (−40 to 350)
Minimum ultimate strength, MPa (ksi)	482.6 (70) [a]
Yield strength, 0.2% offset, MPa (ksi) at temperatures	
37.8°C (100°F)	172 (25) [a]
149°C (300°F)	132 (19.2) [b]
176.67°C (350°F)	126.52 (18.35) [b]
Elongation in 5.08 cm (2 in.), %	30 [c]
Modulus of elasticity, GPa (Mpsi) at temperature [b]	
−40°C (−40°F)	197.2 (28.60)
37.78°C (100°F)	194.0 (28.14)
93.33°C (200°F)	190.3 (27.60)
121.11°C (250°F)	188.2 (27.30)
148.89°C (300°F)	186.2 (27.00)
176.67°C (350°F)	184.4 (26.75)
Allowable stresses (S_m) [d] at 149°C (300°F)	
Welded pipe, MPa (ksi)	
149°C (300°F)	115.14 (16.7)
176.67°C (350°F)	112.03 (16.25)
Forged flanges, lids, end caps, MPa (ksi)	
at 149°C (300°F)	115.14 (16.7)
176.67°C (350°F)	112.03 (16.25)
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures [e]	
−40°C (−40°F)	0.00001476 (0.00000820)
37.78°C (100°F)	0.00001548 (0.00000860)
93.33°C (200°F)	0.00001602 (0.00000890)
121.11°C (250°F)	0.00001638 (0.00000910)
148.89°C (300°F)	0.00001656 (0.00000920)
176.67°C (350°F)	0.00001674 (0.00000930)
Containment vessel closure nut	**Specification**
Material of construction	Nitronic 60, UNS-S21800
Elongation, %	10–12 [f]
Design temperature range, °C (°F)	−40 to 176.67 (−40 to 350)
Ultimate strength, MPa (ksi), room temperature	1655–1813 (240–263) [f]
Yield strength, 0.2% offset, MPa (ksi), room temperature	1344–1496 (195 − 217) [f]
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures [e]	
93.33°C (200°F)	0.0000158 (0.0000088)
204.40°C (400°F)	0.00001660 (0.0000092)

[a] Listed in the appropriate material specification identified under materials of construction.
[b] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Tables Y-1 and TM-1.
[c] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part A for ASME SA-312, SA-182, or SA-479 material.
[d] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 2A.
[e] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 2, Table TE-1, Column B, except that −40°C is from MIL-HDBK-5H, Table 2.7.1.0.
[f] Value presented in ARMCO NITRONIC 60 Stainless Steel Product Data Bulletin, S-56b.

Table 2.17. Mechanical properties of the cast neutron absorber

Material	Cat 277-4
Service temperature range, °C (°F)	−40 to 150 (−40 to 302)
Modulus of elasticity in tension, GPa (Mpsi) at temperatures [a]	
−40°C (−40°F)	13.72 (1.991)
21.11°C (70°F)	4.72 (0.684)
37.78°C (100°F)	2.78 (0.403)
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures [b]	
−40°C (−40°F)	12.700×10^{-6} (7.056×10^{-6})
−20°C (−4°F)	13.000×10^{-6} (7.222×10^{-6})
0°C (32°F)	13.000×10^{-6} (7.222×10^{-6})
40°C (104°F)	12.600×10^{-6} (7.000×10^{-6})
60°C (140°F)	11.599×10^{-6} (6.444×10^{-6})
80°C (176°F)	10.400×10^{-6} (5.778×10^{-6})
100°C (212°F)	9.700×10^{-6} (5.389×10^{-6})
120°C (248°F)	9.101×10^{-6} (5.056×10^{-6})
Poisson's 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] Y/DW-1987.
[b] ORNL/TM-2004/290.

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, aluminum, or nickel-alloy [series 200, passivated]), polyethylene or Teflon FEP bottles, glass bottles inside convenience can, 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 most inward 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 stainless steel, Nitronic 60, or tinned steel. All stainless-steel components are passivated per ASTM A 380, 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 (other than absorbed water in the encapsulated Kaolite) 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.

The ES-3100 containment vessel is fabricated from ASME SA-182, Type 304L stainless steel that is solution annealed and quenched, cleaned, and passivated (JS-YMN3-801580-A001, Appendix 1.3.3). This low carbon (<0.03 wt % carbon) grade of austenitic stainless steel is more resistant to the precipitation of chromium carbide precipitation along the grain boundaries, due to its low carbon content. The solution anneal relieves residual stresses resulting from the method of fabrication and it ensures that the alloy is not susceptible to intergranular corrosion as demonstrated by testing in accordance with ASTM A 262. Cleaning and passivation treatments in accordance with ASTM A 380 enhance the thin, chromium-oxide film that forms on the alloy surface. During content loading operations (Sect. 7.1.1.2) and periodic maintenance (Sect. 8.2.5.2) the interior and exterior surfaces of the containment vessel are routinely inspected for signs of moisture, corrosion, and physical damage.

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- 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.

Physical contact between the convenience cans and the containment vessel wall, bottom, or top is minimized when the silicone support pads are used. The polyethylene or Teflon FEP bottles may be in contact with the stainless steel of the containment vessel, but will not react. During normal shipping operations, the cans and bottles will provide separation of the HEU contents from the containment vessel walls. The contents that cannot be packaged in the proposed cans due to the contents' overall dimensions, such as the unirradiated research reactor fuel elements, will be bundled together and protected on each end with an open-ended can (Fig. 1.4). When space is available inside the containment vessel, stainless-steel metal scrubbers will be placed on the top and bottom of this partially canned assembly, or an empty convenience can will be placed on the top or bottom of this assembly inside the containment vessel. Some solid form content may only be packed inside polyethylene bagging only. The bagging will prevent the uranium material from contacting the stainless-steel containment vessel. Stainless-steel metal scrubbers may be placed on the top and bottom of this assembly. Additionally, glass bottles with enriched uranium oxide (UO_2-Mg) will be packed inside sealed and inerted containers and treated as a pyrophoric content. The passivated nickel-alloy cans are galvanically similar to the stainless steel of the containment vessel and thus will not react. Aluminum clad components, alloys, and convenience cans oxidize quickly when exposed to moisture in the air. Therefore, there will not be any galvanic reaction between the aluminum and the containment vessel materials. Additionally, polyethylene bagging may be used around the convenience container as required by packaging personnel (in some cases the HEU is bagged inside the convenience container). Therefore, galvanic corrosion between the containment vessel wall and convenience containers or contents is highly unlikely. In addition, with the exception of UNX crystals, the environment inside the containment vessel is free of electrolytic solutions, further ensuring that there will be no galvanic reactions occurring inside the containment vessel.

For pyrophoric considerations, broken metal and alloy pieces shall be of a size that: (a) the specific surface area does not exceed 1 cm^2/g, or (b) will not pass freely through a mesh size of ⅜ in. (9.53 mm). Incidental small particles which do not pass the size restriction tests, and powders, foils, turnings, and wires may only be shipped if they are in a sealed, inerted container. Enriched uranium oxide in glass bottles (UO_2-Mg) will be shipped in a sealed, inerted container.

The material testing documented in Y/DZ-2720 does not identify the composition of the volatiles or gases generated during testing. Since Teflon FEP, a fluorine-containing polymer, is used to transport uranyl nitrate crystals and one of the uranium compounds is uranium tetrafluoride (UF_4), the possible development of a corrosive environment inside the containment vessel is investigated. Based on the following literature, FEP is notable among polymers for its high thermal stability. It decomposes at temperatures above ~260°C (500°F). In air or in oxygen, FEP decomposes in one way at lower temperatures and in another at higher temperatures. In this discussion, "oxygen" implies oxygen at a pressure of 300 torr. In air, the partial pressure of oxygen is near 150 torr. Below ~525°C, the decomposition of FEP is first order, and the main decomposition product is hexafluoropropylene (C_3F_6), although tetrafluoroethylene (C_2F_4) is a near second in abundance (Leidecker, Teflon thermal decomposition). The carbon-fluorine compound is one of the strongest compounds found in organic chemistry (its dissociation energy is 460 kJ/mol). The carbon chain is nearly completely covered by fluorine atoms and is, therefore, protected against external influences. This results in the exceptionally high chemical resistance of FEP (Daikin America). Based on the preceding statements, it is reasonable to conclude that most, if not all, of the gas coming from any decomposition of the Teflon FEP bottles would be hexafluoropropylene and tetrafluoroethylene rather than fluorine gas. The maximum temperature predicted (NCT or HAC) inside the ES-3100 containment vessel at the location near the Teflon FEP bottles is 140.56°C (285.00°F). This temperature is considerably below the lower limit of the FEP decomposition temperature [260°C (500°F)]. Due to the difference between the decomposition temperature of FEP [260°C (500°F)] and the maximum predicted temperature from testing [140.56°C (285.00°F)], essentially no C_3F_6 or C_2F_4 and no fluorine is expected to form during transport. Uranium tetrafluoride is a solid composed of agglomerating particles with a texture similar to baking soda. It is nonvolatile, nonhydroscopic, and only slightly soluble in water. A corrosive environment with fluorine as the base is not anticipated for either the uranium tetrafluoride compound or the Teflon bottles. It should be noted that the offgassing rate and quantity used for Teflon FEP at lower temperatures in Appendices 3.5.1 and 3.5.2 are very conservative estimates. The actual values shown for the Teflon bottle sample in Y/DZ-2720 may have resulted from the cumulative tolerance in the testing setup and data recording and not from actual offgassing.

Uranyl nitrate crystals are formed by dissolving uranium metal or any of the uranium oxides in nitric acid and the UNX crystalline precipitates are acquired through a variety of extraction, filtration, and purification processes. The UNX crystals are soluble in water, forming a weak nitric acid solution. Anhydrous uranyl nitrate [Formula: $UO_2(NO_3)_2$; molecular weight: 394.0; Chemical Abstract Service (CAS) Registry No. 10102-06-4] dissolves in water and when exposed to moist air it forms a mixture of the uranyl nitrate hydrates. Uranyl nitrate hexahydrate (UNH) [Formula: $UO_2(NO_3)_2 \cdot 6H_2O$; molecular weight: 502.1; CAS Registry No. 13520-83-7] separates out of solutions of uranyl nitrate at room temperature. The formation of uranyl nitrate hydrates in solution can be influenced by the addition of nitric acid. The higher the nitric acid concentration, the less water molecules take part in the hydrate formation (e.g., trihydrates, dihydrates). Thermal decomposition of UNX crystals has been studied in detail in support of nuclear fuel reprocessing. As presented for shipment, the UNX crystals exist as crystalline solids; however, the melting point for UNH, trihydrate, and dihydrate is reported as ~60°C, 113°C, and 184°C, respectively (Marshall 1951). Heating of UNH crystals up to 200°C results in a stepwise release of water molecules of crystallization (Dash 1999 and Kozlova 2007), which in a closed system results in the partial dissolution of the crystals. During transport of UNH crystals, crystalline solids and a saturated solution of uranyl nitrate will coexist at a temperature above ~60°C (MCW-1424). Given that the NCT maximum containment vessel temperature with insolation is 91.92°C (197.46°F) and the HAC maximum predicted temperature inside the containment vessel at the

location near the Teflon bottles is 140.56°C (285.00°F), the uranyl nitrate dihydrate and lower hydrates will remain in a solid phase during transportation. However, the trihydrate and higher hydrate crystals will release water molecules of crystallization upon heating above their melting point, thus converting them into a lower hydrate species, which require a successively higher temperature to release additional water molecules. The melting point for hexahydrate (~60°C) will be exceeded during NCT and HAC, and the melting point for trihydrate (~113°C) crystals will be exceeded during HAC. The solubility of uranyl nitrate is reported in ARH-724 ADD to be 55.9 and 81.1 lb $UO_2(NO_3)_2$ per 100 lb of saturated solution at 77 and 191°F, respectively. Released water molecules will partially dissolve the UNX crystals forming a weak nitric acid solution (<5% HNO_3). Upon cooling, the uranyl nitrate hydrate melt will recrystallize to a solid form.

While the Teflon bottles have proven to be fully capable of containing UNX crystals during normal shipping operations, there has been no effort to qualify these convenience containers under NCT and HAC testing conditions stipulated in 10 CFR 71.71 and 10 CFR 71.73, respectively. Consequently, solid/liquid UNX contents are therefore assumed to be in contact with the containment vessel internals. The general bulk corrosion can be estimated with published corrosion data for Type 304L stainless steel in nitric acid. Conservatively assuming an exposure to 5% nitric acid for 51 weeks at 200°F (NCT) and 1 week at 300°F (HAC) with corrosion rate data from NiDI Technical Series No. 10 075 (corrosion rate ranges of 0.000–0.005 and 0.005–0.020 in. per year at 200°F and 300°F, respectively), the estimated general corrosion would be 0.0001–0.0053 in. per 12-month exposure. However, given the conservative seal times stipulated in Table 1.3a, these corrosion rates would be reduced to 0.0001–0.0020 in. per 4-month exposure and to 0.0001–0.0012 in. per 2-month exposure. For comparison purposes, using corrosion rate data (0.0000–0.0039 and 0.0039–0.0394 in. per year at 212°F and 302°F, respectively) from the Outokumpu Corrosion Handbook, the estimated general corrosion rates would be 0.0001–0.0046 in. per 12-month exposure, 0.0001–0.0021 in. per 4-month exposure, and 0.0001–0.0014 in. per 2-month exposure. The average general corrosion would be 0.0025 in. per 12-month exposure, 0.0011 in. per 4-month exposure, and 0.0007 in. per 2-month exposure. Under the maximum seal time limit authorized (4 months in Table 1.3a), the average corrosion rate of ~0.001 in. or even the maximum corrosion rate of ~0.002 in. would not have a significant impact on the containment vessel integrity. It should be noted that these calculated corrosion rates are conservative given that the nitric acid concentration will progressively decrease during the exposure interval (i.e., as the nitric acid reacts) and that the maximum HAC temperature was imposed for 1 week with the maximum NCT temperature imposed for the remaining balance of the exposure interval.

As opposed to general corrosion in which all parts of the exposed surface corrode at approximately the same rate, pitting corrosion occurs when discrete areas of the alloy undergo localized attack while the bulk material remains virtually unaffected. Pitting corrosion can occur under acidic conditions involving a high concentration of chlorides, aeration, and moderately high temperatures. It can be inhibited by approaches commonly used to reduce corrosion in general: environment, alloy composition and structure, potential, and temperature. Various inorganic chemicals, including nitrates, will inhibit pitting when added to corrosive solutions. Type B and fissile material packages of UNX solutions with free acid are routinely transported in accordance with NRC requirements [e.g., NRC Certificate of Compliance Nos. 9250 and 9291 for the Model No. 5X22 Package and Liqui-Rad (LR) Transport Unit Package, respectively]. UNX crystals have been routinely transported in stainless-steel containment vessels in accordance with NRC requirements [e.g., NRC Certificate of Compliance Nos. 9250 and 9315 for the Model No. 5X22 Package and ES-3100 Package, respectively]. There have been no reported occurrences of pitting corrosion issues related to the transportation of UNX crystals or solutions in these referenced packages. Routine visual inspections of the ES-3100 containment vessel internals during loading and maintenance operations will identify general or pitting corrosion problems before they would present any significant impact on the containment vessel integrity.

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

All materials are affected to some extent by ionizing radiation, although low exposure levels do not typically cause appreciable effects (i.e., changes in the physical and mechanical properties). Upon exposure to ionizing radiation, a fraction of the incident energy is dissipated by interactions with the orbital electrons or nuclei of individual atoms. In sufficient quantities, the cumulative effects of these interactions may result in properties that differ from those of the unirradiated material. The radiation effects in a given material are proportional to the dose (amount of radiation absorbed), irrespective of the type of radiation.

The contents of the ES-3100 package are not irradiated, and the calculated total dose rates (Sect. 5) are well below those required to significantly damage any of the package materials by radiolytic interactions. The safety-related packaging components most vulnerable to radiation-induced degradation are the containment vessel EPDM O-rings. According to the *Parker O-Ring Handbook*, practically all elastomers suffer no change of their physical properties at a cumulative dose up to 1×10^6 rad. In addition, select EPDM compounds have been successfully tested at 1×10^7 rad of gamma radiation. Based on the calculated dose rate of 0.5 rad/h (Sect. 5.4.4), the maximum cumulative dose for the containment boundary O-ring location would be $<5 \times 10^3$ and $<1 \times 10^4$ rad for an exposure period of 1 or 2 years, respectively. Since the maximum absorbed dose is well below the 1×10^6 rad threshold, there will be no significant degradation of the O-ring material properties due to irradiation. Also, no significant degradation or activation of the other packaging materials of construction is expected at the calculated total dose rates.

Section 4.5.2.3 of NUREG-1609 requires the applicant to demonstrate that any combustible gases generated in the package during a period of one year do not exceed 5% (by volume) of the free gas volume in any confined region of the package. No credit should be taken for getters, catalysts, or other recombination devices. Appendix 3.5.4 evaluates the various packaging arrangements for the generation of hydrogen gas due to the radiolysis of water vapor, free water, interstitial water, polyethylene bags, and polyethylene or Teflon bottles. When the content mass and the material composition are limited as shown in Appendix 3.5.4, the combustible gas concentration limit stated in NUREG-1609 is not exceeded. Getters, catalysts, or other recombination devices are not employed in any of the containment vessel packaging arrangements.

2.3 FABRICATION AND EXAMINATION

2.3.1 Fabrication

2.3.1.1 Drum assembly fabrication

The drum assembly is fabricated in accordance with JS-YMN3-801580-A002 (Appendix 1.3.2), JS-YMN3-801580-A003 (Appendix 1.3.4), and JS-YMN3-801580-A005 (Appendix 1.3.5). The latter two specifications control the casting of the Kaolite 1600 and Cat 277-4 materials inside the liners, spacer cans, and the top plug.

The drum assembly and top plug are fabricated according to the design drawings (Appendix 1.3.7), and the portions of the codes, standards, and regulations to the extent described below:

1. *ASME Boiler and Pressure Vessel Code*, Sect. VIII, Div. 1, 2001 ed. with 2002 and 2003 addenda;

2. *ASME Boiler and Pressure Vessel Code*, Sect. II, Parts A and C, 2001 ed. with 2002 and 2003 addenda;

3. *ASME Boiler and Pressure Vessel Code*, Sect. IX, 2001 ed. with 2002 and 2003 addenda;

4. Military Standard MS27683, *Drum, Metal—Shipping and Storage 16 to 80 Gallons*; and

5. ASTM A 380, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*.

Detailed dimensional requirements and the materials of construction are called out on the drawings in Appendix 1.3.7. Except for the weld studs, documented certified material test reports (CMTRs) are provided for all materials used in weldments for the fabrication of the drum, including weld filler metal. The CMTRs are traceable to heat numbers and demonstrate compliance with the SA or SFA Series material specifications called out. For all other materials, documented Certificates of Compliance (CoCs) are provided certifying that the materials provided comply with the requirements stated on the drawings and specifications. All welding is done in accordance with welding procedure specifications that are written and performance qualified in accordance with the ASME Code, Sect. IX. All welders are performance qualified to weld using these procedures, and their qualifications are documented in accordance with the ASME Code, Sect. IX. The welding fabrication requirements stated in the ASME Code, Sect. VIII, Div. 1, Paragraphs UW-26–UW-48, are met. All butt welds in rolled sheet, pipe, and angle joints are full penetration butt welds. With the exception of the seam welds in the drum body, all welds shall be done by the gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), plasma arc welding, or a capacitor discharge stud welding process. The weld filler metal used in the fabrication of the drum assembly is procured to comply with the SFA specifications of Sect. II, Part C, of the ASME Code that are stated in the welding procedure specifications. Weld filler metal is traceable to heat numbers, and CMTRs are furnished for each heat of weld wire filler. The control of weld filler permits a weld examiner to be able to determine the heat number of the weld filler used in any weld on the drum assembly. Weld symbols are provided on the drawings, indicating for each weld the type of weld and the dimensions of weld. These weld symbols are interpreted in accordance with AWS A2.4.

2.3.1.2 Containment boundary fabrication

The containment boundary consists of the containment vessel, lid assembly, and inner O-ring. The containment vessel is manufactured in accordance with the applicable requirements in the ASME Code, Sect. III, Div. 1, Subsection NB, for Class 1 Components as described on the drawings in Appendix 1.3.7 and JS-YMN3-801580-A001 (Appendix 1.3.3). The containment vessel is fabricated according to the design drawings and the following codes, standards, and regulations as described in JS-YMN3-801580-A001.

1. *ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1, Subsections NB and NCA, Class 1 Components, 2001 ed. with 2002 and 2003 addenda;

2. *ASME Boiler and Pressure Vessel Code*, Sect. II, Parts A and C, 2001 ed. with 2002 and 2003 addenda;

3. *ASME Boiler and Pressure Vessel Code*, Sect. IX, 2001 ed. with 2002 and 2003 addenda; and

4. ASTM A 380, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*.

Detailed dimensional requirements and the materials of construction are called out on the drawings in Appendix 1.3.7. CMTRs are provided for the materials used to fabricate these components in accordance with NCA-3860 of the ASME Code. The suppliers of these materials will meet the requirements of NCA-3800 of the ASME Code. Such parts are traceable to each containment vessel by means of a serial number. The fabricator maintains control of materials to ensure this traceability. Other metallic materials and the O-ring seals are supplied with CoCs in accordance with NCA-3862(g) and (h) of the ASME Code. The weld filler metal used in the fabrication, and repair welding as permitted, of the containment vessels meets the requirements of ASME Code, Sect. III, Subsection NB, Paragraph NB-2400. It is procured to comply with the SFA specifications of Sect. II, Part C, of the ASME Code that is stated in the fabricator's welding procedure specifications. Weld metal is procured traceable to heat numbers, and CMTRs are furnished for each heat of weld wire filler used. The results of the delta ferrite determination are included in the CMTR for the weld filler metal (see Paragraph NB-2433). There are two containment vessel assemblies shown on Drawing M2E801580A012 (Appendix 1.3.7), Parts M2E801580A012-1 and M2E801580A012-4. Part M2E801580A012-4 is fabricated by welding a forged bottom and forged top flange to a cylindrical shell machined from seamless pipe as shown on the drawing. All welds on the containment vessels are accomplished by either the GTAW or GMAW process, manual or automatic, at the discretion of the fabricator unless specifically called out on the drawings. Backing rings, even if removed after the weld has been made, are not used. As previously stated, weld symbols are provided on the drawings, indicating the type of weld and dimensions of the weld. These weld symbols are interpreted in accordance with AWS A2.4. The forming, fitting, and alignment requirements stated in Paragraph NB-4200 are met in the fabrication of the containment vessels unless more stringent requirements are called out on the design drawings.

The preferred fabrication method for the containment vessel body (Part M2E801580A012-1) is from a single forged billet or bar by any process that meets the requirements stated in JS-YMN3-801580-A001 (Appendix 1.3.3) and shown on the design drawings. The formed, heat treated, and finished machined containment vessel body shall meet the applicable requirements of ASME SA-182 for Grade F304L for a forged component. After final forming, parts are solution annealed and quenched per the requirements of ASME SA-182 for Grade F304L. A certified heat treatment report is provided stating the following information for each furnace charge: the serial numbers of the containment vessel bodies heat treated in the furnace charge, the time and date of the heat treating, the person responsible for the heat treating, the time-temperature profile of the furnace and representative parts of the furnace charge, the quench medium, and all other pertinent details of the heat treating. Such a heat treating report is required for all heat treating, both in-process annealing and final heat treatment.

2.3.2 Examination

2.3.2.1 Examination of the drum assembly fabrication

The drum and top plug assemblies are examined and tested according to the design drawings and the applicable portions of the codes, standards, and regulations described below:

1. *ASME Boiler and Pressure Vessel Code*, Sect. VIII, Div. 1, 2001 ed. with 2002 and 2003 addenda;

2. *ASME Boiler and Pressure Vessel Code*, Sect. V, 2001 ed. with 2002 and 2003 addenda; and

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

All welded or weld-repair surfaces shall be visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity using a written weld examination procedure. Weld examiners are qualified to perform visual weld inspections in accordance with SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*, or ANSI/ASNT CP-189, *Qualification and Certification of Nondestructive Testing Personnel*, published by the American Society for Nondestructive Testing. The ASME Code, Sect. IX, is to be employed as the applicable requirement. Section VIII of the ASME Code is invoked for acceptance criteria for Code-specified examinations, which are to be performed in accordance with the provisions of ASME Code, Sect. V. Any indication of inclusions, cracks, or porosity in the welds is cause for rejection. The item may be reworked to meet the specifications. The weld examination procedures, the weld examiners' qualifications, and the weld examination reports are submitted to Consolidated Nuclear Security, LLC (CNS) for record keeping. The acceptance criteria for joint fit-up and alignment or for visual examination of welds are given in the ASME Code, Sect. VIII, Div. 1, Paragraphs UW-31 through UW-36. In addition, any visible defects such as lack of fusion, lack of penetration, linear or crack-like defects, and visible porosity, are cause for rejection. Straightening, flattening, and forming by mechanical or thermal means of some features and components after welding may be required to ensure proper assembly. The surfaces of areas of the weldment that have been reworked are visually examined to ensure that no cracks are present or that the weldment has not been degraded. Welds that are adjacent to these areas are also visually examined. The acceptance criterion is that no cracks are found. The areas worked and the visual inspections are noted on the dimensional inspection report. The external seam weld of the drum assembly is pressure tested by attaching removable lids on both the top and bottom false wire locations and injecting water and air inside the assembly up to the final pressure of 170.30 kPa (24.7 psia). After all testing, inspection, and final machining are complete, the drum assembly and top plug are dimensionally inspected. The dimensions and features such as flatness and run-out to be inspected are indicated on the design drawings. A written inspection report is prepared, submitted, and maintained for each ES-3100 drum assembly.

The above examination criteria address the stainless-steel components. However, the drum assembly also consists of the Kaolite 1600 material and the Cat 277-4 neutron poison. Acceptance criteria for the installation of the Kaolite 1600 material are addressed by JS-YMN3-801580-A003 (Appendix 1.3.4). This specification controls and documents the raw materials used for mixing, casting and vibration methodology, and the baking of the material inside the drum assembly. The final acceptance criterion is achieved by producing a cast Kaolite 1600 material density of 358.8 ± 48 kg/m^3 (22.4 ± 3 lb/ft^3). Acceptance criteria for the installation of Cat 277-4 neutron poison are addressed in JS-YMN3-801580-A005 (Appendix 1.3.5). This specification also controls and documents the raw materials used for mixing, casting, and vibration methodology, and the final density of the casting [1682 +240/−80 kg/m^3 (105 +15/−5 lb/ft^3)]. Further examination criteria to verify the concentration and homogeneity of the Cat 277-4 in each drum assembly are also provided in JS-YMN3-801580-A005. The various parameters specified in NUREG/CR-3854 and in Table 2.11 for a neutron poison are addressed in detail in this specification.

2.3.2.2 Examination of the containment vessel fabrication

The containment vessel is examined and tested according to the design drawings and applicable portions of the following codes, standards, and regulations as described below:

1. *ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1, Subsections NB and NCA, Class 1 Components, 2001 ed. with 2002 and 2003 addenda;

2. ANSI N14.5-1997, *American National Standard for Radioactive Materials—Leakage Tests on Packages for Shipment*;

3. *ASME Boiler and Pressure Vessel Code*, Sect. V, Subsection A, Article 10, Appendix IX, "Helium Mass Spectrometer Test—Hood Technique," 2001 ed., and 2002 and 2003 addenda;

4. *ASME Boiler and Pressure Vessel Code*, Sect. V, Article 6, "Liquid Penetrant Examination," 2001 ed., and 2003 addenda; and

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

Procured materials are examined in accordance with the applicable paragraphs of NB-2500 and meet the stated acceptance criteria. The results of these examinations are included with the CMTRs provided to CNS. All welded or weld-repair surfaces are visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity. The ASME Code, Sect. IX, provides the applicable requirements. Section III of the ASME Code is invoked for acceptance criteria for Code-specified examinations, which are to be performed in accordance with ASME Code, Sect. V. Prior written approval is obtained for any weld repair on materials, and the weld repair areas are both surface and volumetrically examined. The repair area is noted in a sketch supplied with the CMTR for the material that was weld repaired, and the documented results of the weld examination are provided to CNS. The markings on the weldment materials are not removed until after all weld examination is complete. The heat numbers of base metals and weld filler are required on all weld examination reports. Control of weld filler by the fabricator makes it possible for a weld examiner to determine the heat number of the weld filler used in any weld on the containment vessel.

As previously stated, the containment vessel body may be fabricated by two different methods (Appendix 1.3.7, Drawing M2E801580A012). Part M2E801580A012-4 is fabricated by welding a forged bottom and forged top flange to a cylindrical shell machined from seamless pipe as shown on the drawing. Prior to welding these components, all weld preparation areas and the surfaces within one inch of the weld are examined visually and with liquid penetrant. The acceptance criteria for these examinations are those stated in Paragraphs NB-5130(a) through NB-5130(d). The requirements in ASME Code, Paragraphs NB-5110, NB-5120, NB-5210, NB-5220, NB-5260, and NB-5300 apply to the containment vessels. The plug weld shown on Drawing M2E801580A015 (Appendix 1.3.7) shall be examined visually and with penetrant. The requirements in Paragraphs NB-5110 and NB-5350 apply to the plug weld. Materials used in the penetrant examination of welds and in the final surface examinations of finished components shall be specifically recommended by their suppliers for use with austenitic stainless steels, and copies of the certification of contaminant content of materials used shall be supplied with the examination reports (ASME Code, Sect. V, Article 6, T-641). Repair welding shall meet the applicable requirements of NB-2500. Certified written weld examination reports together with the corresponding material surface examination reports and weld map shall be submitted as stated in the procurement specification for the containment vessel. Weld examination reports for all weld and surface examinations shall include the containment vessel serial number, a weld map showing the location of the weld and examination area, the welder's name, the examiner's name, the time and date of the weld examination, the examination procedure number(s) used, the WPS number, the heat numbers of the joined materials, the heat number of the weld filler, and examiner's remarks. The examiner's remarks shall include the results of the examination and the acceptance or rejection of the weld based on the stated criteria. One set of radiographs shall be provided with the radiographic examination reports. If a weld or surface is rejected, a description of the defect and a sketch showing the location shall be provided.

The nonwelded containment vessel body, Part M2E801580A012-1, shall be formed from a single forged billet or bar by any process that meets the requirements stated in JS-YMN3-801580-A001 (Appendix 1.3.3) and shown on the design drawings (Appendix 1.3.7). The formed, heat treated, and finished machined containment vessel body shall meet the applicable requirements of ASME SA-182 for Grade F304L for a forged component. Mechanical properties are verified by testing of coupons. The test

coupons are to be machined from the same heats of materials used to form the containment vessel bodies and shall have the same or greater amount of cold work (plastic strain) as the containment vessels will have as a result of the forming process. The mechanical tensile testing of coupons shall be done in accordance with ASME SA-370. A minimum of six test coupons shall be tested for each final heat treatment furnace charge. The first set of three test coupons, chosen at random, shall be tested without being heat treated. The second set of three or more test coupons shall be heat treated together with the containment vessel bodies and then tested. The heating rates and maximum temperatures of the test coupons shall be representative of the entire furnace charge. Test coupons are not required to be heat treated with intermediate processing annealing steps but are required in the final heat treatment furnace charge. The results of all the testing of the sample coupons shall be documented, certified, and reported to CNS. The mechanical properties test report shall contain the following information: a descriptor of the furnace charge which the test coupons are to represent; the times and dates of the heat treating and the testing; the person responsible for the testing; a statement that these coupons are tested prior to or after heat treatment; a description of the testing, including a sketch of the tensile test specimen; the make, model, serial number, and current calibration data of the machine(s) used in the testing; reference to the written testing procedure that was used; the resulting measured yield strength, ultimate strength, percent elongation and percent reduction in area; and any pertinent remarks.

2.4 GENERAL REQUIREMENTS FOR ALL PACKAGES

The general design standards for all packages in accordance with 10 CFR 71.43(a) through (c) are addressed in the following paragraphs.

2.4.1 Minimum Package Size—10 CFR 71.43(a)

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

Compliance: The drum's 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.

2.4.2 Tamper-Indicating Feature—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 1.3.7) project through slots in the drum lid and provide attachment for 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, but may be installed if required by site-specific requirements.

2.4.3 Positive Closure—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 vessel is sealed using the lid assembly and closure nut to ensure that it will be breached only through a deliberate effort, and then only after the drum assembly has been breached. The design of the containment vessel is analyzed in DAC-M900000-0003 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 190.46 kPa (27.63 psi) [215.46 − 25] and 674.31 kPa (97.80 psi) attained during NCT (Sect. 2.6.3) and HAC (Appendix 3.5.2), 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 vessel 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.

2.5 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES

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

2.5.1 Lifting Devices

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

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

2.5.2 Tie-Down Devices

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

Analysis. The ES-3100 package, as delivered for transport, has no tie-down devices that are structural parts of the package. Therefore, the tie-down requirements of 10 CFR 71.45 are not applicable. The package is secured in the conveyance using blocking, bracing, and tie-down equipment that meets industry-standard practices to prevent shifting during NCT. When using an SGT, safe tie-down and transport of the package is accomplished by methods explained in the NNSA Technical Manual. For

single-unit tie-down, a drum tie-down adapter is positioned on top of the drum and two chains, passing through the adapter, are attached to equipment positioned on the floor of the transport vehicle. The welded ring on the drum lid helps to initially position this drum tie-down adapter as well as prevent inadvertent assembly damage to the studs and nuts. Another method of securing the ES-3100 package is by the use of a Cargo-Restraint Transporter or Cargo Pallet Assembly. In these methods, a frame is positioned around the base and top of either five or six packages. These frames are then chained or locked to the floor as depicted in the NNSA Technical Manual. Tension is applied to the chains to eliminate any slack. The downward load resulting from the chain tensioning is insignificant when compared to the compression loading as specified in 10 CFR 71.71(c)(9).

2.6 NORMAL CONDITIONS OF TRANSPORT

This section demonstrates compliance with 10 CFR 71.43(f) and with 10 CFR 71.51(a)(1) and (b) following the tests and NCT conditions stipulated in 10 CFR 71.71. Package structural evaluation is performed by the combination of full-scale testing, similarity, and analysis as described in the following sections. A summary of 10 CFR 71.71 tests for the ES-3100 package is shown in Table 2.18. The essentially unyielding surface used for the 1.2-m (4-ft) drop test was the indoor drop test pad at the National Transportation Research Center (NTRC). All 9-m (30-ft) drop and crush tests were conducted at the outside drop pad at NTRC. The indoor pad consists of a 5.08-cm (2-in.)–thick steel plate embedded inside a reinforced concrete pad ~127-cm (50-in.) thick. The outside drop pad consists of a 10.16-cm (4-in.)–thick steel plate embedded inside a reinforced concrete pad ~167.6-cm (66-in.) thick. An article has been prepared by the NTRC staff to describe the integrity of these test pads (Shappert 1991). It is shown that the package will not experience any loss in shielding effectiveness or spacing and will not release any radioactive content or undergo leakage of water into the containment vessel during exposure to NCT. The four tests (water spray, free drop, compression, and penetration) made on Test Unit-4 (TU-4) were conducted in the 20.8 to 22.4°C (69.4 to 72.4°F) range, with the 1.2-m drop test conducted at 22.4°C (72.4°F). The maximum regulatory reference air leakage rate is $\leq 1.3792 \times 10^{-4}$ ref-cm^3/s. Compliance with this permitted activity release limit is not dependent on filters or mechanical cooling systems. Following NCT compliance testing, the package was subjected to the sequential HAC test battery.

The ES-3100 package was tested in accordance with a test plan developed by the NTRC at the Oak Ridge National Laboratory (ORNL) [ORNL/NTRC-013]. Testing of ES-3100 prototype units was performed at the NTRC facility, except as noted below. Six full-scale test units were assembled with content weights ranging from 3.6 kg (8 lb) to 50.3 kg (111 lb). One of these test units (TU-4) was subjected to the tests specified in 10 CFR 71.71(c)(5) through (c)(10) excluding (c)(8) prior to the HAC sequential tests stipulated in 10 CFR 71.73 and shown in Table 2.18. Tables 2.18 and 2.19 summarize the testing procedure and the drop orientations for each ES-3100 test unit. The contents used as surrogate payloads for the test units are shown on Drawings M2E801580A029 and M2E801580A027. In the light-weight configuration, the contents consist of three 25.4-cm (10-in.)-high convenience cans with handles, and four silicone rubber pads. These convenience cans, handles and silicone rubber pads are identical to those proposed for transport. The bottom convenience can was filled with steel grit until the convenience can and grit assembly weighed ~3 kg (6.6 lb). The actual weight of the steel grit was 2.77 kg (6.11 lb). The total content weight for the light-weight content configuration including the convenience cans, silicone rubber pads, can handles, and steel grit was ~3.6 kg (8 lb). In the heavy-weight configurations, the surrogate payload consists of three steel cylindrical shaped components with handles, two can spacers filled with neutron-absorbing material and handles, and six silicone rubber pads. These components weighed a total of ~50 kg (110.2 lb). These different weight assemblies bound the range of possible content configurations and structural deformation resulting from compliance testing.

Table 2.18. Summary of NCT—10 CFR 71.71 tests for ES-3100 package

Test [a]	TU-1 (heavy) 12° slap-down	TU-2 (heavy) side drop	TU-3 (heavy) center of gravity over top corner	TU-4 (heavy) top down	TU-5 (light) 12° slap-down
Operational leak test (CALT5 or VTI Smart Station)	1	1	1	1	1
NCT—10 CFR 71.71(c)(5) Vibration				5	
NCT—10 CFR 71.71(c)(6) Water spray				2	
NCT—10 CFR 71.71(c)(7) 1.2 m (4 ft) free drop	2	2	2	3	2
NCT—10 CFR 71.71(c)(9) Compression				6	
NCT— 10 CFR 71.71(c)(10) Penetration				4	

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

Title 10 CFR 71.71(b) specifies that the tests for NCT be conducted at the most unfavorable ambient temperature within the range of −29 to 38°C (−20 to 100°F). The drum is fabricated from Type 304 stainless steel, and the containment vessel is fabricated from Type 304L stainless steel, which is particularly suitable for low-temperature service. The Izod impact strength for the stainless steel used in the package components remains constant over a large range [specifically, from 21.11 to −195.5°C (70 to −320°F)] (*Stainless Steel Handbook*). Tensile strength increases from a minimum of 4.826×10^5 to 1.696×10^6 kPa (70,000 to 246,000 psi), and the yield strength increases ~10% over the same temperature range. The EPDM O-rings in the containment vessel have a normal service temperature range of −40 to 150°C (−40 to 302°F) [Table 2.15]. The normal service temperature range of the drum and containment vessel is −40 to 426.7°C (−40 to 800°F) [ASME Code, Sect. II, Part D]. At −29°C (−20°F), the impact-limiting material has been shown by tests to be stiffer than at 22.4°C (72.4°F).

This condition has been evaluated by the compliance testing conducted on TU-2. TU-2 was chilled prior to being subjected to any structural testing (i.e., 1.2-m NCT drop, 9-m HAC drop, HAC crush, and HAC puncture tests). This unit was chilled to a nominal temperature of −40°C (−40°F). This was accomplished by placing the unit in an environmental chamber in Building 5800 at ORNL with initially setting of the chamber at ~ −57°C (−70°F) for 24 h. After this initial period, the control on the environmental chamber was set to ~ −43°C (−45°F) for another 48 h. Prior to the initiation of structural testing of this unit, it was removed from the environmental chamber and placed in an insulated box. Once transported to the NTRC, sequential structural testing as shown in Table 2.19 was performed as quickly as possible. The other test units were first subjected to the free drop from 1.2 m (4 ft) test prior to the HAC testing of 10 CFR 71.73. These additional tests were conducted to show that the NCT testing would not reduce the effectiveness of the package to withstand HAC testing. The reduction in tensile strength of the stainless steel from 22.4 to 38°C (73 to 100°F) is only ~2%, and the impact-limiting material test trends show that the impact-limiting material may become slightly softer. However, these slight reductions in tensile strength and absorption characteristics should not affect the results significantly compared to those conducted at 38°C (100°F).

Table 2.19. Summary of HAC—10 CFR 71.73 tests for the ES-3100 package

Test [a]	TU-1 (heavy) 12° slap-down	TU-2 (heavy) side drop	TU-3 (heavy) center of gravity over top corner	TU-4 (heavy) top down	TU-5 (light) 12° slap-down	TU-6 [b] 15-m immersion
10 CFR 71.73(c)(1) Free drop 9 m (30 ft)	1	1	1	1	1	
10 CFR 71.73(c)(2) Crush 9 m (30 ft)	2	2	2	2	2	
10 CFR 71.73(c)(3) Puncture 1 m (40 in.)	3, 4, 5, 6	3	3	3	3	
Preheat to >38°C (100 °F) before thermal test	7	4	4	4	4	
10 CFR 71.73(c)(4) Thermal 800°C (1475°F)	8	5	5	5	5	
Operational leak test of containment vessel (CALT5or VTI Smart Station)	9	6	6	6	6	1
Full containment boundary leak test (He Leak Test)	10	7	7	7	7	
10 CFR 71.73(c)(5) Immersion test fissile materials—0.9 m (3 ft)	11	8	8	8	8	
10 CFR 71.73(c)(6) Immersion test—all packages 15 m (50 ft)						2

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

Title 10 CFR 71.71(b) also states that the initial internal pressure within the containment system during NCT drop testing shall be considered as the maximum normal operating pressure. The maximum normal operating pressure is defined in 10 CFR 71.4 as the maximum gauge pressure that would develop in the containment system in a period of 1 year under the heat conditions specified in 10 CFR 71.71(c)(1). The internal pressure developed under these conditions in the ES-3100 containment vessel is calculated in Appendix 3.5.1 and discussed in Sects. 2.6.1.1 and 3.3.2. As noted in these sections, the internal pressure is calculated and rounded up to 215.46 kPa (31.25 psia). Since the decay heat of the proposed contents is ~5 W, little or no impact on the pressure or temperature of the package components will result during NCT. As shown in DAC-M900000-0003, the design absolute pressure of the containment vessel is 801.17 kPa (116.2 psia), and the hydrostatic test pressure stipulated in JS-YMN3-801580-A001 is 1135.57 kPa (164.7 psia). Thus, increasing the internal pressure of the containment vessel to a maximum of 215.46 kPa (31.25 psia) during NCT would have no detrimental effect. Table 2.20 provides a summary of the pressures and temperatures in the various shipping configurations. As discussed in Sect. 2.6.1.4, the containment vessel and the closure nut stresses for this pressure condition are well below the allowable stress values.

Table 2.20. Summary of temperatures and pressures for NCT

Average gas evaluation temperature °C (°F)	Containment vessel absolute internal pressure kPa (psia)
−40 (−40) [a]	76.74 (11.13)
25.0 (77) [b]	101.35 (14.70)
91.92 (197.46) [c]	134.15 (19.457) [d]
91.92 (197.46) [c]	215.24 (31.218) [e]
93.33 (200.00) [f]	215.46 (31.25) [f]

[a] Analysis conducted with no decay heat load in accordance with 10 CFR 71.71(c)(2).
[b] Assembly temperature and pressure.
[c] These values have been calculated in DAC-PKG-801940-A001 with 5-W decay heat and insolation.
[d] This value has been calculated in Appendix 3.5.1 for containment vessel arrangement Number 1.
[e] This value has been calculated in Appendix 3.5.1 for containment vessel arrangement Number 7.
[f] The values have been calculated in either DAC-PKG-801940-A001 or Appendix 3.5.1 and rounded up for conservatism.

Title 10 CFR 71.71(c) specifies that the package service temperature must extend from −40 to 38°C (−40 to 100°F) with insolation. As shown in Sect. 3.3.1 and calculated in DAC-PKG-801940-A001, the upper service temperature with insolation is calculated and rounded up to 93.33°C (200.00°F) for an empty ES-3100 containment vessel. Thermal cycling of the packages from 93.33°C (200.00°F) to −40°C (−40°F) is considered an unlikely event, and the change would occur over a long period of time.

In any event, the 133.33°C (240.00°F) thermal cycle would not result in brittle fracture or fatigue failure in the packaging. The acceptability of the packaging against brittle fracture is discussed in Sect. 2.6.2. The only concern for fatigue or endurance failure is related to the cyclic pressure changes in the containment vessel as the temperature varies from low to high. A 25°C (77°F) ambient temperature normally exists for the containment vessel during assembly. The containment vessel is sealed at an absolute pressure of ~101.35 kPa (14.70 psi). The internal absolute pressure at an average gas temperature of 93.33°C (200.0°F) is 215.46 kPa (31.25 psi) for the ES-3100 containment vessel (Table 2.20). The absolute internal pressure at −40°C or −40°F is 76.74 kPa (11.13 psi) for the containment vessel. Therefore, the maximum cyclic pressure differential for the containment vessel from low to high temperatures is (215.46 − 76.74) kPa or 138.72 kPa (20.12 psi). This cyclic pressure is insignificant when considering the integrity of the containment vessel as shown by the stress levels discussed in Sect. 2.6.1.3.

The ES-3100 package has been tested to determine the effectiveness of the package following a sequential NCT 1.2-m (4-ft) drop test and an HAC test battery. Testing conducted on TU-4 showed that there would be no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels if the actual contents had been subjected to these tests, and no substantial reduction in the effectiveness of the packaging to survive the HAC testing. Thus, the requirements of 10 CFR 71.43(f) are satisfied.

Because some contents may be transported by air, the following criteria and guidance have been incorporated into various sections of this SARP.

1. International Atomic Energy Agency (IAEA) TS-R-1, Paragraph 619 states: “Packages containing radioactive material, to be transported by air, shall be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than the maximum normal operating pressure plus 95 kPa.”

2. In order to also comply with 49 CFR 173.410(i)(2), the range of temperature evaluated will be from −40 to 55°C (ambient temperature).

3. According to IAEA TS-G-1.1, Paragraph 619.3, the evaluation at an ambient temperature of 55°C does not consider the solar radiation input; however, self-heating of the package is taken into account.

A thermal analysis has been conducted that predicts various temperatures of the shipping package evaluated at an ambient temperature of 55°C (131°F) with no insolation but does include 5 W of internal decay heating. The results are shown in Table 3.14 for this condition. The maximum temperature predicted for the containment vessel is 63.39°C (146.11°F). This temperature will be used in subsequent analyses as the maximum average gas temperature inside the containment vessel during air transport. An analysis has been conducted in Appendix 3.5.1 to determine the maximum normal operating pressure (MNOP) for air transport. Table 9 in Appendix 3.5.1 shows the results of this analysis, where the MNOP is determined to be 198.42 kPa (28.778 psia) for air transport. This value of 198.42 kPa (28.778 psia) is bounded by the value determined for ground transportation shown in Table 2.20. Therefore, the MNOP of 215.46 kPa (31.25 psia) is used in further analyses. To comply with TS-R-1, Paragraph 619, an analysis is shown in Appendix 4.5.2 using an upstream pressure of 310.47 kPa (45.03 psia) and a downstream pressure of 0 kPa (0 psia). This provides the maximum pressure differential of 215.46 kPa + 95 kPa (31.250 + 13.78 psia). The analysis in Appendix 4.5.2 for air transport shows that the leaktight criteria obtained on test units is substantially below the calculated results for air transport. Therefore, the requirements of 10 CFR Part 71.51(a)(1) are satisfied. The containment vessel has also been evaluated at the maximum pressure differential shown in Table 9 of Appendix 3.5.1. The margin of safety for each component is significantly large enough to conclude that this maximum pressure differential determined for air transport does not degrade the structural integrity of the containment vessel (Table 2.21a).

2.6.1 Heat

Requirement. 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 vessel 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 3.5.1 and discussed in Sects. 2.6.1.1 and 3.3.2. As noted in these sections, the internal pressure varies with temperature. Based on the isotopic determination of the proposed contents, a conservative maximum decay heat of 5 W is used for the maximum internal heat load in evaluating the package for NCT (Sect. 3.1.2). The maximum calculated and rounded internal absolute pressure in the containment vessel with insolation and using the bounding case parameters is 215.46 kPa (31.25 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 215.46 kPa (31.25 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 top surface of the containment vessel, and on the containment vessel near the O-ring sealing surfaces are 118.86°C (245.94°F), 91.92°C (197.46°F), and 91.87°C (197.36°F), respectively (Sect. 3.3.1). Nevertheless, these temperatures are within the service limits of all packaging components, including

the O-rings. The normal service temperature range of the EPDM O-rings used in the containment vessel is −40 to 150°C (−40 to 302°F) [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 vessel is sealed; thus, the internal pressure will change with temperature. Maximum calculated pressures at various temperatures (Sect. 3.3.1) 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 adjusted temperature of 93.33°C (200.00°F).

The Kaolite 1600 insulation and Cat 277-4 material is poured and cast in place during the fabrication of the drum weldment (Drawing M2E801580A002, Appendix 1.3.7). Although some contraction of these materials may occur during curing, it is assumed for analysis purposes that a zero gap will exist between the Kaolite and the bounding drum and mid liner, and a zero gap exists between the Cat 277-4 and the two liners. Due to differences in 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 DAC-PKG-801940-A002. A maximum stress intensity of 6.604×10^4 kPa (9579 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 stress intensity of 6.550×10^2 kPa (95.0 psi) and 9.329×10^2 kPa (135.3 psi) occurs in the Cat 277-4 and Kaolite 1600 materials, respectively. Based on tabulated data and curves presented in Y/DW-1987 and the curves presented in Y/DW-1890 at 38°C (100°F), these compressive stresses are well below the failure limit of ~4.826×10^3 kPa (700 psi) and 5.171×10^3 kPa (750 psi) for the Cat 277-4 and Kaolite 1600 materials, respectively. Therefore, these thermally induced stresses will not reduce the effectiveness of the drum assembly.

The effects of differences in coefficient of thermal expansion between the HEU contents and their associated convenience cans, polyethylene or Teflon FEP bottles are not addressed. No credit is taken for the ability of the convenience can or bottle to maintain its 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, polyethylene bagging, or bottle is taken. Based on assembly clearances and the flexibility of the polyethylene or Teflon FEP bottles, no radial or vertical interferences will develop during NCT. Based on assembly clearances and insignificant differences in the coefficient of thermal expansion between the stainless-steel, tin-plated carbon steel, aluminum, 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 vessel as the temperature varies slowly over the operating range (Table 2.20). Stress levels imposed on the package during NCT are insignificant, as shown in Tables 2.21, 2.21a, and 2.22. These tabulated stresses were determined by multiplying the stress at the design conditions (DAC-M900000-0003 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 vessel components are well below the ASME 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, 2.21a, and 2.22. The hot environment, cold environment, reduced 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 the Selection and Use 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, 2.21a, 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, 2.21a, and 2.22, the containment vessel stresses during NCT are insignificant. Even at the maximum test temperature and internal pressure (Sect. 3.4.3), the stresses in the containment boundaries were insignificant when compared with the allowable stress intensities shown in Tables 2.4 and 2.5. Corresponding calculated stress regions are shown in Fig. 2.1. Thermal expansion or contraction issues are addressed in Sects. 2.6.1.2 and 2.6.2.

2.6.2 Cold

Requirement. An ambient temperature of −40°C (−40°F) in still air and shade, as required by 10 CFR 71.71(c)(2).

Analysis. The drum is fabricated from Type 304 stainless-steel sheet (Table 2.7). As discussed in Sect. 2.6, stainless steel is excellent for low-temperature service, particularly regarding tensile and impact strength. The thermal insulation (Kaolite) is a lightweight noncombustible cast refractory made from portland cement and vermiculite. The only moisture available for freezing at −40°C (−40°F) would be moisture that had not been removed during the curing and cool-down phase of fabrication. Because there will be no free water present for freezing and the insulation is a bonded mass of random fibers and cement, the properties of the insulation will not change appreciably. The matrix may become less flexible when subjected to the cold temperature, but the inner liner will remain in the position in which it was placed at the time of fabrication. The Kaolite 1600 insulation and Cat 277-4 materials are poured and cast in place during the fabrication of the drum weldment (Drawing M2E801580A002, Appendix 1.3.7). Although some contraction of these material may occur during curing, it is assumed for analysis purposes that a zero gap will exist between the Kaolite and the bounding drum and mid liner and a zero gap exists between the Cat 277-4 and the two liners. Due to differences in the coefficient of thermal expansion, some radial and axial interference is expected due to contraction of the outer drum and inner liners. These radial and axial interferences and induced stresses are calculated in DAC-PKG-801940-A002. A maximum stress intensity of 3.855×10^4 kPa (5591.9 psi) was calculated for the inner liners. This stress value is well below the allowable yield strength of 1.724×10^5 kPa (25000 psi) at −40°C (−40°F). A maximum stress intensity of 164.8 kPa (23.9 psi) and 163.4 kPa (23.7 psi) occurs in the Cat 277-4 and Kaolite 1600 materials, respectively. Based on tabulated data

and curves presented in Y/DW-1987 and the curves presented Y/DW-1972 at −40°C (−40°F), these compressive stresses are well below the failure limit of ~6.895×10^3 kPa (1000 psi) and 5.308×10^3 kPa (770 psi) for the Cat 277-4 and Kaolite 1600 materials, respectively. Therefore, these thermally induced stresses will not reduce the effectiveness of the drum assembly.

Table 2.21. ES-3100 containment vessel evaluation for both hot and cold conditions [a]

Stress locations shown in Fig. 2.1	Hot conditions [10 CFR 71.71(c)(1)] containment vessel stress @ 114.10 kPa (16.55 psi) gauge		Cold conditions [10 CFR 71(c)(2)] containment vessel stress @ −24.61 kPa (−3.57 psi) gauge		Allowable pressure, stress, or shear capacity
	kPa (psi) or kg (lb)	M.S. [b]	kPa (psi) or kg (lb)	M.S. [b]	kPa (psi) or kg (lb)
Top flat portion of sealing lid (center of lid)	1.862×10^3 (270)	107	4.015×10^2 (58)	498	1.999×10^5 (29,000) [c]
Closure nut ring (away from threaded portion)	5.576×10^3 (809)	26	1.902×10^4 (2759) [d]	7.6	1.441×10^5 (20,900)
Top flat head (sealing surface region)	4.724×10^3 (685)	42	7.088×10^3 (1028) [d]	28	1.999×10^5 (29,000) [c]
Cylindrical section (middle) internal pressure	3.176×10^3 (461)	35			1.120×10^5 (16,250) [e]
Cylindrical section (middle) external pressure			2.461×10^1 (3.57)	31	7.584×10^2 (110) [f]
Cylindrical section (shell to flange interface)	4.398×10^3 (638)	38	9.483×10^2 (138)	177	1.682×10^5 (24,400) [c]
Cylindrical section (shell to bottom interface)	9.548×10^3 (1385)	18	2.060×10^3 (299)	82	1.682×10^5 (24,400) [c]
Body flange threads load, kg (lb)	9.072×10^2 (2000) [d]	29	9.072×10^2 (2000) [d]	29	2.608×10^4 (57,500) [g]
Body flange thread region (under cut region)	2.839×10^4 (4117) [d]	5.9	2.839×10^4 (4117) [d]	5.9	1.682×10^5 (24,400) [c]
Flat bottom head (center)	7.982×10^3 (1158)	21	1.722×10^3 (250)	98	1.682×10^5 (24,400) [c]
Closure nut thread load, kg (lb)	9.072×10^2 (2000) [d]	37	9.072×10^2 (2000) [d]	37	3.353×10^4 (73,911) [g]

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment vessel components (DAC-M900000-0003). Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure plus the contribution from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas is dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload. External pressure component is ignored.

[e] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.

[f] Allowable external pressure [kPa (psi)].

[g] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 cm^2 (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

Table 2.21a. ES-3100 containment vessel evaluation for internal pressure developed during air transport in accordance with TS-R-1 Paragraph 618 [a]

Stress locations shown in Fig. 2.1	Containment vessel stress @ 293.43 kPa (42.558 psi) gauge		Allowable pressure, stress, or shear capacity
	kPa (psi) or kg (lb)	M.S. [b]	kPa (psi) or kg (lb)
Top flat portion of sealing lid (center of lid)	4.787×10^3 (694.35)	23.9	1.999×10^5 (29,000) [c]
Closure nut ring (away from threaded portion)	1.434×10^4 (2079.68)	10.0	1.441×10^5 (20,900)
Top flat head (sealing surface region)	1.215×10^4 (1761.86)	16.5	1.999×10^5 (29,000) [c]
Cylindrical section (middle) internal pressure	8.167×10^3 (1184.50)	13.7	1.120×10^5 (16,250) [e]
Cylindrical section (shell to flange interface)	1.131×10^4 (1640.27)	14.9	1.682×10^5 (24,400) [c]
Cylindrical section (shell to bottom interface)	2.455×10^4 (3561.04)	6.9	1.682×10^5 (24,400) [c]
Body flange threads load, kg (lb)	1.566×10^4 (2270.81) [d]	25.3	2.608×10^4 (57,500) [f]
Body flange thread region (under cut region)	3.383×10^4 (4906.11) [d]	5.0	1.682×10^5 (24,400) [c]
Flat bottom head (center)	2.053×10^4 (2976.96)	8.2	1.682×10^5 (24,400) [c]
Closure nut thread load, kg (lb)	1.566×10^4 (2270.81) [d]	32.5	3.353×10^4 (73,911) [f]

[a] Calculated stresses were determined by multiplying the stress at the design conditions (Table 2.6) by a factor equal to the ratio of operating pressures to design pressures (independent of pressure direction) plus contributions from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas are dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload.

[e] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.

[f] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 cm^2 (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

Table 2.22. NCT ES-3100 containment vessel stress compared to the allowable stress at reduced and increased external pressures [a]

Stress locations shown in Fig. 2.1	Reduced external pressure [10 CFR 71.71(c)(3)] containment boundary stress @ 190.46 kPa (27.63 psi) gauge		Increased external pressure [10 CFR 71.71(c)(4)] containment boundary stress @ −63.26 kPa (−9.18 psi) gauge		Allowable pressure, stress, or shear capacity
	kPa (psi) or kg (lb)	M.S. [b]	kPa (psi) or kg (lb)	M.S. [b]	kPa (psi) or kg (lb)
Top flat portion of sealing lid (center of lid)	3.108×10^3 (451)	64	1.033×10^3 (150)	194	1.999×10^5 (29,000) [c]
Closure nut ring (away from threaded region)	9.309×10^3 (1350)	15	1.902×10^4 (2759) [d]	7.6	1.441×10^5 (20,900)
Top flat head (sealing surface region)	7.887×10^3 (1144)	25	7.088×10^3 (1028) [d]	28	1.999×10^5 (29,000) [c]
Cylindrical section (middle) internal pressure	5.302×10^3 (769)	21			1.120×10^5 (16,250) [e]
Cylindrical section (middle) external pressure			6.329×10^1 (9.18)	12	7.584×10^2 (110) [f]
Cylindrical section (shell-to-flange interface)	7.342×10^3 (1065)	23	2.438×10^3 (354)	69	1.682×10^5 (24,400) [c]
Cylindrical section (shell-to-bottom interface)	1.594×10^4 (2312)	11	5.297×10^3 (768)	32	1.682×10^5 (24,400) [c]
Body flange threads load, kg (lb)	9.072×10^2 (2000) [d]	29	9.072×10^2 (2000) [d]	29	2.608×10^4 (57,500) [g]
Body flange thread region (under cut region)	2.839×10^4 (4117) [d]	5.9	2.839×10^4 (4117) [d]	5.9	1.682×10^5 (24,400) [c]
Flat bottom head (center)	1.333×10^4 (1933)	13	4.428×10^3 (642)	38	1.682×10^5 (24,400) [c]
Closure nut thread load, kg (lb)	9.072×10^2 (2000) [d]	37	9.072×10^2 (2000) [d]	37	3.353×10^4 (73,911) [g]

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment vessel components (DAC-M900000-0003). Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure plus the contribution from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas is dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload. External pressure component is ignored.

[e] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.

[f] Allowable external pressure [kPa (psi)].

[g] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 cm^2 (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

The containment vessel is fabricated from Type 304L stainless steel, which is suitable for low-temperature service, particularly regarding impact resistance. This material does not show a transition from ductile to brittle failure at this temperature [−40°C (−40°F)]. The ASME Code, Sect. III, Subsection NB-2311, exempts impact testing of Type 304L stainless steels. The Izod impact strength for Type 304 stainless steel is 149.14 N·m (110 ft-lb) from 21.11 to −195.5°C (70 to −320°F). The tensile strength increases from ~4.826×10^5 to 1.696×10^6 kPa (70,000 to 246,000 psi) between 21.11 and −195.5°C (70 and −320°F), and the yield strength increases ~10% over the same range. NRC Regulatory Guide 7.6, Part B, states, "these designs were made of austenitic stainless steel which is ductile even at low temperatures. Thus, this guide does not consider brittle fracture." The drum, inner liner, top plug, and containment vessel are made from austenitic stainless steel. Similarly, the containment vessel closure nut material is a galling and wear resistant austenitic stainless steel. Therefore, brittle fracture of these structural materials at −40°C (−40°F) is not possible.

The specified O-rings used in the containment vessel have a continuous service temperature range of −40 to 150°C (−40 to 302°F) [Table 2.15]. The low temperature extreme has been verified by compliance testing of TU-2 (Sect. 2.7.1.2). TU-2 was pre-chilled to a nominal temperature of −40°C (−40°F). This was accomplished by placing the units in an environmental chamber in Building 5800 at ORNL and initially setting the chamber control to −56.7°C (−70°F) for 24 h. After this initial period, the control on the environmental chamber was set to −42.8°C (−45°F) for at least 48 h. Prior to the initiation of structural testing of this unit, it was removed from the environmental chamber and placed in an insulated box and transported to NTRC for testing.

As previously noted, the containment vessels will be assembled for shipment in a temperature environment of ~25°C (77°F). If the package should be exposed to −40°C (−40°F) for an extended period, all components will equalize near this low temperature. The absolute internal pressure inside the containment vessel would decrease to a pressure of 76.74 kPa (11.13 psi), assuming no decay heating (Table 2.20). Therefore, the pressure differential across the containment vessel at −40°C (−40°F) is −24.61 kPa (−3.57 psia) {[76.739 − 101.35 kPa] (11.13 − 14.7 psia)}. Due to similarities between the coefficient of thermal expansion for Type 304 or 304L stainless steel and the containment vessel closure nut material (ARMCO NITRONIC, ASME SA-479), the compression of the O-rings does not change appreciably during the temperature excursion from 25°C (77°F) to −40°C (−40°F). The calculated stresses shown in Tables 2.21 and 2.21a were determined by multiplying the stress at the design conditions (DAC-M900000-0003 and Table 2.6) by a factor equal to the ratio of operating pressure to design pressure and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Sect. 2.6.1.4, all stresses in the containment vessel components are well below the ASME Code allowable stress intensity limits. As demonstrated by the information presented above, the packaging is acceptable for NCT at −40°C (−40°F).

2.6.3 Reduced External Pressure

Requirement. An absolute external pressure of 25 kPa (3.5 psi) is required by 10 CFR 71.71(c)(3).

Analysis. Reducing the absolute external pressure from ambient pressure to 25 kPa (3.5 psi) will have no effect on the drum assembly because the plastic plugs and aluminum tape covering the ventilation holes for the Cat 277-4 will allow the internal pressure of the drum assembly to equalize. This reduced pressure and a maximum internal pressure produces the maximum pressure differential across the containment vessel of 190.46 kPa (27.63 psi) [215.46 − 25]. The containment vessel is designed and fabricated in accordance with Sects. III and IX of the ASME Code for an internal pressure differential of 699.82 kPa (101.5 psi) as shown in DAC-M900000-0003. A summary of the resulting stress intensities at various locations identified in Fig. 2.1 on the containment vessel in comparison with the ASME Code allowable limits for this condition is shown in Table 2.22. These tabulated stresses were determined by

multiplying the stress at the design conditions (DAC-M900000-0003 and Table 2.6) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Table 2.22, all stresses in the containment vessel components are well below the ASME Code allowable stress intensity limits. Therefore, the ES-3100 packaging is acceptable for NCT at an absolute external pressure of 25 kPa (3.5 psi).

2.6.4 Increased External Pressure

Requirement. An absolute external pressure of 140 kPa (20 psi) is required by 10 CFR 71.71(c)(4).

Analysis. Increasing the absolute external pressure from ambient pressure to 140 kPa (20 psi) would have no effect on the drum assembly because the plastic plugs and aluminum tape covering the ventilation holes for the Cat 277-4 will allow the internal pressure of the drum assembly to equalize. At this increased external pressure, the maximum pressure differential across the containment vessel would be −63.26 kPa (76.74 − 140 kPa) [−9.18 psi], assuming the vessel's absolute pressure and temperature to be 76.74 kPa (11.13 psi) and −40°C (−40°F), respectively. Each containment vessel is designed and fabricated in accordance with Sects. III and IX of the ASME Code for a minimum external pressure of 150 kPa (21.7 psi) gauge. A comparison of the resulting stress intensities at various locations on the containment vessel (Fig. 2.1) with the ASME Code allowable limits for this condition is shown in Table 2.22. These tabulated stresses were determined by multiplying the stress at the design conditions (DAC-M900000-0003 and Table 2.6) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Table 2.22, all stresses in the containment vessel components are well below the ASME Code allowable stress intensity limits. Therefore, the ES-3100 packaging is acceptable for NCT at an external absolute pressure of 140 kPa (20 psi).

2.6.5 Vibration

Requirement. Vibration normally incident to transportation is required by 10 CFR 71.71(c)(5).

Analysis. Vibration testing on a prototypical ES-3100 package (TU-4) was conducted in accordance with the ES-3100 test plan and documented in the test report (ORNL/NTRC-013). Testing was conducted with the package restrained as shown in Fig. 2.3. The containment vessel was assembled with the mock-up content weighing 49.90 kg (110 lb). The total weight of the test unit was 201.8 kg (445 lb). The unit was subjected to an endurance test with random vibrations modeled after the power spectral density plot for the SGT vibration envelope in the vertical axis (Cap 2002). At this level of vibration intensity, the test compares with MIL-STD-810F. MIL-STD-810F is a standard random vibration test for basic transportation vibrations generated by a large truck or tractor-trailer combination. MIL-STD-810F defines 60 min of testing as equal to 1609 km (1000 miles) of common carrier transportation. Assuming that the two random vibration tests are similar in intensity, TU-4 had ~6436 km (4000 miles) of simulated random vibration testing. Based on a nominal shipping distance of 3218 km (2000 miles), TU-4 was subjected to a test that was approximately two times more severe than that required by 10 CFR 71.71(c)(5). As shown by the following paragraphs, containment, shielding effectiveness, and subcriticality were maintained even when the package was subjected to such an arduous environment.

The test was run at ~22.8°C (73°F) rather than at the high or low temperatures specified for NCT. This was reasonable because the thermal coefficients of expansion of the flange and closure nut materials are very close. Therefore, the temperature extremes would not have a significant effect on the closure tightness.



Note: MD-1 test unit removed during actual testing.

Fig. 2.3. ES-3100 vibration testing arrangement.

Summarizing 10 CFR 71.43(f), the tests and conditions of NCT shall not substantially reduce the effectiveness of the packaging to withstand HAC sequential testing. The effectiveness of the ES-3100 to withstand HAC sequential testing is not diminished through application of the tests and conditions stipulated in 10 CFR 71.71. The justification for this statement is provided by physical testing of both the ES-2M (GAB1296-2) and ES-3100 (ORNL/NTRC-013) test packages. Due to the similarities in design, fabrication, and construction materials of the ES-2M and the ES-3100 packages, the physical characteristics of the Kaolite 1600 will hold true for both designs. The integrity of the Kaolite 1600 is not significantly affected by the NCT vibration and 1.2-m drop tests. Prior to testing the ES-2M design, each test unit was radiographed to determine the integrity of the Kaolite 1600 impact and insulation material. Following casting of the material inside the drum, some three-dimensional curving cracks were seen in some packages near the thinner top sections from the bottom of the liner to the bottom drum edge. After vibration testing, radiography of the ES-2M TU-4 showed that the lower half of the impact limiter was broken into small pieces. In order to evaluate these findings, TU-4 was reassembled and subjected to HAC sequential testing. After vibration and impact testing, many three-dimensional curving cracks were seen around the impact areas, and the inner liner was visibly deformed. Nevertheless, TU-4 maintained the adequate spacing required for shielding effectiveness and subcriticality. Temperatures at the containment boundary were also similar to other packages not subjected to vibration testing prior to HAC

testing. No inleakage of water was recorded following immersion. Additionally, TU-4 of the ES-3100 test series was subjected to tests and conditions stipulated in 10 CFR 71.71(c)(5) through (c)(10), excluding (c)(8). Following completion of both the NCT and HAC tests, the containment vessel was removed, and a full-body helium leak test was conducted to the leaktight criterion ($\leq 2 \times 10^{-7}$ cm^3/s) in accordance with ANSI N14.5-1997.

Following compliance testing of the ES-3100 shipping package, minor changes were incorporated into the proposed design as described in Sect. 2.7.1.5. During the vibration test, the shipping package is restrained from movement in the vertical direction with a tie-down arrangement similar to that used on an SGT for a single package. Based on the acceleration spectral density presented in the letter from J. S. Cap to G. W. Crowder (Cap 2002), the largest contributor to shipping package motion is in the vertical direction. Since the containment vessel and contents are not restrained within the inner liner cavity, the containment vessel is free to bounce up and down. In the vertical direction, the top plug and the bottom of the inner liner restrict the movement of this vessel. Because the inner liner contour has not changed with respect to the containment vessel, and there are clearances between the containment vessel flange and the inner liner in the vertical direction, the cast neutron poison and inner liner are not directly impacted by the movement of the containment vessel. Therefore, changes in the neutron poison and minor radial dimension changes in the mid liner will not affect the outcome of vibration testing. Based on the success of the previously tested units and the fact that these proposed changes will have little or no effect on testing, vibration normally incident to transport does not reduce the effectiveness of the packaging during HAC testing. Thus, the requirements of 10 CFR 71.43(f) are satisfied.

Procedures will be followed to ensure that the packaging is assembled as specified (Sect. 7). The drum, lid, and fasteners are refurbished as required before each use. The ⅝-in.–diam flange nuts on the drum are torqued to 40.67 N·m (30 ft-lb) nominal. The closure nut on the containment vessel is torqued to 162.7 N·m (120 ft-lb) nominal. The package is acceptable for vibration normally incident to transport in an SGT.

2.6.6 Water Spray

Requirement. A water spray that simulates exposure to rainfall of ~5.08 cm (2 in.) per hour for at least 1 h is required by 10 CFR 71.71(c)(6).

Analysis. A water spray of 5.08 cm (2 in.) per hour was directed from above and around the periphery of the ES-3100 TU-4 for a minimum of 1 h as shown in Fig. 2.4. The drum had four plastic plug-sealed ventilation holes near the top that prevent water from entering the insulation cavity. Aluminum duct tape covering the installation holes in the mid liner prevents water from entering the neutron poison cavity. There was evidence of water leakage into the volume between the containment vessel and the inner liner at the conclusion of the test. Water entered this cavity through the holes provided in the lid for the TID lugs, but none penetrated the containment boundary. The criticality analysis shown in Sect. 6 was conducted with moderation by water to the most reactive credible extent and close full reflection of the containment system by water on all sides. Because the package remained subcritical under these conditions, the ES-3100 package is acceptable for use under the water spray conditions of NCT.



Fig. 2.4. Water spray test arrangement for TU-4.

2.6.7 Free Drop

Requirement. A free drop of 1 m (4 ft) onto a flat, essentially unyielding, horizontal surface in a position for which maximum damage is expected is required by 10 CFR 71.71(c)(10). This test shall be made between 1½ and 2½ h after the conclusion of the water spray test (Sect. 2.6.6).

Analysis. The ES-3100 test package, TU-4, previously sprayed with water (Sect. 2.6.6) with a measured gross weight of 201.85 kg (445 lb) and containing a content weight of 49.90 kg (110 lb), was tested in accordance with 10 CFR 71.71(c)(7). The temperature and pressure at the time of the drop test was 22.8°C (73°F) and ~101.35 kPa (14.70 psi), respectively. As discussed in Sect. 2.6, the response of the test package would not have been significantly different if it had been tested at the extremes of the temperature range dictated by 10 CFR 71.71(b) with the containment vessel at the maximum normal operating pressure.

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

TU-4 was dropped from 1.2 m (4 ft) in a vertical position, with the drum's top initially striking the unyielding surface (Fig. 2.5). This attitude was assumed to be the most vulnerable orientation for producing damage to the sealing surfaces of the containment vessel and for introducing buckling into the cylindrical portion of the containment vessel body. The long axis of the drum was 0° from vertical. The test package made a free fall, with initial contact on the drum's lid. Damage consisted of shortening the drum height from 110.81 cm (43⅝ in.) to 110.49 cm (43½ in.) There were no breaks in the drum assembly. Additional details and sketches can be obtained from the test report (ORNL/NTRC-013). Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, the drop test damage would be nearly identical had this test been conducted on the proposed configuration using the Cat 277-4 neutron absorber. On this basis, the ES-3100 package meets the requirements of 10 CFR 71.71(c)(7).

In addition to the tests conducted on TU-4, all test units (except TU-6) were initially subjected to a free drop of 1.2 m (4 ft) onto a flat, essentially unyielding horizontal surface. As shown in Table 2.18, the orientations for these drops were two drops bottom to lid slapdown with the long axis of the drum ~12° from parallel to the drop pad; one drop with the long axis of the test unit parallel to the drop pad; two drops with the center of gravity drop over the drum/lid interface with the long axis of the drop rotated ~24.6° from perpendicular to the drop pad; and one with the long axis of the drum perpendicular to the drop pad. Package description, damage from testing, and drop orientation concerns are discussed in Sect. 2.7.1 for each test unit. Following the 1.2-m (4-ft) drop, each of these test units was subjected to the full HAC sequential test battery. The robustness of the ES-3100 containment vessel was demonstrated through whole boundary helium leak testing to $\leq 2.0 \times 10^{-7}$ cm^3/s (leaktight). This helium leak test eclipses the required criteria for both NCT and HAC based on the bounding case contents. Visual inspection of the containment boundaries showed no distortion or deformation from testing. Therefore, based on the various drop orientations, the severity of the HAC test sequence, and the testing conducted on TU-4, the ES-3100 shipping package has been shown to meet the requirements of 10 CFR 71.43, 71.51(a)(1), and 71.71(c)(7).

2.6.8 Corner Drop

Requirement. 10 CFR 71.71(c)(8) requires a free drop onto each corner of the package in succession, or in the case of a cylindrical package, onto each quarter of each rim, from a height of 0.3 m (1 ft) onto a flat, essentially unyielding, horizontal surface. This test applies only to fiberboard, wood, or fissile material rectangular packages not exceeding 50 kg (110 lb) and fiberboard, wood, or fissile material cylindrical packages not exceeding 100 kg (220 lb).

Analysis. This test is not applicable because the range of package weights for the ES-3100 [146.88 kg (323.79 lb) to 187.81 kg (414.05 lb)] exceeds the weight restrictions defined in the preceding paragraph for fissile material cylindrical packages.

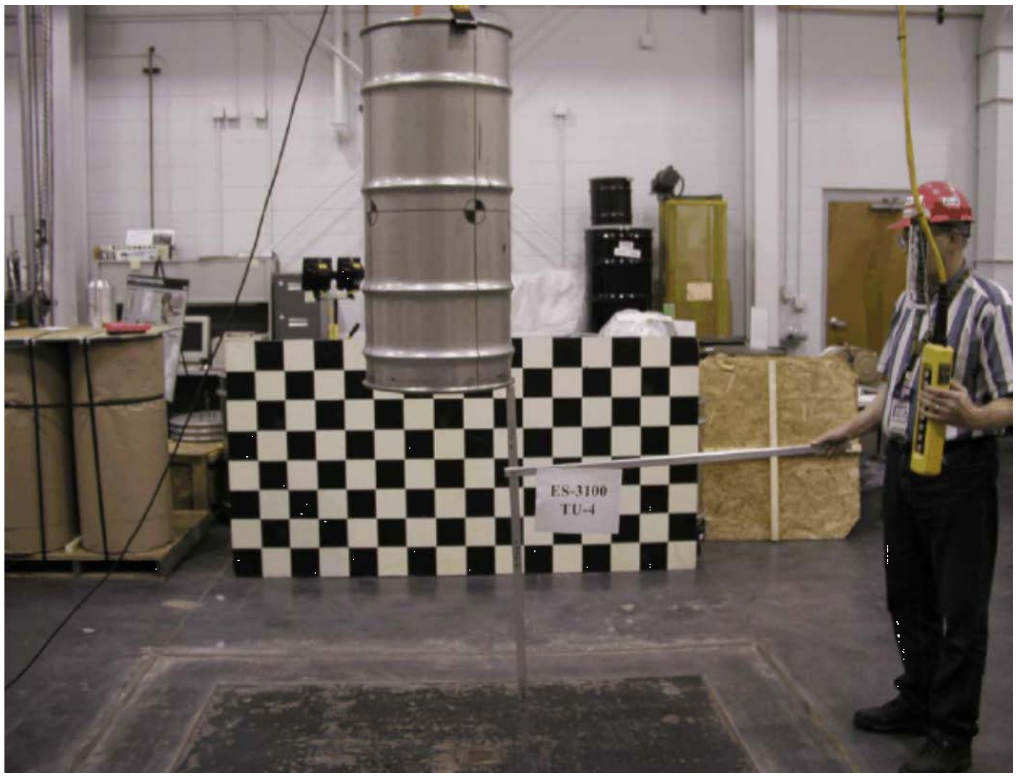


Fig. 2.5. NCT free drop test on TU-4.

2.6.9 Compression

Requirement. Title 10 CFR 71.71(c)(9) requires that packages weighing up to 5000 kg (11,000 lb) must be subjected for a period of 24 h to a compressive load applied uniformly to the top and bottom of the package in the position in which the package would normally be transported. The compressive load must be the greater of the following:

1. the equivalent of five times the weight of the package or

2. the equivalent of 13 kPa (2.0 psi) multiplied by the vertically projected area of the package.

Analysis. The proposed maximum weight of the ES-3100 shipping package is calculated to be 187.81 kg (414.05 lb) [Table 2.8]. As shown on Drawing M2E801580A010 (Appendix 1.3.7), the data plate states that the maximum gross weight of the ES-3100 shipping package is 190.51 kg (420 lb). In accordance with Item 1 above, the minimum compressive load would be 5 × 190.51 kg or 952.55 kg (2100 lb). The vertically projected area of the package is 1891 cm^2 (293.16 $in.^2$) or the area of the lid weldment. Based on Item 2 above, the minimum compressive load would be 13 kPa × 1891 cm^2 or 250.72 kg (552.75 lb). Therefore, the approach stipulated in Item 1 above represents the greatest compressive load for this configuration. A conservative 1043 kg (2300 lb) compressive load was uniformly applied to the top and bottom of TU-4 for at least 24 h (Fig. 2.6). The test package had been sprayed with water as noted in Sect. 2.6.6. No change in height or diameter of the test unit resulted from the test.

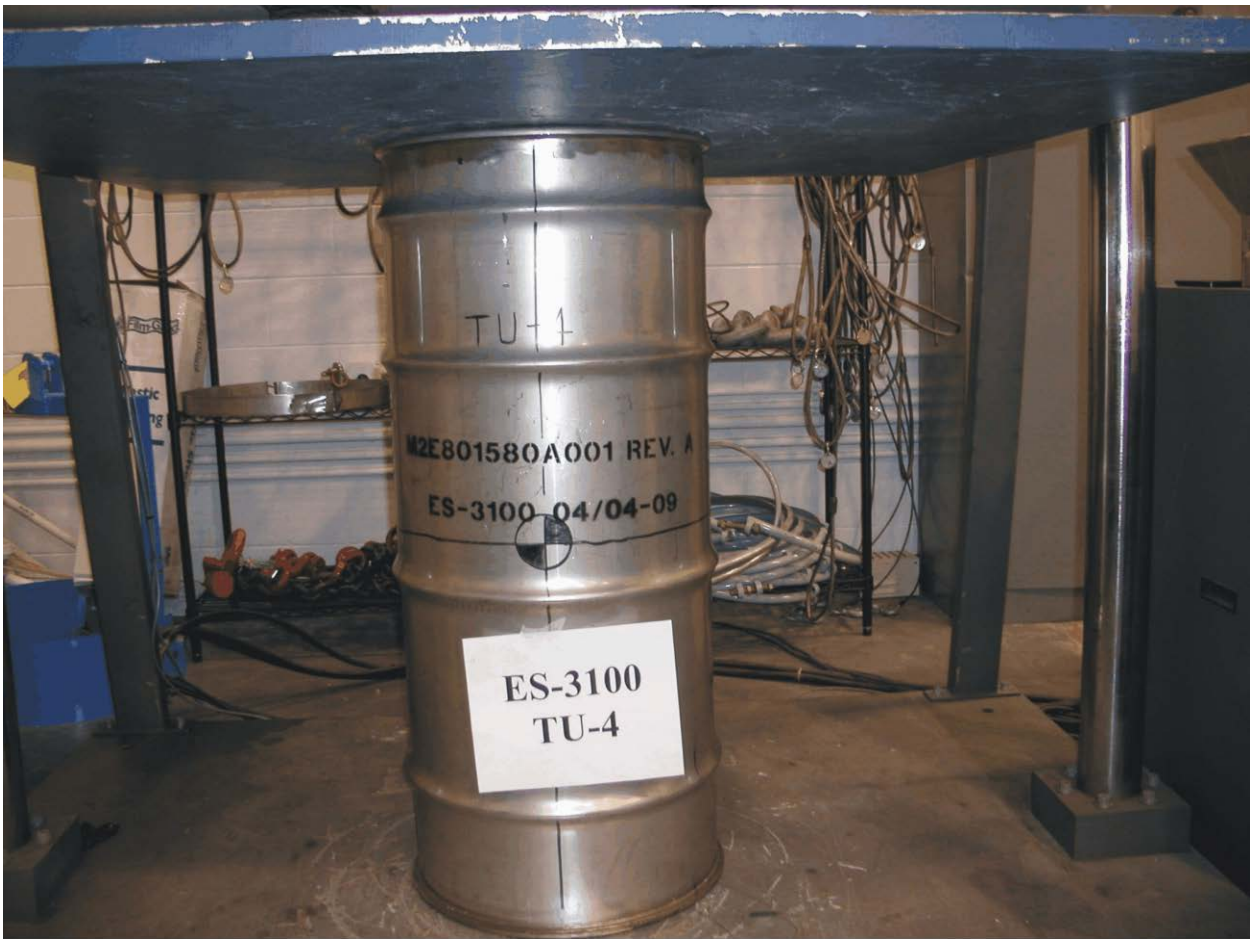


Fig. 2.6. Compression test on TU-4.

Due to the design of the ES-3100 drum lid, the applied compressive load was distributed equally around the lid and supported primarily through the outer drum contour and Kaolite 1600 substrate. Little or no load is transferred to the neutron poison (BoroBond4 in TU-4) and internal liners. Therefore, the changes in the design of the liners and neutron poison proposed for this shipping package should not impact the outcome resulting from compression testing. Based on the results of compliance testing of TU-4 and the insignificant changes in the design, the ES-3100 package meets the requirements of 10 CFR 71.71(c)(9).

2.6.10 Penetration

Requirement. Impact of the hemispherical end of a vertical steel cylinder of 3.2-cm (1.25-in.) diam and 6-kg (13-lb) mass dropped from a height of 1 m (40 in.) onto the exposed package surface that is expected to be most vulnerable to puncture is required by 10 CFR 71.71(c)(10). The long axis of the cylinder must be perpendicular to the package surface.

Analysis. A 6-kg (13-lb) steel cylinder was dropped from 1 m (40 in.) onto the surface of TU-4, which was previously subjected to water spray, free drop, vibration and compression tests. The penetration bar impacted the side of the drum at the welded seam near the package's center of gravity. The bar did not penetrate the drum, but an indentation 0.64-cm (0.25-in.) deep was recorded at the drum seam weld as shown in Fig. 2.7. The magnitude of this indentation is insignificant. Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, the magnitude of indentation would be nearly identical had this test been conducted on the proposed configuration using the Cat 277-4 neutron absorber. On this basis, the ES-3100 package meets the requirements of 10 CFR 71(c)(10).



Fig. 2.7. Penetration test damage on TU-4.

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

This section demonstrates compliance with 10 CFR 71.73, "Hypothetical Accident Conditions." It shows that the package will experience no loss in shielding effectiveness or spacing and no release of radioactive content or leakage of water into the containment vessel during HAC. A summary of the tests and analyses conducted on the ES-3100 configuration is shown in Table 2.23.

Table 2.23. Test and analysis summary for the ES-3100 package [a]

Container	NCT water spray, compression, penetration, vibration	1.2-m (4-ft) drop	9-m (30-ft) drop and crush test				1.2-m (4-ft) puncture drop	Preheat >38°C (100°F)	HAC thermal burn test	O-ring cavity leak check (operational)	Full-body helium leak test [b]	0.9-m (3-ft) immer. test	15-m (50-ft) immer. test
			Top drop	Center of gravity over lid corner	Bottom to lid slapdown	Side drop							
TU-1		1—YES			12° 2—YES		3—YES [c]	4—YES	5—YES	6−YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES 1.6×10^{-7} cm^3/s	8—YES	
TU-2		1—YES				2—YES	3—YES	4—YES	5—YES	6−YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES Pulsing between 1.0×10^{-9} to 1.4×10^{-6} cm^3/s	8—YES	
TU-3		1—YES		24.6° 2—YES			3—YES	4—YES	5—YES	6−YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES 1.0×10^{-7} cm^3/s	8—YES	
TU-4	YES	1—YES	2—YES				3—YES	4—YES	5—YES	6−YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES 2.0×10^{-7} cm^3/s	8—YES	
TU-5		1—YES			12° 2—YES		3—YES	4—YES	5—YES	6−YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES 3.1×10^{-8} cm^3/s	8—YES	
TU-6										1−YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s			2—YES
Impact analysis		YES	YES	YES	YES	YES							
Thermal analysis	YES [d]							YES	YES [d]				

[a] Numbering refers to sequence of activities.
[b] Full-body helium leak test conducted following HAC testing. Leakage value recorded after 20 min of the test period.
[c] TU-1 was puncture tested in four different orientations.
[d] Thermal analysis was conducted to determine time for cooling to −40°C and to evaluate the application of decay heating and insolation during the cool-down phase.

Title 10 CFR 71.51 requires that the ES-3100 package satisfy the standards under HAC specified in 10 CFR 71.73. For the tests specified in 10 CFR 71.73, six test packages were subjected to the five sequential tests: free drop, crush, puncture, thermal, and immersion. The configuration for TU-1 through TU-4 used full-scale shipping packages with steel mock-ups similar to the maximum contents to be shipped in the ES-3100 configuration. TU-5, also a full-scale shipping package, was dropped with a mock-up of the lightest component proposed for shipping at that time. All test units were first subjected to the NCT free drop from 1.2 m (4 ft). In addition to the 1.2-m (4-ft) drop, TU-4 was also subjected to the full battery of tests in accordance with applicable paragraphs of 10 CFR 71.71(c)(5) through (c)(10) except (c)(8). These preliminary tests were conducted to provide evidence that the ES-3100's ability to withstand HAC testing was not degraded through NCT testing. Demonstration of the ES-3100 package's ability to satisfy the requirements of HAC is provided in the following sections. A summary of the test results is provided in each area of Sect. 2.7; details are documented in the test report (ORNL/NTRC-013).

Although physical testing of the ES-3100 containers was performed generally at or near room temperature except for TU-2, the effectiveness of the Kaolite insulating material at various temperature extremes was examined through the use of laboratory testing and structural analysis of a similar package, the ES-2LM (DAC-EA-900000-A002). For low-temperature service, Kaolite specimens were tested at −28.89 and −40°C (−20 and −40°F). These tests showed little change in the response of the material as compared to room temperature. Furthermore, structural analyses for bounding soft and stiff material cases were run. The Kaolite 1600 data used in these bounding analyses were from laboratory experiments that used a heavily cured sample (stiff) and a sample to which borax had been added (soft) [Y/DW-1661]. Following the production run for the ES-2100 and DPP-2 shipping containers, new casting specimens were available for compression testing. In order to reduce the total cost of Kaolite testing, specimens were tested to approximately −40°C (−40°F) to cover both the cold conditions stipulated in 10 CFR 71.71(c)(2) and the −29°C (−20°F) temperature stipulated in 10 CFR 71.71(b)(1) and at 38°C (100°F). The results of Kaolite specimen testing are documented in Y/DW-1890 and Y/DW-1972. Upon further review of the data, the new test data was somewhat stiffer in the cold/high-density specimens than the data previously used in Y/DW-1972. Therefore, in order to encompass the extremes of all existing data, additional drop simulation sequences using the new bounding curves have been conducted on the ES-3100 package as documented in DAC-EA-801699-A001 and DAC-EA-801699-A002. In addition to the analytical effort, TU-2 was pre-chilled to a nominal temperature of −40°C (−40°F). This was accomplished by placing the unit in an environmental chamber in Building 5800 at ORNL and initially setting the chamber control to −56.7°C (−70°F) for 24 h. After this initial period, the control on the environmental chamber was set to −42.8°C (−45° F) for at least 48 h. Prior to the initiation of structural testing of this unit, the unit was removed from the environmental chamber and placed in an insulated box and transported to the NTRC. High-temperature [up to 38°C (100°F)] behavior was not addressed. However, in light of the fact that the insulation material is typically used as a cast refractory insulation in furnace applications and that structural tests were performed in the range of 20.8 to 30.6°C (69.4 to 87°F) or just 7.4 to 17.2°C (13 to 30°F) below the high-temperature limit, it is not anticipated that any decline in impact absorption would be detrimental at 38°C (100°F).

Extensive computer impact simulation and analysis was conducted using LS-DYNA software. The results are documented in DAC-EA-801699-A001 and DAC-EA-801699-A002. Early in the design phase, simulation was used to determine areas of large structural deformation and stress concentrations. Prior to the compliance testing in accordance with 10 CFR 71.71, simulation was used to determine the drop orientation that would cause the most structural damage to the drum assembly and thereby propose a worst-case scenario for potential breeching of the containment vessel. Prior drop test programs have shown the slapdown orientation to cause the most structural degradation of a drum-style container. Computer software LS-DYNA was used to simulate a 9-m (30-ft) drop orientation at a slapdown angle of 12° with a friction factor of $\mu = 0.0$ as calculated using the computer code Slapdown,

Version 05.20.93. Slapdown calculated that no matter what friction factor was assumed, the lid-end velocity peaked at ~14° (DAC-EA-801699-A001, Appendix 6.11). The maximum lid-end velocity versus the slapdown angle is presented in Fig. 6.11.6 of DAC-EA-801699-A001, and the logic for the development of this figure is explained in Appendix 6.11 of DAC-EA-801699-A001. Because of the mitigating effects of the length-to-diameter ratios and the relative closeness of the 12° increase in velocity to the maximum values (shown in DAC-EA-801699-A001, Fig. 6.11.6), the 12°slapdown is considered the worst-case slapdown. Based on the correlation of data obtained from preliminary drop tests of the similar ES-2M configuration and computer-simulated drops, several orientations were eliminated from the drop test matrix (Table 2.23). Several other impact simulations have been conducted using a wide range of material properties for the impact limiter material (Kaolite 1600) to determine the variance in structural deformation. Results of these simulations are documented in DAC-EA-900000-A002, Sect. 5.6. Although the analysis shows some variance, the magnitude of difference was not large enough to degrade the performance of the drum assembly and containment boundary. Due to the similarities in design, fabrication, and material used in construction of the shipping packages, these same results would hold true for the ES-3100 package.

Title 10 CFR 71.73(b) requires that the HAC tests, except for the water immersion tests, be conducted at the most unfavorable ambient temperature within the range of −29 to 38°C (−20 to 100°F). This requirement was previously discussed in Sect. 2.6 for NCT, in which it was concluded that the tests performed at 70 to 90°F ambient temperatures should provide essentially the same results, except for thermal, as those made at any ambient temperature between −29 to 38°C (−20 to 100°F). Buckling failures are not anticipated for this package design. This assumption is based on the fact that no evidence of buckling occurred when the package was subjected to the compression test in accordance with 10 CFR 71.71(c)(9); the water immersion tests in accordance with 10 CFR 71.73(c)(5) and 71.73(c)(6); and the 1.2- and 9-m drop test conducted on TU-4. ASME Code calculations further substantiate that buckling failures of the containment vessel are not anticipated for this package design (DAC-M900000-0003).

Title 10 CFR 71.73(b) states that the HAC initial pressure within the containment vessel during testing shall be considered as the maximum internal normal operating pressure. The internal pressures in the ES-3100 containment vessel at various temperatures for NCT are discussed in Sects. 3.3.1 and 3.3.2 and tabulated in Table 2.20. The maximum normal absolute operating pressure due to insolation and the bounding case parameters is 215.46 kPa (31.25 psia) for the containment vessel. This pressure is well below the design internal gauge pressure of 699.82 kPa (101.5 psi). Increasing the internal pressure in the containment vessel to 215.46 kPa (31.25 psia) before free drop (Sect. 2.7.1), crush (Sect. 2.7.2), puncture (Sect. 2.7.3), or water immersion (Sect. 2.7.5) testing would have no detrimental effect on the containment vessel's structural integrity due to the low stresses shown in Tables 2.21 and 2.21a. Temperature and pressure increases in the containment vessel due to the compliance thermal tests are discussed and evaluated in Sects. 2.7.4 and 3.4.3. A summary of these pressures is presented in Appendix 3.5.2.

Summarizing 10 CFR 71.43(f) and 71.55(d)(4), the tests and conditions of NCT will not substantially reduce the effectiveness of the packaging to withstand HAC sequential testing. The effectiveness of the ES-3100 to withstand HAC sequential testing is not diminished through application of the tests and conditions stipulated in 10 CFR 71.71. The justification for this statement is provided by physical testing of both the ES-2M and ES-3100 test packages, and the analytical structural deformation predicted in DAC-EA-801699-A001 and DAC-EA-801699-A002 (summarized in Sect. 2.7.8). Due to the similarities in design, fabrication, and material used in construction of both the ES-2M and the ES-3100 package, the physical characteristics of the Kaolite 1600 will hold true for both designs. The integrity of the Kaolite 1600 is not significantly affected by the NCT vibration and 1.2-m (4-ft) drop tests. Prior to testing the ES-2M design, each test unit was radiographed to determine the integrity of the Kaolite 1600 impact and insulation material. Following casting of the material inside the drum, some three-dimensional curving cracks were seen in some packages near the thinner top sections from the bottom of the liner to the bottom drum edge. After vibration testing, radiography of the ES-2M TU-4 showed that the lower half of the impact limiter was broken into small pieces. In order to evaluate these findings, TU-4 was reassembled and subjected to HAC sequential testing. After vibration and impact testing, many three-dimensional curving cracks were seen around the impact areas, and the inner liner was visibly deformed. Nevertheless, the ES-2M TU-4 maintained the adequate spacing required for shielding effectiveness and subcriticality. Temperatures at the containment boundary were also similar to other packages not subjected to vibration testing prior to HAC testing. No inleakage of water was recorded following immersion. Additionally, TU-4 of the ES-3100 test series was subjected to tests and conditions stipulated in 10 CFR 71.71(c)(5) through (c)(10), excluding (c)(8). Following completion of these NCT tests, the test unit was subjected to the full HAC test battery. Following these tests, the containment vessel was removed and subjected to a full-body helium leak test. Criteria for a leaktight condition were achieved. Based on the success of these units, vibration normally incident to transport does not reduce the effectiveness of the packaging during HAC testing. Thus, the requirements of 10 CFR 71.43(f) and 71.55(d)(4) are satisfied.

2.7.1 Free Drop

Requirement. A free drop of 9 m (30 ft) onto a flat, unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected is required by 10 CFR 71.73(c)(1).

Analysis. Six test packages were drop tested from 9 m (30 ft) in accordance with 10 CFR 71.73(c)(1) with the setup as shown in Fig. 2.8. A description of the drop pad is presented in Sect. 2.6.7. Four different drop positions were used in the testing based on the analytical results from LS-DYNA drop simulations. The ES-3100 test units were designated as TU-1 through TU-5. TU-4 was subjected to the full NCT testing (water spray, 1.2-m (4-ft) drop, compression, penetration, and vibration) prior to HAC testing. The gross weight of the ES-3100 test units varied between 157.4 kg (347 lb) and 204.6 kg (451 lb). Mock-up components weighing between 3.6 kg (8 lb) [TU-5] and 50.3 kg (111 lb) [TU-3] were used during testing. Discussion of the damage to each test package resulting from the 9-m (30 ft) drop is given in subsequent paragraphs. Rationale for the four drop positions is included in the discussion for each test unit. Minor changes to the mid liner and the substitution of the neutron poison from BoroBond4 to Cat 277-4 are further evaluated in Sect. 2.7.8.



Fig. 2.8. 9-m drop test arrangement for all test units.

2.7.1.1 End drop

TU-4, weighing 201.8 kg (445 lb), was dropped from 9-m (30 ft) with the long axis of the drum perpendicular to the impact surface within 0.2°. The mock-up components are shown on Drawing M2E801580A027. The concern for this drop orientation was that the containment vessel assembly would crush, buckle or compress the insulation to a thickness that would result in excessive O-ring temperatures during the thermal testing cycle. Following initial impact, the package bounced very little before landing on its side. The damage to the drum consisted of reducing the overall height from 43.5 in. [following the 1.2-m (4-ft) drop] to a minimum 42.63 in. The diameter of the drum was measured at six locations along the long axis of the package and at two radial locations. The measurements and pictorials of the damage are recorded on Test Form 1 of Procedure TTG-PRF-08 shown in the test report data sheets (ORNL/NTRC-013) and are summarized in Tables 2.24 and 2.25 and Fig. 2.9.

Table 2.24. Recorded height damage to TU-4 from 1.2- and 9-m drop tests (in.)

	0°	90°	180°	270°
Predrop height	43.50	43.50	43.63	43.63
Post 1.2-m drop height	43.50	43.50	43.50	43.50
Post 9-m drop height	43.00	43.13	42.88	42.63

Table 2.25. Recorded diametrical damage to TU-4 from 1.2- and 9-m drop tests (in.)

Axial measurement location	0 to 180°			90 to 270°		
	Predrop test	Post 1.2-m drop test	Post 9-m drop test	Predrop test	Post 1.2-m drop test	Post 9-m drop test
Top false wire	19.25	19.25	19.25	19.38	19.38	19.38
Top rolling hoop	19.25	19.25	19.13	19.25	19.25	19.88
CG & top rolling hoop	19.25	19.25	19.81	19.25	19.25	19.38
CG rolling hoop	19.13	19.13	19.13	19.25	19.25	19.25
Bottom rolling hoop	19.13	19.13	19.25	19.25	19.25	19.25
Bottom false wire	19.38	19.38	19.25	19.25	19.25	19.25



Fig. 2.9. 9-m drop test damage on TU-4.

2.7.1.2 Side drop

TU-2, weighing 202.8 kg (447 lb), was chilled to −40°C (−40°F) prior to conducting the drop tests. This unit was sequentially dropped from 1.2 m (4 ft), 9 m (30 ft), crushed from 9 m (30 ft), and puncture tested with the long axis of the drum parallel to the impact surface. The mock-up component used in TU-2 is shown on Drawing M2E801580A027; it weighed 49.9 kg (110 lb). There were two concerns for this drop orientation. The primary concern was that the containment vessel assembly would crush or compress the insulation to a thickness that would result in excessive O-ring temperatures during the thermal testing cycle. Another concern was that the cold temperatures might cause excessive loads and deformation in the containment vessel body during impact. This, in turn, might cause leaking above the regulatory limit to occur. The test package made a free fall with initial contact occurring between the rolling hoops of the drum and the impact surface with the ambient temperature at 24.2°C (75°F). Since it was important to evaluate the package at the regulatory minimum temperature, individual results of each test were not recorded. Time required to measure the package between drops would have allowed the package to further increase in temperature. Tables 2.26, 2.27, and 2.28 and Fig. 2.10 show cumulative results of damage to TU-2 from drop testing.

Table 2.26. Recorded diametrical damage to TU-2 from NCT and HAC drop testing (in.)

Axial measurement location	0 to 180°		90 to 270°	
	Predrop test	Post drop test [a]	Predrop test	Post drop test [a]
Top false wire	19.25	17.63	19.25	19.81
Top rolling hoop	19.25	17.38	19.25	19.75
CG & top rolling hoop	19.25	17.00	19.25	20.00
CG rolling hoop	19.25	16.00	19.25	20.25
Bottom rolling hoop	19.25	15.50	19.25	20.13
Bottom false wire	19.25	18.00	19.25	19.38

[a] Includes cumulative damage from 1.2-m drop, 9-m drop, and crush test.

Table 2.27. Recorded flat contour damage to TU-2 from NCT and HAC drop tests (in.)

Axial measurement location	Flat width @ 0°	Flat width @ 180°
Top false wire	8	6.25
Top rolling hoop	9	8.88
CG & top rolling hoop	10.13	9.63
CG rolling hoop	9.88	12.00
Bottom rolling hoop	9.88	14.88
Bottom false wire	9.38	0
Crease (see Fig. 2.10 for location)	–	15.25

Table 2.28. Recorded height damage to TU-2 from NCT and HAC drop tests (in.)

	0°	90°	180°	270°
Predrop height	43.50	43.50	43.50	43.50
Post-drop height [a]	44.75	43.75	42.75	43.63

[a] Includes cumulative damage from 1.2-m drop, 9-m drop, and crush test.



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

2.7.1.3 Corner drop

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

Table 2.29. Recorded height damage to TU-3 from 1.2- and 9-m drop tests (in.)

	0°	90°	180°	270°
Predrop height	43.50	43.50	43.50	43.50
Post 1.2-m drop height	43.00	43.50	43.63	43.50
Post 9-m drop height	40.63	43.25	43.75	43.38

Table 2.30. Recorded diametrical damage to TU-3 from 1.2- and 9-m drop tests (in.)

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



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

2.7.1.4 Oblique drops

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

2.7.1.4.1 TU-1 slapdown

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

Table 2.31. Recorded height damage to TU-1 from 1.2- and 9-m drop tests

(in.)

	0°	90°	180°	270°
Predrop height	43.50	43.50	43.50	43.50
Post 1.2-m drop height	43.50	43.50	43.50	43.50
Post 9-m drop height	42.63	43.38	43.25	43.38
Buckle	44.50			

Table 2.32. Recorded diametrical damage to TU-1 from 1.2- and 9-m HAC drop tests

(in.)

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

Table 2.33. Recorded flat contour damage to TU-1 from 1.2- and 9-m drop tests (in.)

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



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

2.7.1.4.2 TU-5 slapdown

TU-5, weighing 157.4 kg (347 lb), was dropped from 9 m (30 ft), with the long axis of the drum at an oblique angle of 12.5° (desired angle was 12°) from the impact surface. The mock-up component (Drawing M2E801580A029), weighing 3.6 kg (8 lb), was the hardware; the majority of the mass was located near the bottom of the containment vessel (ORNL/NTRC-013). Based on Sect. 3.1 of NRC Regulatory Guide 7.8, the structural performance of the package must be evaluated for the minimum and maximum weight of the contents. Therefore, this unit was tested at the minimum proposed weight to see if the containment vessel would react differently from the much heavier mock-up content used in TU-1 in a similar drop orientation. The test package made a free fall with initial contact occurring between the bottom rim of the drum and the impact surface with the ambient temperature at 30.6°C (87°F). A secondary contact occurred between the top drum lid and the impact surface. No drum studs, nuts, or washers were lost during this impact test. The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained. A general description of damage is provided in Tables 2.34, 2.35, and 2.36 and Fig. 2.13.

Table 2.34. Recorded height damage to TU-5 from 1.2- and 9-m drop tests

(in.)

	0°	90°	180°	270°
Predrop height	43.50	43.50	43.50	43.50
Post 1.2-m drop height	43.88	43.50	43.50	43.50
Post 9-m drop height	44.50	43.50	43.38	43.50

Table 2.35. Recorded diametrical damage to TU-5 from 1.2- and 9-m HAC drop tests

(in.)

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

Table 2.36. Recorded flat contour damage to TU-5 from 1.2- and 9-m drop testing (in.)

Axial measurement location	Maximum width of flats post 1.2-m drop	Maximum width of flats post 9-m drop
Top false wire	5.38	8.38
Top rolling hoop	4.25	8.38
CG & top rolling hoop	3.88	7.63
CG rolling hoop	2.50	7.50
Bottom rolling hoop	3.25	8.25
Bottom false wire	5.00	9.25



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

2.7.1.5 Summary of results

Damage resulting from physical testing is quantitatively described including photographs in Sect. 2.7.1. The full-scale test units were fabricated in accordance with drawings created for production hardware. During the procurement process for the full-scale test units, several small changes were suggested by the manufacturer to improve the efficiency and to reduce the cost of fabrication. These changes were incorporated and tested. However, following compliance testing the following changes have been made to the proposed production hardware. First, a change in the neutron poison from BoroBond4 to Cat 277-4 has been adopted; second, the mid liner design has been changed to a continuous shell by reducing the diameter of the step in the inner liner for the containment vessel flange from 22.35 cm (8.8 in.) to 21.84 cm (8.6 in.); and third, the silicone rubber pad thickness on the drum assembly bottom liner was increased by ~0.15 cm (0.06 in.). The second change increased the amount of Kaolite 1600 around the containment vessel flange, increased the final volume of the neutron poison, and slightly decreased the volume of the Kaolite 1600 adjacent to the neutron poison. The third change was made to stiffen the rubber pad so it would remain in place during vibration normally incurred during transport. In order to evaluate the impact of these changes, analytical drop simulations were conducted and documented in DAC-EA-801699-A001 and DAC-EA-801699-A002. The drop simulations were conducted in the same attitude and temperature regime as those conducted during the compliance testing phase for certification. The results of the structural deformation from compliance testing, drop simulation using BoroBond4, and drop simulations using Cat 277-4 material are presented in Sect. 2.7.8. The analytical structural deformation results shown in Tables 2.52–2.61 are nearly identical for the two neutron poisons. The analytical results are also well representative of the results recorded during compliance testing. Analytical strain prediction in the structural components is also compared. Although there are minor differences between simulations, the overall magnitude of the strains is very similar. The thermal aspects of these changes are addressed in Sect. 3. NCT and HAC results predicted for an undamaged package show that the change in neutron poison actually reduces the final temperature of the containment vessel components. Therefore, the substitution of Cat 277-4 material and the minor changes in the inner and mid liners for production hardware should not reduce the effectiveness of the packaging when subjected to the regulatory requirements of 10 CFR 71, and the results of compliance testing would be analogous.

2.7.2 Crush

Requirement. Title 10 CFR 71.73(c)(2) requires that the specimen be subjected to a dynamic crush test in which the specimen is placed on a flat, essentially unyielding, horizontal surface so as to suffer maximum damage by the drop of a 500-kg (1100-lb) mass from 9 m (30 ft) onto the specimen. The mass must consist of a solid mild steel plate 1 m (40 in.) by 1 m (40 in.) and must fall in a horizontal attitude. The crush test is required only when the specimen has a mass $\leq$ 500 kg (1100 lb), an overall density $\leq$ 1000 kg/m^3 (62.4 lb/ft^3) based on external dimensions, and radioactive contents >1000 A_2 not as special form radioactive material. For packages containing fissile material, the radioactive contents >1000 A_2 criterion does not apply.

Analysis. Six test packages were subjected to the dynamic crush test from 9 m (30 ft) in accordance with 10 CFR 71.73(c)(2). The previously drop-tested packages (described in Sect. 2.7.1) were restrained in the orientation used for drop testing. Discussion of the damage to each test package that resulted from the crush test is given in subsequent paragraphs, with details given in the test reports (ORNL/NTRC-013). Rationale for the three drop positions is included in Sect. 2.7.1 for each test unit. The impact of the steel plate only increased the overall concern for each orientation.

TU-1, weighing 202.3 kg (446 lb), was positioned in a horizontal attitude with the damaged portion of the test unit, resulting from prior drop tests, placed on the drop pad (0° mark facing down on test pad). The 500-kg (1100-lb) crush plate was centered over the sealing lid location on the containment

vessel and dropped from 9 m (30 ft) and squarely contacted the top false wire of the drum at an ambient temperature of 29°C (84.2°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.37, 2.38, and 2.39. Since the length of the crush plate did not encompass the entire length of the test package, a crush edge indentation is recorded in Table 2.39. A pictorial of the damage is shown in Fig. 2.14.

Table 2.37. Recorded height damage to TU-1 from the 9-m crush test

(in.)

	0°	90°	180°	270°
Pre-crush height	44.50	43.38	43.25	43.38
Post 9-m crush test height	44.88	43.38	44.00	43.63

Table 2.38. Recorded diametrical damage to TU-1 from the 9-m crush test

(in.)

Axial measurement location	0 to 180°		90 to 270°	
	Precrush test	Post 9-m crush test	Precrush test	Post 9-m crush test
Top false wire	18.50	15.63	19.38	20.63
Top rolling hoop	18.50	16.00	19.38	20.43
CG & top rolling hoop	18.50	16.25	19.38	20.25
CG rolling hoop	18.63	16.50	19.38	19.88
Bottom rolling hoop	18.63	18.25	19.25	19.50
Bottom false wire	17.81	17.81	19.38	19.25

Table 2.39. Recorded flat contour damage to TU-1 from the 9-m crush test

(in.)

Axial measurement location	Flats width maximum @ 0°	Flats width maximum @ 180°
Top false wire	9.00	8.50
Top rolling hoop	10.00	10.00
CG & top rolling hoop	10.00	10.13
CG rolling hoop	9.00	10.63
Bottom rolling hoop	8.25	--
Bottom false wire	9.75	--
Dent where edge of plate struck test unit	--	9.13



Fig. 2.14. Cumulative damage following 9-m crush on TU-1.

TU-2 (chilled package), weighing 202.8 kg (447 lb), was positioned in a horizontal attitude with the long axis of the drum parallel with respect to the drop pad. The damaged portion of the test unit, resulting from prior drop tests, was placed nearest the drop pad (0° mark facing down on pad). The 500-kg (1100-lb) crush plate was centered over the test unit's center of gravity and dropped from 9 m (30 ft) squarely onto the top false wire of the drum at an ambient temperature of 26.8°C (80.4°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the cumulative damage is shown in Tables 2.26, 2.27, and 2.28 in Sect. 2.7.1.2. Figure 2.10 is a photograph of the damage.

TU-3, weighing 203.7 kg (449 lb), was positioned in the same oblique attitude as previously drop tested from 9 m (30 ft). The long axis of the drum was at an oblique angle of 24.7° (desired angle was 24.6°) from the impact surface with the damaged portion of the lid in contact with the drop pad (0° mark in contact with pad). The 500-kg (1100-lb) crush plate was dropped from 9 m (30 ft) with the center of gravity of both the plate and test unit in line at an ambient temperature of 30.5°C (86.9°F). The initial impact of the plate was with the edge of the drum bottom. A secondary contact occurred between the bottom drum rim and the impact surface. One drum stud was sheared from the test unit; however, the lid was still firmly attached to the drum, with no visible separation or rips. Therefore, the thermal barrier and neutron poison was maintained in position. Tables 2.40, 2.41, and 2.42 describe the measured damage which is recorded on Test Form 3 (ORNL/NTRC-013). A photograph of the damage to TU-3 is shown in Fig. 2.15.

Table 2.40. Recorded height damage to TU-3 from the 9-m crush test

(in.)

	0°	90°	180°	270°
Precrush height	40.63	43.25	43.75	43.38
Post 9-m crush test height	39.38	42.43	39.13	42.50

Table 2.41. Recorded flat contour damage to TU-3 from the 9-m crush test

(in.)

Axial measurement location	Flats width maximum precrush	Flats width maximum post-crush
Top of test unit	14.00	18.38
Bottom of test unit	0.00	17.88

Table 2.42. Recorded diametrical damage to TU-3 from the 9-m crush test

(in.)

Axial measurement location	0 to 180°		90 to 270°	
	Precrush test	Post 9-m crush test	Precrush test	Post 9-m crush test
Top false wire	19.25	19.25	19.19	19.06
Top rolling hoop	18.63	18.75	19.88	20.25
CG & top rolling hoop	19.13	19.25	19.38	19.75
CG rolling hoop	19.13	19.13	19.38	19.25
Bottom rolling hoop	19.13	19.13	19.38	19.75
Bottom false wire	19.13	18.00	19.25	19.38



Fig. 2.15. Cumulative damage following 9-m crush test on TU-3.

TU-4, weighing 201.8 kg (445 lb), was positioned vertically with the previously damaged drum top in contact with the drop pad. The 500-kg (1100-lb) crush plate was dropped from 9 m (30 ft) and squarely contacted the bottom of the test unit. The center of the 500-kg (1100-lb) crush plate was positioned over the radial test unit's center of gravity, in this case over the center of the drum's bottom at an ambient temperature of 29.8°C (85.6°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.43 and 2.44, and a photograph is shown in Fig. 2.16.

Table 2.43. Recorded height damage to TU-4 from the 9-m crush test (in.)

	0°	90°	180°	270°
Precrush height	43.00	43.13	42.88	42.63
Post 9-m crush test height	39.38	40.38	40.63	39.75

Table 2.44. Recorded diametrical damage to TU-4 from the 9-m crush test (in.)

Axial measurement location	0 to 180°		90 to 270°	
	Precrush test	Post 9-m crush test	Precrush test	Post 9-m crush test
Top false wire	19.25	19.25	19.38	19.38
Top rolling hoop	19.13	20.00	19.88	20.13
CG & top rolling hoop	19.81	20.00	19.38	20.06
CG rolling hoop	19.13	19.43	19.25	19.50
Bottom rolling hoop	19.25	19.94	19.25	20.00
Bottom false wire	19.25	19.25	19.25	19.25



Fig. 2.16. Cumulative damage from 9-m drop and crush testing on TU-4.

TU-5, weighing 157.4 kg (347 lb), was positioned in a horizontal attitude with the damaged portion of the test unit resulting from prior drop tests placed on the drop pad (0° mark facing down on test pad). The 500-kg (1100-lb) crush plate was centered over the test unit's center of gravity and dropped from 9 m (30 ft) squarely onto the top false wire of the drum at an ambient temperature of 29.6°C (85.3°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.45, 2.46, and 2.47. Figure 2.17 is a photograph of the damage. Since the length of the crush plate did not encompass the entire length of the test package, additional indentations are recorded on Test Form 3 (ORNL/NTRC-013).

Table 2.45. Recorded height damage to TU-5 from the 9-m crush test

(in.)

	0°	90°	180°	270°
Precrush height	44.50	43.50	43.38	43.50
Post 9-m crush test height	45.00	43.50	43.75	43.88

Table 2.46. Recorded diametrical damage to TU-5 from the 9-m crush tests

(in.)

Axial measurement location	0 to 180°		90 to 270°	
	Precrush test	Post 9-m crush test	Precrush test	Post 9-m crush test
Top false wire	18.75	18.69	19.38	19.38
Top rolling hoop	18.75	17.13	19.38	19.63
CG & top rolling hoop	18.75	17	19.38	20
CG rolling hoop	18.75	16.75	19.25	20
Bottom rolling hoop	18.75	16.50	19.25	19.75
Bottom false wire	18.44	17.00	19.31	19.38

Table 2.47. Recorded flat contour damage to TU-5 from the 9-m crush test

(in.)

Axial measurement location	Flats width maximum @ 0°	Flats width maximum @ 180°
Top false wire	8.88	0.00
Top rolling hoop	8.50	12.50
CG & top rolling hoop	8.00	12.00
CG rolling hoop	8.75	11.38
Bottom rolling hoop	10.25	11.38
Bottom false wire	11.38	10.50



Fig. 2.17. Cumulative damage from 9-m drop and crush testing on TU-5.

Conclusion. As noted in the discussion above, plastic deformation of the drum occurred in all test packages at the impacted areas. However, the position of the impact-limiting material (Kaolite) and neutron poison material (BoroBond in TU-1 through TU-5) was maintained in all test packages. The largest area of deformation along the side of the test packages was a flat measuring 31.75 cm (12.50 in.) wide at the drum's top rolling hoop and ending with a width of 26.67 cm (10.50 in.) at the drum bottom in TU-5.

2.7.3 Puncture

Requirement. A free drop of 1 m (40 in.) from a position to obtain maximum damage onto the upper end of a solid, vertical, cylindrical, 15-cm (6-in.)–diam mild steel bar mounted on an unyielding horizontal surface, is required by 10 CFR 71.73(c)(3). The bar must be ≥20 cm (8 in.) long with the top end rounded to 6-mm (0.25-in.) maximum radius. The long axis of the bar must be vertical.

Analysis. The six units previously dropped and crushed from 9-m (30 ft) [Sects. 2.7.1 and 2.7.2] were dropped from 1 m (40 in.) in accordance with 10 CFR 71.73(c)(3). The puncture bar was bolted to the steel plate of the inside drop pad surface at NTRC (see Sect. 2.6.7 regarding the indoor drop test pad). A description of the drop orientations and results are shown in Table 2.48. Figures 2.18–2.24a show the results of puncture testing.

Table 2.48. 1-m (40-in.) puncture drop test description and results

Test Unit	Test unit's long axis drop orientation	Axial and radial location from drum lid [a]	Recorded damage [indentation depth (in.)] [b]	Photograph
1	Horizontal	Test unit's CG (0° mark)	0.63	Fig. 2.18
1	Horizontal	8 in. down (180° mark)	0.38	Fig. 2.20
1	28° oblique from vertical	Drum lid's edge (90° mark)	Three impact locations 1. 0.63 2. 0.38 3. 0.13	Fig. 2.18
1	40° oblique from vertical	In line with test unit's CG (270° mark)	Two impact locations 1. 0.75 2. 0.13	Fig. 2.19
2	Horizontal	Test unit's CG (0° mark)	0.13	Fig. 2.21
3	24.6° oblique from vertical	In line with test unit's CG (270° mark)	Two impact locations 1. Additional flattening of lid 2. 0.88	Fig. 2.22
4	Vertical	Center of drum's lid & CG	0.13	Fig. 2.23
5	Horizontal	8 in. down (0° mark)	0.13	Fig. 2.24

[a] See detailed description of test units in Sect. 5.4.3 of ORNL/NTRC-013.
[b] For detailed description of damaged locations, see Test Form 4 for TU-1, TU-3, TU-4, and TU-5 and Test Form 3 for TU-2 (ORNL/NTRC-013).



Fig. 2.18. 28° oblique and horizontal puncture tests on TU-1.



Fig. 2.19. 40° oblique puncture test on TU-1.



Fig. 2.20. Horizontal puncture test over TU-1's containment vessel flange.



Fig. 2.21. Horizontal CG puncture test on TU-2.



Fig. 2.22. 24.6° oblique puncture test on TU-3.



Fig. 2.23. Vertical puncture test on TU-4.



Fig. 2.24. Horizontal puncture test over TU-5's containment vessel flange.

Conclusion. Although all test units were deformed by this puncture test, no drum surfaces were breached, thereby maintaining the integrity of the thermal barrier and neutron poison.

2.7.4 Thermal

Requirement. Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent and in sufficiently quiescent ambient conditions to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C (1475°F) for a period of 30 min, or any other thermal test that provides the equivalent total heat input to the package and that provides a time-averaged environmental temperature of 800°C (1475°F). The fuel source must extend horizontally at least 1 m (40 in.) but may not extend more than 3 m (10 ft) beyond any external surface of the specimen, and the specimen must be positioned 1 m (40 in.) above the surface of the fuel source. For purposes of calculation, the surface absorptivity must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction must be allowed to proceed until it terminates naturally.

Analysis. The six test units previously subjected to both NCT and HAC drop testing were thermally tested in accordance with 10 CFR 71.73(c)(4). To determine the maximum temperatures reached during thermal testing, temperature-indicating patches were placed at various locations throughout the test packages at assembly. The temperature range for each patch used is identified in Table 2.49. When the temperature of an indicator was reached, the color would change to black (i.e., blackout temperature). The range of possible blackout temperatures of the patches was from 51.67 to 260°C (125 to 500°F). For TU-1 through TU-5, Table 2.49 defines the number and location of the temperature-indicating patches. A temperature adjustment to compensate for conducting the HAC compliance tests with BoroBond4 and substituting Cat 277-4 for the production shipping containers was evaluated. This adjustment was determined by using an undamaged package and subjecting it to a thermal environment representative of that required by 10 CFR 71.73(c)(4). Based on the analytical results shown in DAC-PKG-801699-A001 and DAC-PKG-801940-A001, the containment vessel in a package using Cat 277-4 would be 2.5 to 8°F cooler than a package with BoroBond4. Therefore, the results from TU-3 are used without further adjustment.

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

Table 2.49. Thermax temperature-indicating patches for test units

Patch location	Internal surface	External surface	Temperature range °C (°F)	Test report figure [a]
Inner liner of drum assembly		8 (full range [b]) 10 (5B & 5C)	52 to 260 (125 to 500) "B" 77–127 (171–261) [c] "C" 132–182 (270–360) [d]	5.3
Top plug weldment		4 (full range)	52 to 260 (125 to 500)	5.31
Containment vessel body flange	8 (4B & 4C)	8 (4B & 4C)	"B" 77–127 (171–261) "C" 132–182 (270–360)	5.28
Containment vessel body (end cap and cylinder)		5 (B)	"B" 77–127 (171–261)	5.28
Containment vessel sealing lid	4 (B)	4 (B)	"B" 77–127 (171–261)	5.29
Test mock-up components		6 (B)	"B" 77–127 (171–261)	5.26 & 5.27

[a] ORNL/NTRC-013.
[b] Full range labels consist of two strips; the first strip spans from 1250–3000°F in 250°F increments, and the second strip spans from 3250–5000°F in 250°F increments.
[c] Temperature-indicating labels described as "B" labels read between 1710°F and 2610°F in increments of between 90°F and 110°F.
[d] Temperature-indicating labels described as "C" labels read between 2700°F and 3600°F in increments 90°F and 110°F.

A total of 18 thermocouples was installed on the furnace surfaces and on the test package support stand (ORNL/NTRC-013). All units were tested in a horizontal attitude with the end of the package facing the right and left side walls of the furnace. The test units were thermally tested with the 0° mark on the drum facing the floor of the furnace.

TU-1 through TU-5 were preheated to >38°C (100°F) by placing the packages in an environmental chamber, which was heated by a torpedo-type kerosene space heater controlled by a mechanical bulb thermostat with a control range of 38 to 93°C (100 to 200°F). The general construction of the environmental chambers was similar: a welded steel frame with fiberglass insulation panels or blankets. The set-point temperature of the environmental chambers was monitored and adjusted for the duration of the preheat cycle. Initially, the thermostat was set to 66°C (150°F) for ~23 h to 24 h. The thermostat set point was then reduced to ≥43°C (110°F) for the remainder of the preheat cycle. All of packages were preheated for at least 47 h. Six thermocouples were attached to the exterior surface of each test package after preheating. Metal retainer clips were welded to the drum to hold the thermocouples in place. The thermocouple tips were inserted underneath the metal clips and the wire was wrapped around the metal clip. To eliminate any radiant heat exchange between the thermocouples and the furnace walls, the tips and metal clips were covered with a ceramic coating.

No test package was loaded into the furnace until all functioning thermocouples on the furnace walls and support stand had a reading of 800°C (1475°F) or higher. All packages were placed in the preheated furnace on the support stand positioned with the long axis horizontal, the package lid facing toward a furnace side wall and oriented as described above. These packages were exposed to the radiation environment for a minimum of 30 min after all functioning furnace thermocouples, and at least five of the six test package exterior surface thermocouples, reached 800°C (1475°F). During the testing, the thermocouple temperature data were recorded every 15 s.

A minimum of 24 h prior to the beginning of all testing, the furnace was turned on with a set-point temperature of 871°C (1600°F). After each test, the furnace was allowed to reheat for a minimum of 45 min after obtaining the set-point temperature before testing the next unit. The furnace control temperature data recorder ran continuously for the duration of the preheat. No test package was loaded into the furnace until all functioning thermocouples on the furnace walls and support stand had a reading of 800°C (1475°F) or higher.

Each test package was removed from the furnace and placed in an area where it was not exposed to artificial cooling. As the furnace door was opened for each test unit, smoking or flaming was visible from the TID lug hole at 0°. Flaming continued on some packages for 22 min and smoking continued up to 1 h on others. All of the packages were allowed to cool naturally to room temperature. The post-thermal test weights of each unit were recorded on Test Form 1 (ORNL/NTRC-013). The drums were disassembled, and the damage was photographed. The post-thermal test weight of each loaded containment vessel was also recorded. Each package was visually inspected, and the condition of the package and any observations were recorded.

After the containment vessels were removed from TU-1 through TU-5, two different leak tests were performed on each containment vessel. An operational leak test was conducted between the O-rings using either a CALT5 leak tester or a VTI smart station vacuum decay leak detector. Following this operational leak test, a full body helium leak test was conducted. Details of these leak tests are provided in the test report (ORNL/NTRC-013) and the results are summarized in Table 2.23. All six containment vessels were then removed from the drum assembly and immersed under a head of water of at least 0.9 m (3 ft) in a horizontal position for a period of ≥8 h. Following the immersion test of 10 CFR 71.73(c)(6), the containment vessels of TU-1 through TU-5 were opened to remove the contents, gather available data, and look for signs of water in-leakage. No water in-leakage was detected in any of the units.

The blackout temperatures on the surface of the containment boundaries, inner liners, and mock-up components used in TU-1 through TU-5 are given in the test report (Test Form 5 for each test unit). Maximum blackout temperatures recorded on the surface of all test units are tabulated in Table 2.50. These values and temperature adjustments are discussed in Sect. 3.4.3.

Conclusion. All six test packages were intact following the 30-min exposure to the high- temperature thermal environment as required in 10 CFR 71.73(c)(4). Examination during disassembly showed that the containment vessel surfaces, flanges, fasteners, sealing surfaces, and O-rings were not damaged by the thermal testing. All six containment vessel assemblies met the subsequent 0.9-m (3-ft) water immersion test and maintained a full-body helium leak rate $\leq 2.0 \times 10^{-7}$ cm^3/s. Following compliance testing, minor changes were made to the mid liner, and the neutron poison was changed from BoroBond4 to Cat 277-4. In order to evaluate the impact of these changes, extensive analytical drop simulations were utilized. The models, material properties, and drop orientations are described in DAC-EA-801699-A001 and DAC-EA-801699-A002. Results comparing structural deformation and maximum strains in the various material of construction are shown in Sect. 2.7.8. Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, similar compliance test results would be expected had testing been conducted on packages employing the new proposed Cat 277-4 neutron poison. Therefore, the requirements of 10 CFR 71.73(c)(4) were satisfied, and containment was maintained.

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 vessel					
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 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.

2.7.4.1 Summary of pressures and temperatures

The ES-3100 shipping packages will typically be loaded at an ambient temperature and absolute pressure of ~25°C (77°F) and 101.35 kPa (14.70 psi), respectively. If the temperature of the package increases during shipment due to external temperature or insolation, the drum will not pressurize because four ventilation holes are drilled near the top of the drum, and the drum is not sealed at the drum lid–flange interface. The containment vessel is sealed at assembly. The internal pressure will increase due to transport temperatures, insolation (Sect. 3.3.1), decay heating, and the temperatures during HAC (Sect. 3.4.3). Temperature and pressures are summarized in Tables 3.5 and 3.7.

The maximum HAC adjusted internal absolute pressure in the containment vessel of the ES-3100 has been calculated and rounded up to 775.66 kPa (112.50 psia). This predicted pressure is based on a conservative maximum rounded average gas temperature of 140.56°C (285.00°F) as shown in Sect. 3.4.3 and Appendix 3.5.2.

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 or 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 167.22°C (332.99°F) [Sect. 3.4.3].

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 1.3.7). 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 expansion will exist.

2.7.4.3 Stress calculations

The temperature gradient on the containment vessel 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 Code, Sect. III, Div. 1. Thermal stress is defined as a self-balancing stress produced by a nonuniform distribution of temperature (ASME Code, 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 Code, Paragraph NB-3213.9). This general stress is further classified 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 Code, 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 Code, 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 (DAC-M900000-0003) 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 vessel components (based on nominal dimensions for the components) are well below the ASME 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).

Analysis. The containment vessels for the ES-3100 test packages (TU-1 through TU-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 either the CALT5 manufacturer's instructions manual using the CALT5 leak tester or the VTI instructions manual using the VTI smart station vacuum decay leak detector. 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 are recorded on the data sheet of Procedure TTG-PRF-14 shown in test report ORNL/NTRC-013 for units TU-1 through TU-5. 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.

Table 2.51. HAC ES-3100 containment vessel 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 @674.31 kPa (97.80 psi) gauge & 140.56°C (285.0°F)		Immersion condition 10 CFR 71.73 (c)(6) containment boundary stress @−150 kPa (−21.7 psi) gauge & −2.22°C (28°F)		Allowable pressure, stress, or shear capacity
	kPa (psi)	M.S. [b]	kPa (psi)	M.S. [b]	kPa (psi)
Top flat portion of sealing lid (center of head)	1.100×10^4 (1596)	18	2.441×10^3 (354)	82	1.999×10^5 (29,000) [c]
Closure nut ring (away from threaded portion)	3.295×10^4 (4779)	4.4	1.902×10^4 (2759) [d]	7.6	1.441×10^5 (20,900)
Top flat head (sealing surface region)	2.792×10^4 (4049)	7.2	7.087×10^3 (1028) [d]	28	1.999×10^5 (29,000) [c]
Cylindrical section (middle) internal pressure	1.877×10^4 (2722)	6.0			1.120×10^5 (16,250) [e]
Cylindrical section (middle) external pressure			1.496×10^2 (21.7)	5.1	7.584×10^2 (110) [f]
Cylindrical section (shell-to-flange interface)	2.599×10^4 (3769)	6.5	5.766×10^3 (836)	29	1.682×10^5 (24,400) [c]
Cylindrical section (shell-to-bottom interface)	5.642×10^4 (8183)	3.0	1.252×10^4 (1816)	13	1.682×10^5 (24,400) [c]
Body flange threads load, kg (lb)	1.655×10^3 (3648)	16	9.072×10^2 (2000) [d]	29	2.608×10^4 (57,500) [g]
Body flange thread region (under cut region)	5.481×10^4 (7950)	3.1	2.839×10^4 (4117) [d]	5.9	1.682×10^5 (24,400) [c]
Flat bottom head (center)	4.717×10^4 (6841)	3.6	1.047×10^4 (1518)	16	1.682×10^5 (24,400) [c]
Closure nut thread load, kg (lb)	1.655×10^3 (3648)	20	9.072×10^2 (2000) [d]	37	3.353×10^4 (73,911) [g]

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment vessel components (DAC-M900000-0003). Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure plus the contribution from preload. Allowable stress values are taken from Table 2.5 up to 176.7°C (350°F).

[b] Margin of safety = allowable stress/actual stress.

[c] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[d] Stress and shear load in these areas is dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload. External pressure component is ignored.

[e] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.

[f] Allowable external pressure [kPa (psi)].

[g] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area for the body material. Thread shear area = 38.026 cm^2 (5.894 $in.^2$). Allowable shear capacity is defined as $1.2 \times S_m \times$ thread shear area for the closure nut material.

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 vessel 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 vessel 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 vessel of TU-6 was subjected to this 15-m (50-ft) water immersion test. No visible 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 ~4753. Therefore, the deep water immersion test is not applicable.

2.7.8 Summary of Damage

After testing six full scale ES-3100 test packages under HAC, the drum, drum lid, and top plug were damaged as expected. The containment vessel flange, O-ring grooves, and closure nut were not damaged. Plastic deformation occurred in the six drum assemblies in the impact areas from the 1.2-m (3.9-ft) 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 (TU-1 through TU-6) 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, after compliance testing on the first seven test units, the following changes have been made to the proposed production hardware. First, a change in the neutron poison from BoroBond4 to Cat 277-4 has been adopted; second, the mid liner design has been changed to a continuous shell by reducing the diameter of the step in the inner liner for the containment vessel flange from 22.35 cm (8.8 in.) to 21.84 cm (8.6 in.); and third, the silicone rubber pad thickness on the drum assembly bottom liner was increased by ~0.15 cm (0.06 in.). The second change increased the amount of Kaolite 1600 around the containment vessel flange, increased the final volume of the neutron poison, and slightly decreased the volume of the Kaolite 1600 adjacent to the neutron poison. The third change was made to stiffen the rubber pad so it would remain in place during vibration normally incurred during transport. In order to evaluate the impact of the above changes on the original HAC test units (TU-1 through TU-5), analytical drop simulations were conducted and documented in DAC-EA-801699-A001 and DAC-EA-801699-A002. The drop simulations were conducted in the same attitude and temperature regime as those conducted during the compliance testing phase for certification. Temperature dependent material properties were used in the analysis. The results of the structural deformation from compliance testing, drop simulation using BoroBond4, and drop simulations using Cat 277-4 material are presented in the following tables and figures. The analytical

structural deformation results shown in Tables 2.52–2.61 are nearly identical for the two neutron poisons. The analytical results are also well representative of the results recorded during compliance testing as depicted in Figs. 2.25–2.30. Analytical strain prediction in the structural components is also compared for the two neutron poisons. Although there are minor differences between the compliance testing and drop simulations, the overall magnitude of the strains is very similar. The thermal aspects of these changes are addressed in Sect. 3. NCT and HAC results predicted for an undamaged package show that the change in neutron poison actually reduces the final temperature of the containment vessel components. Therefore, the substitution of Cat 277-4 material and the minor changes in the inner and mid liners for production hardware should not reduce the effectiveness of the packaging when subjected to the regulatory requirements of 10 CFR 71.71 and 71.73, and the results of compliance testing would be analogous. Some of the test units lost ~0.45 kg (1 lb) of their gross weight due to boiling off of the water trapped in the refractory and BoroBond4 materials (Table 2.62).

Assuming all water loss is from the neutron poison, the BoroBond4 material lost ~9.4% of its water content. Using the temperature data recorded during HAC testing shown in Table 2.50 and applying the temperature adjustments discussed in Sect. 3.4.3, the average temperature of the neutron poison would be ~150°C (302°F). Since the ES-3100 test units were not fabricated packages with Cat 277-4, thermogravimetric analysis (TGA) was used to compare the neutron poison's propensity to lose water. The results of this analysis are shown in Y/DV-1914, *Summary of TGA Testing of Borated Concrete and Adhesive-Backed Silicone Foam*. Samples of both BoroBond4 and Cat 277-4 were TGA tested, and the results were compared at 150°C (302°F). The BoroBond4 samples lost ~ 61.6% of their original water content. The dry Cat 277-4 lost a maximum of only 6.61%. The BoroBond4 TGA samples lost ~6.5 times the amount of water lost by the ES-3100 test units during HAC compliance testing. Assuming comparable results would be expected for the Cat 277-4 material due to similarity in the structural configuration, installation methodology, and LS-DYNA drop simulation structural deformation results, the Cat 277-4 water loss would be only 1.02%. Criticality safety analysis assumes a greater percent loss; therefore, additional conservatism is being applied in this SARP.

The maximum blackout temperature recorded adjacent to the O-rings during testing was 127.22°C (241°F) [Table 2.50]. Using the adjustments discussed in Sect. 3.4.3, the maximum adjusted temperature at the containment boundary O-rings during shipment under HAC was calculated to be 156.19°C (313.14°F). As shown in Fig. 2-24 of the *Parker O-Ring Handbook*, these O-ring materials can survive at the predicted temperature shown in Table 3.21 [156.19°C (313.14°F)] for several hundred hours. Since the predicted temperature is only ~6.1°C (11°F) above the continuous service temperature of 302°F for the EPDM O-ring, the thermally tested packages with insolation would cool to acceptable limits within 24 h. Therefore, these adjusted temperatures would not adversely affect the containment vessel O-rings.

Table 2.52. Diametrical damage comparison of TU-1 with analytical predictions

(in.)

Axial measurement location	0 to 180°			90 to 270°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	15.63	15	14.9	20.63	20.7	20.7
Top rolling hoop	16	15.3	15.1	20.44	20.8	20.8
CG & top rolling hoop	16.25	15.9	15.7	20.25	20.6	20.7
CG rolling hoop	16.5	16.4	16.2	19.88	20.1	20.4
Bottom rolling hoop	18.25	18.3	18.1	19.5	19.6	19.8
Bottom false wire	17.81	18.1	18	19.25	19.4	19.4

Table 2.53. Flat contour damage comparison of TU-1 with analytical results

(in.)

Axial measurement location	Flats width @ 0°			Flats width @ 180°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	9	10.5	10.5	8.5	10.5	10.9
Top rolling hoop	10	11	11	10	11	11
CG & top rolling hoop	10	10.1	10.1	10.13	10.1	10.1
CG rolling hoop	9	8.4	8.4	10.63	10.1	10.1
Bottom rolling hoop	8.25	7.6	7.6	---	0	0
Bottom false wire	9.88	10.1	10.1	---	0	0



Fig. 2.25. Visual comparison of the cumulative damage on the crush side surface after the three drop tests (from top to bottom: TU-1, analytical results with BoroBond, analytical results with Cat 277-4).

Table 2.54. Cumulative analytical 12° slapdown drop tests maximum effective plastic strain results

Component	Component material	Effective plastic strain (in./in.)			
		Offset crush		Centered crush	
		Model with BoroBond	Model with Cat 277-4	Model with BoroBond	Model with Cat 277-4
CV body	Type 304L stainless steel	0.0457	0.0564	0.0741	0.0643
CV lid	Type 304L stainless steel	0.0005	0.0013	0.0006	0.0018
CV closure nut	SA-479 Nitronic 60	0.0000	0.0001	0.0003	0.0000
Angle	Type 304 stainless steel	0.1045	0.1070	0.0917	0.0944
Drum	Type 304 stainless steel	0.3972	0.3920	0.3537	0.3443
Drum bottom	Type 304 stainless steel	0.2877	0.2879	0.2919	0.3000
Liner	Type 304 stainless steel	0.2702	0.2060	0.2363	0.2846
Lid	Type 304 stainless steel	1.0797	0.9689	1.0795	0.5828
Lid stiffener	Type 304 stainless steel	0.0838	0.0894	0.0303	0.0288
Drum lid studs	Type 304 stainless steel	>0.57	0.4018	0.3174	0.2390
Lid hex nut	Silicon bronze - C65100	0.0086	0.0028	0.0000	0.0000
Drum washer	300 series stainless steel	0.1003	0.0790	0.0597	0.0775
Top plug weldment	Type 304 stainless steel	0.2715	0.2665	0.1636	0.1644

Table 2.55. Diametrical damage comparison of TU-2 with analytical predictions

(in.)

Axial measurement location	0 to 180°			90 to 270°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	17.63	18.1	18	19.81	19.6	19.6
Top rolling hoop	17.38	16.6	16.6	19.75	19.75	20.1
CG & top rolling hoop	17	16.5	16.5	20	20	20.4
CG rolling hoop	16	16.3	16.3	20.25	20.25	20.5
Bottom rolling hoop	15.5	16.1	16.1	20.13	20.13	20
Bottom false wire	18	17.6	17.6	19.25	19.38	19.4

Table 2.56. Flat contour damage comparison of TU-2 with analytical predictions

(in.)

Axial measurement location	Flats width @ 0°			Flats width @ 180°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	8	9.2	9.2	6.25	0	0
Top rolling hoop	9	8.4	9.3	8.88	10.1	10.1
CG & top rolling hoop	10.13	8.4	8.4	9.63	8.4	9.3
CG rolling hoop	9.88	9.3	9.3	12	9.3	9.3
Bottom rolling hoop	9.88	9.3	9.3	14.88	10.1	10.1
Bottom false wire	9.38	10.1	10.1	0	0	0



Fig. 2.26. Visual comparison of the cumulative damage on the rigid surface side after the four drop tests (from left to right: TU-2, analytical results with BoroBond, analytical results with Cat 277-4).



Fig. 2.27. Visual comparison of the cumulative damage on the crush plate side after the three drop tests (from left to right: TU-2, analytical results with BoroBond, analytical results with Cat 277-4).

Table 2.57. Cumulative analytical side drop test maximum effective plastic strain results

Component	Component material	Effective plastic strain (in./in.)	
		Model with BoroBond	Model with Cat 277-4
CV body	Type 304L stainless steel	0.0462	0.0525
CV lid	Type 304L stainless steel	0.0004	0.0004
CV closure nut	SA-479 Nitronic 60	0.0000	0.0005
Angle	Type 304 stainless steel	0.0816	0.0845
Drum	Type 304 stainless steel	0.2623	0.2814
Drum bottom	Type 304 stainless steel	0.2807	0.2827
Liner	Type 304 stainless steel	0.2005	0.2022
Lid	Type 304 stainless steel	0.6411	0.6413
Lid stiffener	Type 304 stainless steel	0.0217	0.0171
Drum studs	Type 304 stainless steel	0.1753	0.2364
Drum hex nut	Silicon bronze - C65100	0.0000	0.0018
Drum washer	300 series stainless steel	0.1034	0.0439
Top plug weldment	Type 304 stainless steel	0.1258	0.1286

Table 2.58. Diametrical damage comparison of TU-3 with analytical predictions [diameter (in.)]

Axial measurement location	0 to 180°			90 to 270°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	19.25	19	19	19.06	19	19
Top rolling hoop	18.75	18.9	18.9	20.25	20.6	20.6
CG & top rolling hoop	19.25	19.4	19.4	19.75	19.9	19.8
CG rolling hoop	19.13	19.3	19.3	19.25	19.4	19.4
Bottom rolling hoop	19.13	19.3	19.3	19.75	20.4	20.4
Bottom false wire	18	18.6	18.6	19.38	19.4	19.4

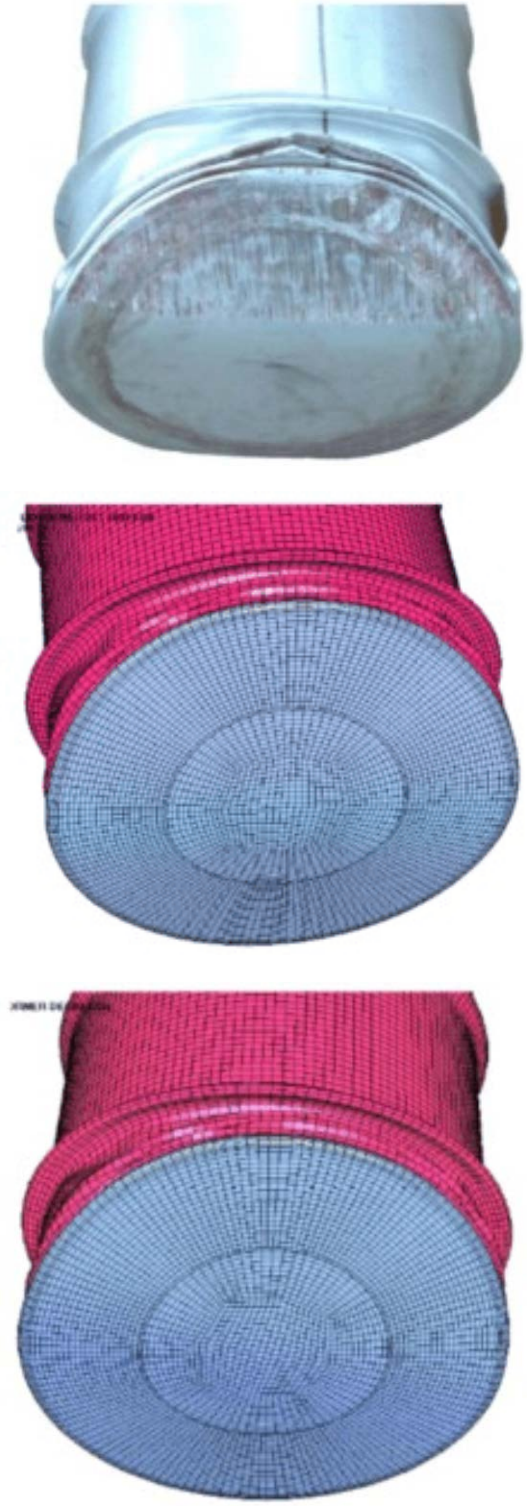


Fig. 2.28. Visual comparison of the cumulative bottom damage after the three drop tests (from top to bottom: TU-3, analytical results with BoroBond, analytical results with Cat 277-4).

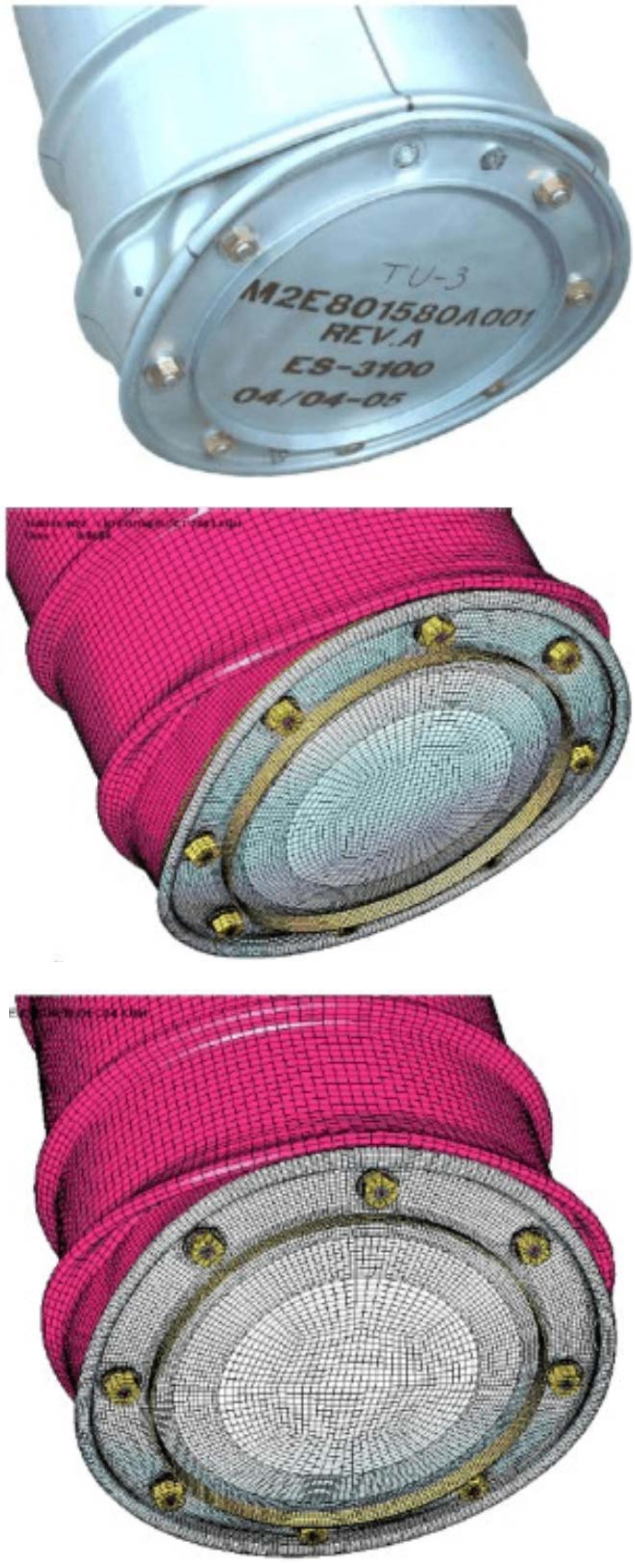


Fig. 2.29. Visual comparison of the cumulative lid damage after the three drop tests (from top to bottom: TU-3, analytical results with BoroBond, analytical results with Cat 277-4).

Table 2.59. Cumulative analytical corner drop test maximum effective plastic strain results

Component	Component material	Effective plastic strain (in./in.)	
		Model with BoroBond	Model with Cat 277-4
CV body	Type 304L stainless steel	0.0364	0.0371
CV lid	Type 304L stainless steel	0.0024	0.0051
CV closure nut	SA-479 Nitronic 60	0.0000	0.0002
Angle	Type 304 stainless steel	0.0464	0.0462
Drum	Type 304 stainless steel	0.3787	0.3830
Drum bottom	Type 304 stainless steel	0.0731	0.0761
Liner	Type 304 stainless steel	0.5507	0.5254
Lid	Type 304 stainless steel	0.3579	0.3622
Lid stiffener	Type 304 stainless steel	0.0272	0.0272
Drum studs	Type 304 stainless steel	0.5578	0.5598
Drum hex nut	Silicon bronze - C65100	0.2258	0.2266
Drum washer	300 series stainless steel	0.1111	0.1528
Top plug weldment	Type 304 stainless steel	0.1170	0.1166

Table 2.60. Diametrical damage comparison of TU-4 with analytical predictions [diameter (in.)]

Axial measurement location	0 to 180°			90 to 270°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	19.25	19.3	19.3	19.38	19.3	19.3
Top rolling hoop	20.00	20.2	20.1	20.13	20.2	20.1
CG & top rolling hoop	20.00	20.2	20.2	20.06	20.2	20.2
CG rolling hoop	19.44	20.1	20.1	19.5	20.1	20.1
Bottom rolling hoop	19.94	20.5	20.5	20	20.5	20.5
Bottom false wire	19.25	19.4	19.4	19.25	19.4	19.4



Fig. 2.30. Visual comparison of the cumulative damage after the three drop tests (from left to right: TU-4, analytical results with BoroBond, analytical results with Cat 277-4).

Table 2.61. Cumulative analytical top drop test maximum effective plastic strain results

Component	Component material	Effective plastic strain (in./in.)	
		Model with BoroBond	Model with Cat 277-4
CV body	Type 304L stainless steel	0.0053	0.0083
CV lid	Type 304L stainless steel	0.0034	0.0072
CV closure nut	SA-479 Nitronic 60	0.0000	0.0011
Angle	Type 304 stainless steel	0.0304	0.0308
Drum	Type 304 stainless steel	0.1258	0.1237
Drum bottom	Type 304 stainless steel	0.0312	0.0267
Liner	Type 304 stainless steel	0.3585	0.3812
Lid	Type 304 stainless steel	0.1415	0.1389
Lid stiffener	Type 304 stainless steel	0.0098	0.0100
Drum studs	Type 304 stainless steel	0.1541	0.1535
Drum hex nuts	Silicon bronze - C65100	0.0170	0.0173
Drum washer	300 series stainless steel	0.0510	0.0506
Top plug weldment	Type 304 stainless steel	0.0944	0.0960

Table 2.62. ES-3100 test package weights before and after 10 CFR 71.73(c)(4) HAC testing

Test Unit	Pre-test [a] weight [kg (lb)]	Post-test [a] weight [kg (lb)]	Thermal test weight loss [kg (lb)]	BoroBond4 or Cat 277-4 original weight [kg (lb)]	Water weight in BoroBond4 or Cat 277-4 [kg (lb)]	Water loss percent [d] (%)
1	202.3 (446)	202.3 (446)	0.0 (0)	20.7 (45.64) [b]	4.91 (10.82) [c]	0.00
2	202.8 (447)	202.8 (447)	0.0 (0)	20.5 (45.19) [b]	4.86 (10.72) [c]	0
3	203.7 (449)	203.2 (448)	0.45 (1)	20.5 (45.19) [b]	4.87 (10.74) [c]	9.31
4	201.8 (445)	201.4 (444)	0.45 (1)	20.4 (44.97) [b]	4.84 (10.66) [c]	9.38
5	157.4 (347)	156.9 (346)	0.45 (1)	20.6 (45.42) [b]	4.89 (10.77) [c]	9.29

[a] ORNL/NTRC-013.
[b] Weight of BoroBond4 and water obtained from casting data (Barton).
[c] This weight is based on TGA measurements and calculation showing that the minimum water percent is 23.71%.
[d] All weight loss attributed to loss of water in BoroBond4 or 277-4.

Following the thermal test, all six containment boundaries were subjected to leak testing of the O-ring cavity as well as the full-body helium leak check. To verify the entire containment boundary, all test units were drilled and tapped for a helium leak check using the procedure documented in the test report (ORNL/NTRC-013). The procedure consisted of creating a near vacuum inside the containment vessel and supplying a helium environment around the exterior of the assembly. The maximum recorded helium leak rate for any of these containment vessels was 2.0×10^{-7} cm^3/s as documented after 17 min of leak checking. This procedure measures leakage in the opposite direction to leakage from the vessel. It could be postulated that the additional pressure differential (ambient on the exterior and a near vacuum inside) would help to further compress the O-rings during this test. However, since the containment vessel closure nut is screwed down, the additional pressure does not compress the O-ring more than a few ten thousands of an inch based on mismatch between the internal and external threaded joint. Only rotation of the closure nut will alter O-ring compression significantly. Pictures taken of all containment vessel tops following testing showed that the closure nut had rotated a maximum of 0.15 cm (0.060 in.) [Fig. 2.31] from its original radial position obtained during assembly (Fig. 2.32) except for TU-4, which showed no rotation. Based on the pitch of the closure nut, this rotation translates into only 0.0009 cm (0.00035 in.) decompression of the O-rings. This compares to the original nominal compression of 0.064 cm (0.025 in.). According to the *Parker O-Ring Handbook*, the minimum squeeze for all seals, regardless of cross section, should be ~0.018 cm (0.007 in.). Using the nominal compression of 0.064 cm (0.025 in.) and subtracting the decompression from rotation and the minimal pressure differential compression, there is ample O-ring compression. Therefore, the leak test in either direction for this containment vessel arrangement is valid. As required in 10 CFR 71.73(c)(5), the containment vessels were submerged under a 0.9-m (3-ft) head of water following the leakage tests, with no water in-leakage permitted. Following this immersion test, the containment vessels were opened. The lid assembly, with the O-rings in place on the body, are joined together by torquing the closure nut and sealing lid assembly to 162.7 ± 6.8 N·m (120 ± 5 ft-lb). The lowest break-loose torque value of 40.7 N·m (30 ft-lb) was recorded for TU-4. Visual inspection following the testing indicated that neither the vessel bodies, the O-rings, the seal areas, nor the vessel lid assemblies were damaged during the tests. In TU-5, the convenience cans had buckled from the pressure differential caused during the leak testing operation. However, the containment vessel wall showed little or no signs of impact. Therefore, based on the success of these seven test units (including the containment vessel of TU-6) and the analytical drop simulation effort, the structural integrity of the ES-3100 package, with the previously mentioned modifications, meets all the applicable requirements of 10 CFR 71.73 for transport of the proposed contents.



Fig. 2.31. Containment vessel markings at assembly (swivel hoist ring removed prior to testing).

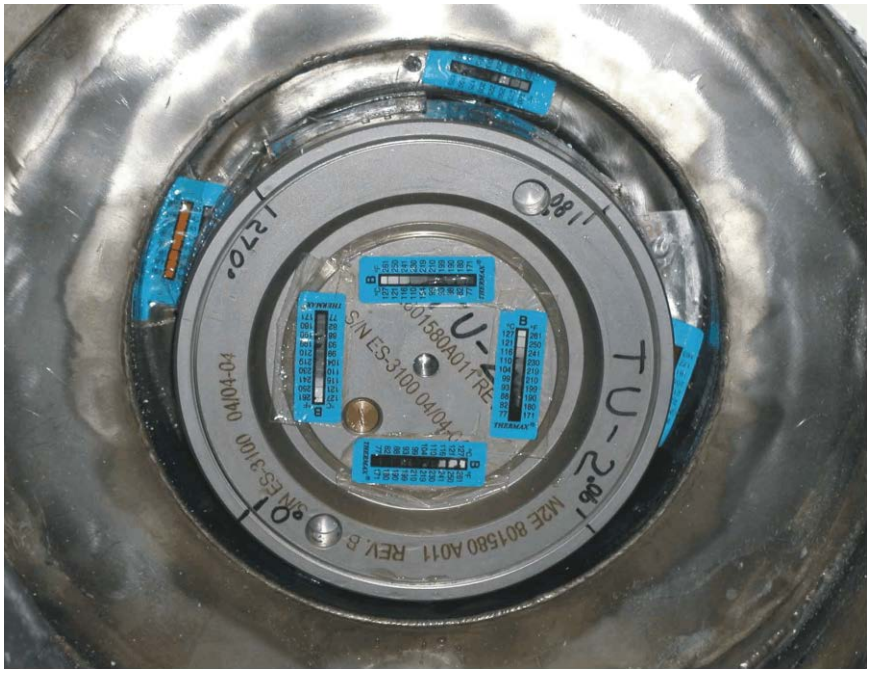


Fig. 2.32. Containment vessel marking after compliance testing.

2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

The proposed contents to be shipped in the ES-3100 have only trace amounts of transuranic isotopes. Since the contents contain no more than an A_2 quantity of plutonium in any isotope or form and will be shipped in accordance with 10 CFR 71.5 per 10 CFR 71.88(a)(3), the requirements in 10 CFR 71.74 are not applicable.

2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

The expanded tests specified in 10 CFR 71.55(f)(1), (2), or (3) for fissile material package designs for air transportation were not conducted. The issue of subcriticality is addressed in Sect. 6 with content mass limits as addressed in Sect. 1.2.2 for air transport.

2.10 SPECIAL FORM

The package does not include any special form of radioactive material. Hence, the requirements of 10 CFR 71.75 and 71.77 are not applicable.

2.11 FUEL RODS

The contents do not utilize cladding for the containment of radioactive materials. Therefore, this requirement is not applicable.

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3. THERMAL EVALUATION

Design analysis, similarity, and full-scale testing (see Sect. 2) have demonstrated that the ES-3100 shipping package is in compliance with the applicable requirements of Title 10 Code of Federal Regulations (CFR) 71 (10 CFR 71) when used to ship highly enriched uranium (HEU) having a maximum gross weight up to 35.2 kg (77.60 lb). The ES-3100 has a nominal gross shipping weight that ranges from 146.88 kg (323.79 lb) to 187.81 kg (414.05 lb) for the empty and maximum weight containment vessel configurations shown in Table 2.8, respectively.

3.1 DESCRIPTION OF THERMAL DESIGN

The drum assembly of the shipping package is defined as the structure that maintains the position of and provides 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 nominal weight of the drum assembly is 131.89 kg (290.76 lb).

The ES-3100 package is evaluated for a maximum heat source of 5 W (Sect. 3.1.2); however, no active cooling systems or specific thermal design features are required. A lightweight cast refractory insulation between the inner liner and the drum provides thermal protection of the contents from external heat sources.

Thermal criteria are applied to the package in accordance with 10 CFR 71 for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). These requirements specify that each package design provide containment, shielding, and criticality safety at temperatures ranging from −40 to 38°C (−40 to 100°F) with full insolation. Also, in accordance with *Packaging and Transportation of Radioactive Material* [10 CFR 71.43(g)], a package must be designed, constructed, and prepared for transport so 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. In addition, each package will experience no significant reduction in effectiveness as the result of being exposed to a thermal radiation environment of 800°C (1475°F) for 30 min with an emissivity coefficient of at least 0.9.

The maximum internal pressures and thermal stresses for both NCT and HAC are discussed and calculated (Sects. 3.3.2, 3.3.3, and 3.4.3) for use in the structural evaluation. The calculated pressures are well below the design pressures of the package components, and the effect of thermal stresses on the package is negligible (Sects. 2.6.1.2 and 2.7.4.2).

Compliance with the NCT thermal requirements is shown by analysis (Sect. 3.3.1). Since the components to be shipped have a maximum decay heat load of 5 W, a thermal analysis was conducted for the ES-3100 package (DAC-PKG-801940-A001). The maximum predicted temperature on the exterior of the package, while stored at 38°C (100°F) in the shade, is 40.22°C (104.39°F) [Table 3.14]. 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. 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, center of containment vessel lid, and on the containment vessel near the O-ring sealing surfaces are 118.86°C (245.94°F), 91.92°C (197.46°F), and 91.87°C (197.36°F), respectively (Sect. 3.3.1 and Table 3.15). For conservatism, the O-ring sealing surface temperature will be assumed to be 91.87°C (197.36°F). At the low-temperature range and neglecting decay heating, the package components would stabilize at −40°C (−40°F), which is within normal operating limits of the packaging materials (Sect. 2.2).

Six full-scale packages were subjected to the HAC thermal test following the drop, crush and puncture tests (Sects. 2.7.1 through 2.7.3). All of these test packages were exposed to a thermal radiation environment of >800°C (>1475°F) for well over 30 min in a furnace. Other temperature conditions before and during the thermal testing are given in ORNL/NTRC-013 for the furnace, test packages, and package supports. The maximum temperature recorded during the tests on the external surface of any of the containment vessels was 127.2°C (261°F). This containment vessel maximum temperature reading is the highest value shown in Table 3.4. This temperature was recorded on Test Unit (TU)-4 and TU-5 on the containment vessel sealing lid. The maximum internal temperature adjacent to the O-rings was 116°C (241°F). Temperature adjustments are then added to the containment vessel's maximum recorded temperature to correct for measuring accuracy, internal decay heating, insolation heating during cool down, location of crush plate damage, neutron poison substitution, thermal capacitance difference between mockups and actual contents, and material density variations. Detailed discussion of each temperature adjustment is provided in Sect. 3.4.3. Although TU-5 was tested with a mock-up that represented the lightest proposed content at that time, a new lower weight limit has been established (empty containment vessel). The containment vessel's recorded temperature values were lower on all other test units, which consisted of much heavier mock-up contents. Therefore, a temperature correction is needed for weight differences of the contents shipped and the tested weights.

3.1.1 Design Features

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 and one filled with noncombustible cast neutron poison; a stainless-steel top plug with noncombustible cast refractory insulation, silicone rubber pads, silicon bronze hex-head nuts, and a stainless-steel lid and bottom (Drawing M2E801580A031, Appendix 1.3.7). The drum's diameter (inner diameter of 18.25 in.) and corrugations meet the requirements of Military Standard MS27683. All other dimensions are controlled by Drawing M2E801580A004 (Appendix 1.3.7). Modifications to the drum from MS27683 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 1.3.7). Four 0.795-cm (0.313-in.)–diam equally spaced holes are drilled in the top external sidewall to prevent a pressure buildup between the drum and inner liner. The holes are filled with a plastic plug to provide a moisture barrier for the cast refractory insulation during 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. Drum and inner liner wall thickness is 0.15 cm (16 gauge, 0.0598 in.).

The volume between the drum and mid liner is filled with a lightweight noncombustible cast refractory material called Kaolite 1600 (Kaolite product data sheet). 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 insulation, JS-YMN3-801580-A003 (Appendix 1.3.4), is referenced on Drawings M2E801580A002 and M2E801580A008 (Appendix 1.3.7) for the drum body 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 inside the center liner tube is filled with a noncombustible cast neutron poison (absorber) material called Cat 277-4, which is created by mixing Cat 277-0 material from Shieldwerx (SWX-277-0) and boron carbide (B_4C). The material is composed of aluminum, magnesium, calcium boron, carbon, silicon, sulfur, sodium, iron, and water. The final mixture will have an average density of 1762 kg/m^3 (110 lb/ft^3). The procedure for manufacturing and documenting this material, JS-YMN3-801580-A005 (Appendix 1.3.5), is referenced on Drawing M2E801580A002 (Appendix 1.3.7). This neutron poison material has a maximum continuous service temperature limit of 150.0°C (302°F). At this temperature, the moisture inside the Cat 277-4 material remains an integral part of the composite material, and moisture content loss is negligible.

The top plug is fabricated in accordance with Drawing M2E801580A008 (Appendix 1.3.7), 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 SA-240. Four lifting inserts are welded into the top sheet for loading and unloading operations. The internal volume of the top plug assembly is filled with Kaolite 1600 in accordance with JS-YMN3-801580-A003 (Appendix 1.3.4).

Three silicone rubber pads complete the drum assembly. One pad is placed on the bottom of the most inward 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 lid and closure nut assembly. Pads are molded to the shapes as defined on Drawing M2E801580A009 (Appendix 1.3.7) using silicone rubber with a Shore A durometer reading of 22 ± 5.

3.1.2 Content's Decay Heat

The maximum decay heat and radioactivity of the contents (Sect. 4) are based on a maximum of 35.2 kg of HEU in the isotopic and mass distribution at fabrication as shown in Table 3.1.

Table 3.1. Isotopic mass and weight percent for the HEU contents [a]

Nuclide	Weight percent	Mass (g)
^{232}U	0.000004	0.001408
^{233}U	0.600000	211.200000
^{234}U	2.000000	704.000000
^{235}U	54.819996	19,296.638592
^{236}U	40.000000	14,080.000000
^{238}U	0.000000	0.000000
Transuranic	0.080000 [b]	28.160000
^{237}Np	2.500000	880.000000
Total	**100.000000**	**35,200.000000**

[a] Weight percent values of individual isotopes are those that generate the largest activity within the allowable ranges presented in Sect. 1.2.2.

[b] The transuranic weight percent of 0.080000 applies to ground transport only. The maximum transuranic weight percent in contents transported by air will be 0.004000.

Using the ORIGEN-S program (NUREG/CR-0200) for determining decay heat values and predicting the isotopic decay patterns from 0 to 70 years from original fabrication, the following decay heat loads are predicted and shown in Table 3.2. Isotopic mass distribution has been calculated in Sect. 4 and shown in Table 2 of Appendix 4.5.1. The maximum decay heat load is rounded up from 3.494 to 5 W, and 5 W is used in subsequent analyses for temperature predictions. Contributions from the transuranics and ^{237}Np at the bottom of Table 3.2 remain constant for the time period evaluated. The decay heat per gram value used for the transuranic isotopes was an average of the decay heat values for ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu and ^{241}Am.

3.1.3 Summary Tables of Temperatures

3.1.3.1 NCT summary tables

Thermal evaluation of the package design for NCT was performed by analysis (DAC-PKG-801940-A001). The ES-3100 shipping container has been conservatively evaluated empty of all containment vessel internal components for NCT. A summary of the maximum and minimum predicted temperatures for the drum assembly and containment vessel are shown in Table 3.3. A comprehensive discussion of the NCT evaluation is provided in Sect. 3.3.

Table 3.2. Decay heat for 35.2 kg of HEU content (watts)

Decay heat (Watts per gram)	Isotope	Decay time								
		0 years	5 years	10 years	20 years	30 years	40 years	50 years	60 years	70 years
1.7920E-02	Pb-210	0.0000E+00	2.535964E-12	1.955594E-11	1.463541E-10	4.579875E-10	1.015647E-09	1.854660E-09	3.028017E-09	4.529408E-09
2.6280E+03	Pb-212	0.0000E+00	4.773325E-05	5.328363E-05	4.958338E-05	4.477305E-05	4.070278E-05	3.678051E-05	3.330227E-05	3.015706E-05
2.8650E+02	Bi-210	0.0000E+00	2.500751E-11	1.927998E-10	1.433898E-09	4.517486E-09	1.000300E-08	1.831195E-08	2.984767E-08	4.456984E-08
2.4500E+05	Bi-212	0.0000E+00	4.214730E-04	4.698388E-04	4.387465E-04	3.972902E-04	3.592885E-04	3.257780E-04	2.950312E-04	2.670481E-04
1.4420E+02	Po-210	0.0000E+00	3.472645E-10	2.680638E-09	1.990171E-08	6.275130E-08	1.391089E-07	2.548637E-07	4.132651E-07	6.193899E-07
5.1130E+03	Rn-222	0.0000E+00	7.235482E-09	2.894193E-08	1.155517E-07	2.599014E-07	4.607670E-07	7.199484E-07	1.033126E-06	1.407499E-06
1.8230E+03	Ra-223	0.0000E+00	1.189035E-08	4.502854E-08	1.639320E-07	3.359551E-07	5.452674E-07	7.844815E-07	1.044803E-06	1.319195E-06
5.4700E+03	Ra-224	0.0000E+00	8.625971E-04	9.627200E-04	9.011059E-04	8.163866E-04	7.378287E-04	6.677427E-04	6.045882E-04	5.475952E-04
2.8380E+01	Ra-225	0.0000E+00	5.994152E-07	1.294737E-06	2.589474E-06	3.884210E-06	5.172953E-06	6.473684E-06	7.732456E-06	9.051169E-06
2.8600E-02	Ra-226	0.0000E+00	6.302640E-09	2.517029E-08	1.006812E-07	2.255258E-07	4.007110E-07	6.262368E-07	9.000895E-07	1.224283E-06
1.5200E-02	Ra-228	0.0000E+00	3.124058E-15	1.048485E-14	3.124058E-14	5.499198E-14	7.959929E-14	1.044206E-13	1.294558E-13	1.544911E-13
2.0290E+03	Ac-225	0.0000E+00	3.428182E-05	6.256431E-05	1.251286E-04	1.876929E-04	2.498287E-04	3.123930E-04	3.745288E-04	4.370931E-04
3.5000E-02	Ac-227	0.0000E+00	1.614311E-10	6.139787E-10	2.222211E-09	4.559248E-09	7.429885E-09	1.067202E-08	1.418433E-08	1.789927E-08
1.7460E+04	Ac-228	0.0000E+00	4.376020E-13	1.470146E-12	4.376020E-12	7.694912E-12	1.116131E-11	1.465229E-11	1.814328E-11	2.165884E-11
1.1250E+03	Th-227	0.0000E+00	1.204834E-08	4.580540E-08	1.660717E-07	3.408269E-07	5.535723E-07	7.967100E-07	1.059385E-06	1.339428E-06
2.6850E+01	Th-228	0.0000E+00	8.242674E-04	9.187935E-04	8.582968E-04	7.788949E-04	7.032741E-04	6.389964E-04	5.784997E-04	5.217840E-04
6.0870E-03	Th-229	0.0000E+00	3.856882E-05	5.502484E-05	1.099211E-04	1.645603E-04	2.198423E-04	2.738386E-04	3.291206E-04	3.844025E-04
5.8220E-04	Th-230	0.0000E+00	5.697049E-06	1.135311E-05	2.274721E-05	3.410032E-05	4.549442E-05	5.697049E-05	6.803670E-05	7.951277E-05
5.7940E+02	Th-231	0.0000E+00	4.550499E-05	4.550499E-05	4.550499E-05	4.550499E-05	4.550499E-05	4.550499E-05	4.550499E-05	4.550499E-05
2.6590E-09	Th-232	0.0000E+00	5.428104E-12	1.089364E-11	2.178729E-11	3.268093E-11	4.342483E-11	5.428104E-11	6.551160E-11	7.636781E-11
9.5900E+00	Th-234	0.0000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
1.4390E-03	Pa-231	0.0000E+00	1.343862E-07	2.690500E-07	5.386554E-07	8.079830E-07	1.074534E-06	1.343862E-06	1.613190E-06	1.879741E-06
5.2710E+01	Pa-233	0.0000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
7.0800E-01	U-232	9.9686E-04	9.470208E-04	9.021619E-04	8.174285E-04	7.396731E-04	6.698926E-04	6.070902E-04	5.492721E-04	4.974351E-04
2.8070E-04	U-233	5.9280E-02	5.927847E-02	5.927771E-02	5.927518E-02	5.927266E-02	5.927011E-02	5.926762E-02	5.926507E-02	5.926252E-02
1.7910E-04	U-234	1.2609E-01	1.260924E-01	1.260907E-01	1.260871E-01	1.260837E-01	1.260801E-01	1.260766E-01	1.260732E-01	1.260697E-01
6.0000E-08	U-235	1.1578E-03	1.157798E-03	1.157798E-03	1.157798E-03	1.157798E-03	1.157798E-03	1.157798E-03	1.157798E-03	1.157798E-03
2.0000E-06	U-236	2.4656E-02	2.465563E-02	2.465562E-02	2.465561E-02	2.465561E-02	2.465560E-02	2.465559E-02	2.465559E-02	2.465558E-02
8.5111E-09	U-238	0.0000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
1.1580E-01	transuranic	3.261285E+00	3.261285E+00	3.261285E+00	3.261285E+00	3.261285E+00	3.261285E+00	3.261285E+00	3.261285E+00	3.261285E+00
2.0100E-05	Np-237	1.768800E-02	1.768800E-02	1.768800E-02	1.768800E-02	1.768800E-02	1.768800E-02	1.768800E-02	1.768800E-02	1.768800E-02
	Total watts	**3.491158E+00**	**3.493385E+00**	**3.493638E+00**	**3.493521E+00**	**3.493358E+00**	**3.493217E+00**	**3.493107E+00**	**3.493016E+00**	**3.492946E+00**

Table 3.3. 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. 3.3.1
Maximum drum temperature with insolation, °C (°F)	118.86 (245.94) [a]	N/A	Sect. 3.3.1
Maximum containment vessel temperature with insolation, °C (°F)	91.93 (197.48) [a]	427 (800) [b]	Sect. 3.3.1
Maximum O-ring temperature, °C (°F)	91.87 (197.36) [a]	150 (302) [c]	Sect. 3.3.1

[a] DAC-PKG-801940-A001.
[b] *ASME Boiler and Pressure Code*, Sect. II, Part D, maximum allowable temperature for Sect. III, Div. 1, Subsection NB vessel.
[c] Maximum ethylene propylene diene monomer O-ring seal life up to 150°C (302°F) for 1000 h of continuous service (*Parker O-Ring Handbook*, Fig. 2-28).

3.1.3.2 HAC temperature summary tables

Thermal evaluation of the package design for HAC was performed by a combination of physical testing and analysis. Temperature indicators (patches) were placed on the surface of each containment vessel, inner liner, and mock-up component during thermal testing. The blackout temperatures that occurred during thermal testing are recorded for each test unit; the maximum blackout temperatures are listed in Table 3.4. In order to more accurately predict the final HAC temperatures, the blackout temperatures are increased to account for (1) the temperature interval between blackout dots; (2) the ambient temperature of the package prior to insertion into the furnace; (3) the temperature increase due to the effects of applying solar insolation during post-HAC thermal test cool down; (4) the temperature increase due to the decay heat load of the actual contents being shipped; (5) effects of crushing at different locations along the body of the shipping package; (6) thermal capacitance difference in the proposed contents and hardware used during testing; (7) temperature difference occurring when using Cat 277-4 in place of Borobond4; and (8) temperature difference resulting from variations in Kaolite 1600 and Cat 277-4 material densities. A summary of the maximum and minimum predicted temperatures for the drum assembly and containment vessel is shown in Table 3.5. A comprehensive discussion of the HAC evaluation is provided in Sect. 3.4.

Table 3.4. 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 containment vessel body wall high	99 (210)	99 (210)	99 (210)	99 (210)	104 (219)
Adjacent to containment vessel 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 for recorded values.
[b] Temperature-indicating patch may have been damaged due to impact with surrounding structure.

Table 3.5. Summary of results of evaluation under HAC for the ES-3100 shipping arrangement using bounding case parameters

Condition	Results	Design limits	SARP reference
Maximum adjusted containment vessel temperature during testing, °C (°F)	167.22 (332.99)	426.67 (800) [a]	Sect. 3.4.3
Maximum adjusted O-ring temperature, °C (°F)	156.19 (313.14) [b]	150 (302) [b]	Sect. 3.4.3

[a] *ASME Boiler and Pressure Code*, Sect. II, Part D, maximum allowable temperature for Sect. III, Div. 1, Subsection NB vessel.
[b] Maximum ethylene propylene diene monomer O-ring seal life at 156.19°C (313.14°F) is several hundred hours (*Parker O-Ring Handbook*, Fig. 2-24). Limit shown is for 1000 h of continuous service at a temperature up to 150°C (302°F).

3.1.4 Summary Tables of Maximum Pressures

3.1.4.1 Maximum NCT pressures

Table 3.6 summarizes the results from Appendix 3.5.1 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 offgas 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 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.) diam by 12.38-cm (4.875-in.)–high cans;

2. one shipment will contain five cans with external dimensions of 10.8-cm (4.25-in.) diam by 12.38-cm (4.875-in.)–high cans and three can spacers;

3. one shipment will contain three cans with external dimensions of 10.8-cm (4.25-in.) diam by 22.23-cm (8.75-in.) high and two can spacers;

4. one shipment will contain three cans with external dimensions of 10.8-cm (4.25-in.) diam by 25.4 cm (10 in.) high;

5. one shipment will contain six nickel cans with external dimensions of 7.62-cm (3.00-in.) diam by 12.07-cm (4.75-in.) high;

6. one shipment will contain three polyethylene bottles with external dimensions of 12.54-cm (4.94-in.) diam by 22.1-cm (8.7-in.) high;

7. one shipment will contain three Teflon bottles with external dimensions of 11.91-cm (4.69-in.) diam by 23.88-cm (9.4-in.) high;

8. one shipment will contain a brazed assembly of two cans with final external dimensions of 10.8-cm (4.25-in.) diam by 44.46-cm (17.50-in.) high. An empty can with external dimensions of 10.8-cm (4.25-in.) diam by 22.23-cm (8.75-in.) high will be placed on top or bottom of the 44.46-cm (17.50-in.)-high can;

9. one shipment will contain fuel rods, or tubes, or plates greater than 43.18 cm (17.00 in.) in length. These items are bundled together and protected on both ends with an open-ended can with external dimensions of ≤12.7-cm (5.0-in.) diam by ≤ 22.23-cm (8.75-in.) high. Total assembly height will be ≤77.47 cm (30.5 in.). If space is available inside the containment vessel, stainless-steel metal scrubbers will be added on the bottom and top of this assembly or an empty can will be placed on top or bottom of this partially canned assembly;

10. one shipment will contain three cans brazed together with external dimensions of 4.25-in. diam by ~30-in. high; and

11. one shipment will contain closed cans with diameters >4.25 in. In this situation, the void volume inside the loaded containment vessel must be ≥55 $in.^3$

Table 3.6. Total pressure inside the containment vessel at 91.93°C (197.48°F) [a]

CVA	n_a [b] (lb-mol)	n_v [b] (lb-mol)	n_{po} [b] (lb-mol)	n_{bo} [b] (lb-mol)	n_{tf} [b] (lb-mol)	n_{H2} [b] (lb-mol)	n_{O2} [b] (lb-mol)	n_T [b] (lb-mol)	P_T (psia)
1	2.1527E-05	6.6047E-04	0.0000E+00	0.0000E+00	0.0000E+00	3.6862E-05	1.8431E-05	7.3729E-04	19.457
7	4.7285E-04	2.8668E-04[c]	0.0000E+00	0.0000E+00	2.2296E-05	2.5558E-05	1.2779E-05	8.2016E-04	31.218
11	2.5278E-06	7.7556E-05	0.0000E+00	0.0000E+00	0.0000E+00	4.3285E-06	2.1643E-06	8.6577E-05	19.457

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] n_a—molar quantity of dry air in the gas mixture;
n_v—molar quantity of water vapor in the gas mixture;
n_{po}—molar quantity of gas due to offgassing of the silicone rubber pads;
n_{bo}—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
n_{tf}—molar quantity of gas due to offgassing of the Teflon bottles;
n_{H2}—molar quantity of hydrogen gas due to radiolysis of water;
n_{O2}—molar quantity of oxygen gas due to radiolysis of water; and
n_T—total molar quantity in the gas mixture.

[c] This value is the molar quantity of water vapor generated from the efflorescence of UNX crystals.

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% for all configurations except for CVA 7; CVA 7 assumes the air is 100% dry;

2. the convenience cans and bottles are assumed to not be sealed to maximize the void volume inside the containment vessel;

3. convenience can and bottle geometry does not change during pressure increase inside containment vessel;

4. if metal convenience cans are used, the total amount of polyethylene bagging and lifting slings is limited to 500 g per containment vessel shipping arrangement;

5. the mass of offgassing material (polyethylene bagging or bottles, Teflon bottles, silicone pads, lifting slings) is assumed to be 1490 g for the offgassing evaluation of CVA 7;

6. CVA 11 uses metal cans and, therefore, is limited to 500 g of polyethylene bagging and lifting slings.

The offgassing material limits identified in assumptions 4 and 5 have been established based on the needs of shippers. All configurations are limited to 500 g of polyethylene in the form of bags, slings, and/or bottles. When the requirement to ship material in Teflon bottles arose, the upper limit of 1490 g of offgassing material was established. This limit is a combination of three Teflon bottles (330 g per bottle) and the original 500-g allowance for polyethylene material. These offgassing material limits have been used in calculations pertaining to containment vessel pressure, radioactive material leakage criteria, and criticality control. Therefore, portions of the safety basis for this shipping package have been based on these material limits.

NUREG-1609, Sect. 4.5.2.3, requires the applicant to demonstrate that any combustible gases generated in the package during a period of one year do not exceed 5% (by volume) of the free gas volume in any confined region of the package. No credit should be taken for getters, catalysts, or other recombination devices. The analysis conducted in Appendix 3.5.4 evaluates the different packaging arrangements for the generation of hydrogen gas due to the radiolysis of water vapor, free water, interstitial water, polyurethane bags, and polyurethane or Teflon bottles. By limiting the mass and the material composition as shown in Appendix 3.5.4, the combustible gas concentration limit stated in NUREG-1609 is not exceeded. These limits are further discussed and shown in Tables 1.3 and 1.3a. Getters, catalysts, or other recombination devices are not employed in any of the containment vessel packaging arrangements. The analysis conducted in Appendix 3.5.1 predicts the maximum normal operating pressure inside the containment vessel for the various packaging arrangements and masses discussed previously. This appendix also includes the hydrogen gas generation predicted by Appendix 3.5.4.

The uranyl nitrate crystals (UNX) in any hydrated state are very efflorescent and will lose water molecules at the temperature shown in Table 3.3 [91.93°C (197.48°F)]. As shown in Table 3.6, the containment vessel pressure is calculated to be 215.24 kPa (31.218 psia) with the contribution from UNX crystal efflorescence. This calculation is shown in greater detail in Appendix 3.5.1.

3.1.4.2 Maximum HAC pressures

Table 3.7 summarizes the results from Appendix 3.5.2 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 3.6 for each CVA at standard temperature [25°C (77°F)];

2. the convenience cans and bottles are assumed to not be sealed in order to maximize 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. if metal convenience cans are used, the total amount of polyethylene bagging and lifting slings is limited to 500 g per containment vessel shipping arrangement;

5. the mass of offgassing material (polyethylene bagging or bottles, Teflon bottles, silicone pads, lifting slings) is assumed to be 1490 g for the offgassing evaluation of CVA 7;

6. CVAs that utilize closed convenience cans with a diameter greater than 10.8 cm (4.25 in.) will have a minimum void volume of $\geq$55 $in.^3$ for gas evolution and expansion;

7. hydrogen and oxygen molar quantities calculated in Appendix 3.5.1 are conservatively added to the gas mixture for HAC; and

8. the contribution in pressure generated by the efflorescence of UNX crystals is incorporated into the results for CVA 7.

Table 3.7. Total pressure inside the containment vessel at 140.36°C (284.64°F) [a] with efflorescence

CVA	n_{MNOP} [b] (lb-mol)	n_{po} [b] (lb-mol)	n_{bo} [b] (lb-mol)	n_{tf} [b] (lb-mol)	n_{r-H2} [b] (lb-mol)	n_{r-O2} [b] (lb-mol)	n_{CE-WV} [b,c] (lb-mol)	n_T [b] (lb-mol)	P_T (psia)
1	9.0270E-04	1.3458E-05	3.1529E-04	0.0000E+00	3.6862E-05	1.8431E-05	0.0000E+00	1.2867E-03	38.459
7	1.0042E-03	0.0000E+00	3.1529E-04	2.2296E-05	2.5558E-05	1.2779E-05	1.2286E-03	2.6087E-03	112.458
11	1.0600E-04	1.3485E-05	3.1529E-04	0.0000E+00	4.3285E-06	2.1643E-06	0.0000E+00	4.4127E-04	112.318

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] n_{MNOP}—molar quantity of the gas mixture at maximum normal operating pressure at standard temperature [25°C (77°F)];
n_{po}—molar quantity of gas due to offgassing of the silicone rubber pads;
n_{bo}—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
n_{tf}—molar quantity of gas due to offgassing of the Teflon bottles;
n_{r-H2}—molar quantity of hydrogen gas due to radiolysis of water;
n_{r-O2}—molar quantity of oxygen gas due to radiolysis of water;
n_{CE-WV}—molar quantity of water vapor due to efflorescence of UNX crystals; and
n_T—total molar quantity in the gas mixture.

[c] Efflorescence of UNX crystals as water vapor.

The offgassing material limits identified in assumptions 4 and 5 have been established based on the needs of shippers. All configurations are limited to 500 g of polyethylene in the form of bags, slings, and/or bottles. When the requirement to ship material in Teflon bottles arose, the upper limit of 1490 g of offgassing material was established. This limit is a combination of three Teflon bottles (330 g per bottle) and the original 500 g allowance for polyethylene material. These offgassing material limits have been used in calculations pertaining to containment vessel pressure, radioactive material leakage criteria, and criticality control. Therefore, portions of the safety basis for this shipping package have been based on these material limits.

3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

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 (initial design) or Cat 277-4 (final design)], silicone rubber pads, and air are listed in Table 3.8. Properties used to evaluate thermal stresses due to differences in coefficient of thermal expansion are listed in Table 3.9.

3.2.2 Component Specifications

Component specifications are listed in Tables 3.10 and 3.11.

Table 3.8. Thermal properties of the materials used in the thermal analysis

Material	Temperature (°F)	Thermal conductivity (Btu/h-in.-°F)	Density ($lb_m/in.^3$)	Specific heat (Btu/lb_m-°F)	Emissivity
Stainless steel	−279.67	0.443 [a]	0.285 [a]	0.065 [a]	0.22 [a]
	−99.67	0.607	–	0.096	–
	260.33	0.799	–	0.123	–
	620.33	0.953	–	0.133	–
	980.33	1.088	–	0.139	–
	1340.33	1.223	–	0.146	–
	1700.33	1.348	–	0.153	–
	2240.33	1.526	–	0.163	–
Kaolite 1600	68	0.0093 [b]	0.011 [c]	0.2 [d]	–
	212	0.0091	–	–	–
	392	0.0081	–	–	–
	572	0.0072	–	–	–
	1112	0.0082	–	–	–
Neutron poison (Cat 277-4)	−31	0.0457 [e]	0.0579 [f]	0.125 [e]	–
	73.4	0.0485	–	0.186	–
	140	0.04	–	0.239	–
	212	0.0295	–	0.242	–
	302	0.0305	–	0.291	–
Neutron poison (BoroBond4)	25	0.0450 [g]	0.0683 [g]	0.2160 [g]	–
	77	0.0576	–	–	–
	100	0.0632	–	–	–
	104	0.0642	–	–	–
Silicone rubber	–	0.0161 [h]	0.047 [h]	0.300 [h]	1.0 [i]

Table 3.8. Thermal properties of the materials used in the thermal analysis

Material	Temperature (°F)	Thermal conductivity (Btu/h-in.-°F)	Density ($lb_m/in.^3$)	Specific heat (Btu/lb_m-°F)	Emissivity
Air	−9.67	1.074×10^{-3} [a]	4.064×10^{-5} [a, j]	0.240 [a]	–
	80.33	1.266×10^{-3}	–	0.241	–
	170.33	1.445×10^{-3}	–	0.241	–
	260.33	1.628×10^{-3}	–	0.242	–
	350.33	1.796×10^{-3}	–	0.244	–
	440.33	1.960×10^{-3}	–	0.246	–
	530.33	2.114×10^{-3}	–	0.248	–
	620.33	2.258×10^{-3}	–	0.251	–
	710.33	2.393×10^{-3}	–	0.254	–
	800.33	2.523×10^{-3}	–	0.257	–
	890.33	2.644×10^{-3}	–	0.260	–
	980.33	2.759×10^{-3}	–	0.263	–
	1070.33	2.870×10^{-3}	–	0.265	–
	1160.33	2.985×10^{-3}	–	0.268	–
	1250.33	3.096×10^{-3}	–	0.270	–
	1340.33	3.212×10^{-3}	–	0.273	–
	1520.33	3.443×10^{-3}	–	0.277	–

[a] Incropera and DeWitt.
[b] ORNL/TM-2003/49.
[c] Based on a baked density of 19.4 lbm/ft^3 (0.011 $lbm/in.^3$). Specification JS-YMN3-801580-A003 (Appendix 1.3.4) requires a baked density of 22.4 ± 3 lbm/ft^3. Using a lower value for the Kaolite density results in higher temperatures on the containment vessel because the heat capacity of the Kaolite is minimized—allowing more heat to flow to the containment vessel; therefore, the thermal analyses are performed using a low-end density of 19.4 lbm/ft^3. The HAC analyses also consider a high-end density of 30 lbm/ft^3.
[d] Breuer, fax communication to J. C. Anderson.
[e] ORNL/TM-2004/290. Specific heat values are presented in MJ/m^3-K and converted to mass-based units using a density of 105 lbm/ft^3.
[f] Based on a cured density of 100 lbm/ft^3 (0.0579 $lbm/in.^3$). Y/DW-1987, presents a range of measured densities between ~100 and 110 lbm/ft^3 for Cat 277-4. Therefore, in order to minimize the heat capacity of the material and allow more heat to be transferred to the containment vessel, the lower-end value is used. The HAC analyses also consider a high-end density of 110 lbm/ft^3.
[g] Hall, e-mail communication with presentation attachment to G. A. Byington.
[h] Therm 1.2.
[i] Conservatively modeled as 1.0.
[j] Constant density evaluated at 100°F.

Table 3.9. Mechanical properties of the materials used in the static stress analyses

Material	Temperature (°F)	Modulus of elasticity (psi)	Poisson's ratio	Density ($lb_m/in.^3$)	Coefficient of thermal expansion (in./in./°F)
Stainless steel	−40	28.6×10^6 [a]	0.29 [b]	0.285 [d]	8.2×10^{-6} [e]
	100	28.14×10^6	—	—	8.6×10^{-6}
	200	27.6×10^6	—	—	8.9×10^{-6}
	300	27.0×10^6	—	—	9.2×10^{-6}
Kaolite	—	29,210 [c]	0.01 [c]	0.013 [f]	5.04×10^{-6} [g]
Neutron absorber (Cat 277-4)	−40	1.991×10^6 [h]	0.33 [h]	0.0608 [h]	7.056×10^{-6} [i]
	−4	—	—	—	7.222×10^{-6}
	32	—	—	—	7.222×10^{-6}
	70	0.984×10^6	0.28	—	—
	100	0.403×10^6	0.25	—	—
	104	—	—	—	7.000×10^{-6}
	140	—	—	—	6.444×10^{-6}
	176	—	—	—	5.778×10^{-6}
	212	—	—	—	5.389×10^{-6}
	248	—	—	—	5.056×10^{-6}
	284	—	—	—	4.889×10^{-6}
	302	—	—	—	4.833×10^{-6}

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 2, Tables TE-1, B column, and TM-1.
[b] STRAIN 2.0.
[c] DAC-EA-801699-A001. (The Poisson's ratio of Kaolite is assumed to be a small value of 0.01.)
[d] Incropera and DeWitt.
[e] MIL-HDBK-5H.
[f] Specification JS-YMN3-801580-A003 (Appendix 1.3.4) requires a baked density of 22.4 ± 3 lbm/ft^3.
[g] E-mail communication, Ken Moody (Thermal Ceramics, Inc.) to Paul Bales (BWXT Y-12), December 9, 2004.
[h] Y/DW-1987.
[i] ORNL/TM-2004/290. Coefficient of thermal expansion at each temperature taken as the maximum of values for Runs 2, 3, and 5.

Table 3.10. 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-in. long, ARC FT, Type 304 or 304L stainless-steel studs
Drum hex nuts	5/8-11 UNC-2B, silicon bronze C65100
Drum lid weldment	Modified 30-gal, 16-gauge (MS27683) lid, Type 304 or 304L stainless steel; and an 11-gauge-thick sheet, Type 304 or 304L stainless steel, ASME SA-240
Drum weldment	Modified 30-gal, 16-gauge (MS27683), Type 304 or 304L stainless steel, ASME SA-240, manufactured per Drawing M2E801580A004 (Appendix 1.3.7)
Drum plugs	Nylon plastic plug, Micro Plastic, Inc.
	Impact limiter, insulation enclosure, neutron absorber, and drum packing material
Insulation and impact limiter (not removable)	Lightweight cast refractory insulation, Kaolite 1600, 358.8 ±48.1 kg/m^3 (22.4 ±3 lb/ft^3) density, cast in stainless-steel shells in the drum and top plug
Neutron absorber	Cat 277-4, 1681.9 + 240.3/−80.1 kg/m^3 (105 + 15/−5 lb/ft^3) density
Top plug (removable)	Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (lifting inserts)
Inner liners	Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (modified angle)
Silicone pads	Silicone rubber, 22 ±5 Shore A, color black/gray
Aluminum foil duct tape	McMaster Carr Part # 7616A21, temperature range −40 to 121°C (−40 to 250°F)
	Containment vessel
Containment vessel plug	Part # 04-2126, Modified VCO threaded plug with O-ring, 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 (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 stainless steel per ASME SA-479, UNS-S21800 (closure nut) Method 2: Type F304L stainless-steel ASME SA-182 (body, flange, and end cap); Type 304, stainless steel, ASME SA-479 (sealing lid), Nitronic 60 stainless steel 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 diene monomer, Specification M3BA712A14B13F17 in ASTM D 2000 per SPC-M801580-0002 (Appendix 1.3.9)
Containment vessel lid assembly retaining ring	Smalley Steel Ring Co., Part #WSM-400-S02, Type 302 stainless steel
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-in. OD × 0.50-in. long, 18-8 stainless steel

Table 3.10. ES-3100 packaging material specifications

Component	Specifications
Containment vessel packing material	
Convenience cans	Stainless steel, aluminum, 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, glass, or Teflon FEP
Silicone rubber pads	Silicone rubber, 22 ±5 Shore A, color black/gray
Can spacers	Stainless-steel can filled with Cat 277-4
Bagging	Polyethylene
Metal scouring scrubbers	Stainless steel, McMaster Carr Part #7361T13

Table 3.11. Component allowable service temperature and pressure

Component	Allowable service temperature range [°C (°F)]	Allowable pressure range [kPa (psia)]
Drum assembly		
Stainless-steel drum and lid	−40 to 871 (−40 to 1600) [a]	48.3 (7)
Silicon bronze nuts	−40 to 871 (−40 to 1600) [a]	N/A
Stainless-steel washers	−40 to 871 (−40 to 1600) [a]	N/A
Stainless-steel mid liner	−40 to 871 (−40 to 1600) [a]	N/A
Stainless-steel inner liner	−40 to 871 (−40 to 1600) [b]	N/A
Stainless-steel top plug weldment	−40 to 871 (−40 to 1600) [a]	N/A
Kaolite 1600	−40 to 871 (−40 to 1600) [a]	N/A
Cat 277-4	−40 to 150 (−40 to 302) [c]	N/A
Silicone rubber pads	−40 to 232 (−40 to 450)	N/A
Containment vessel		
Stainless-steel body and sealing lid	−40 to 427 (−40 to 800) [d]	149.62 (21.7) external 699.82 (101.5) internal
Nitronic 60 closure nut	−40 to 427 (−40 to 800) [d]	149.62 (21.7) external 699.82 (101.5) internal
Stainless-steel retaining ring	−40 to 427 (−40 to 800) [d]	N/A
Dowel pins	−40 to 427 (−40 to 800) [d]	N/A
Brass VCO plug (with O-ring)	−40 to 204 (−40 to 400) [e]	
Ethylene propylene diene monomer O-rings	−40 to 150 (−40 to 302) [e]	5.52×10^3 (800) with no backing rings [e]
Containment vessel silicone pads	−40 to 232 (−40 to 450)	N/A

[a] This limit is established by the proximity of the Kaolite 1600 material.
[b] This limit is established based on the fact that the inner liner material is identical to the drum material.
[c] This limit is established based on criticality limits of moisture loss.
[d] This limit is established by the *ASME Boiler and Pressure Vessel Code*.
[e] This limit is provided by the *Parker O-Ring Handbook* for each material's continuous service limit.

3.3 THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT

Thermal evaluation of the package design for NCT was performed by analysis and documented in DAC-PKG-801699-A001 and DAC-PKG-801940-A001.

DAC-PKG-801699-A001 uses a two-dimensional axisymmetric finite element model of the ES-3100 shipping container constructed using MSC.Patran and imported as an orphaned mesh into ABAQUS/CAE for application of boundary conditions, interactions, and loads. MSC.Patran and ABAQUS/CAE have been benchmarked against physical test data for a Y-12 packaging application and shown to provide accurate results (DAC-PKG-801805-A003). The model was constructed of DCAX4 (four-node linear axisymmetric heat transfer quadrilateral) and DCAX3 (3-node linear axisymmetric heat transfer triangular) elements for evaluation for NCT and HAC. The actual contents of the ES-3100 shipping container were not specifically modeled—instead, the content source heat load (if desired) was modeled by applying a uniform heat flux to the inner surfaces of the containment vessel. This was a conservative approach in that package temperatures will not be reduced in a transient analysis by the heat capacity of the contents. Thermal properties of the materials used in the analysis are presented in Table 3.8. Prior to the change of neutron absorber from BoroBond4 to Cat 277-4, parameters, such as Kaolite 1600 density, BoroBond4 thermal conductivity, and decay heat loads, were varied to encompass the range of potential variations in material properties. The available thermal conductivity information on BoroBond4 was limited to moderate temperatures in the range of −3.89°C (25°F) to 40°C (104°F) [Hall 2004]. Using the available thermal conductivity data for BoroBond4, thermal analyses for NCT and HAC were performed and are documented in DAC-PKG-801699-A001. Nodal locations for temperatures presented are shown in Fig. 3.1.

Based on the results reported in DAC-PKG-801699-A001 and shown in Tables 3.12 and 3.13, it was determined that the higher temperatures occurred when the lowest density of the Kaolite 1600 was used. Therefore, a subsequent analysis using the proposed Cat 277-4 neutron absorber during NCT with a Kaolite 1600 density of 19.4 lb/ft^3 was conducted and documented in DAC-PKG-801940-A001. A two-dimensional axisymmetric finite element model of the ES-3100 shipping container was constructed using ANSYS software for application of boundary conditions, interactions, and loads. A schematic of the finite element model is presented in Fig. 3.2 with details of the upper and lower portions of the model shown in Figs. 3.3 and 3.4, respectively. The model consists of five materials: stainless steel (drum, liners, and containment vessel), Kaolite, neutron absorber, silicone rubber, and air in the gaps between the drum liner and containment vessel and between the drum liner and top plug. Degree-of-freedom “ties” are made at the interfaces of the different material regions in order to allow the heat to flow through the model. The actual contents of the ES-3100 shipping container are not specifically modeled—instead, the content source heat load (if desired) is modeled by applying a uniform heat flux to the inner surfaces of the containment vessel. This is a conservative approach in that package temperatures will not be reduced in a transient analysis by the heat capacity of the contents. The results for the steady state condition at 38°C (100°F) in the shade, and the transient condition of applying solar insolation are shown in Tables 3.14 and 3.15 for the proposed configuration (package with Cat 277-4 neutron absorber).

3.3.1 Heat and Cold

The ambient temperature requirement for NCT is 38°C (100°F). Since the components to be shipped have an assumed decay heat load of 5 W, a thermal analysis was conducted for the ES-3100 package with and without full solar insolation. The maximum predicted temperature, while stored at 38°C (100°F) in the shade, for the external drum assembly and the containment vessel is 40.22°C (104.39°F) and 46.45°C (115.61°F), respectively. 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 use or nonexclusive use).

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 top surface of the containment vessel, and on the containment vessel near the O-ring sealing surfaces, are 118.86°C (245.94°F), 91.92°C (197.46°F), and 91.87°C (197.36°F), respectively, for the ES-3100 (Table 3.15). 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) for the ethylene propylene diene monomer (EPDM) O-rings [Table 3.11] in accordance with *Parker O-Ring Handbook*. Thus, the seal will not be affected by this maximum normal operating temperature.

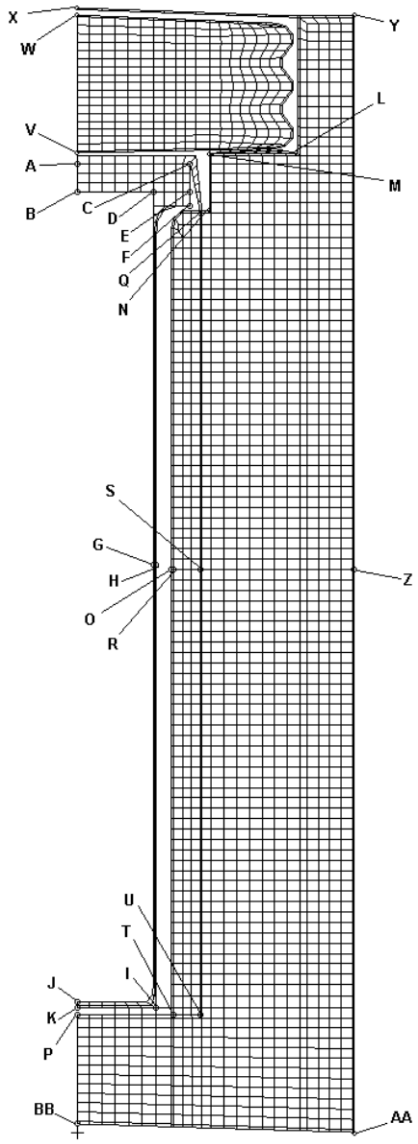


Fig. 3.1. MSC.Patran axisymmetric finite element model of the ES-3100 shipping container with BoroBond 4—nodal locations of interest (elements representing air not shown for clarity).

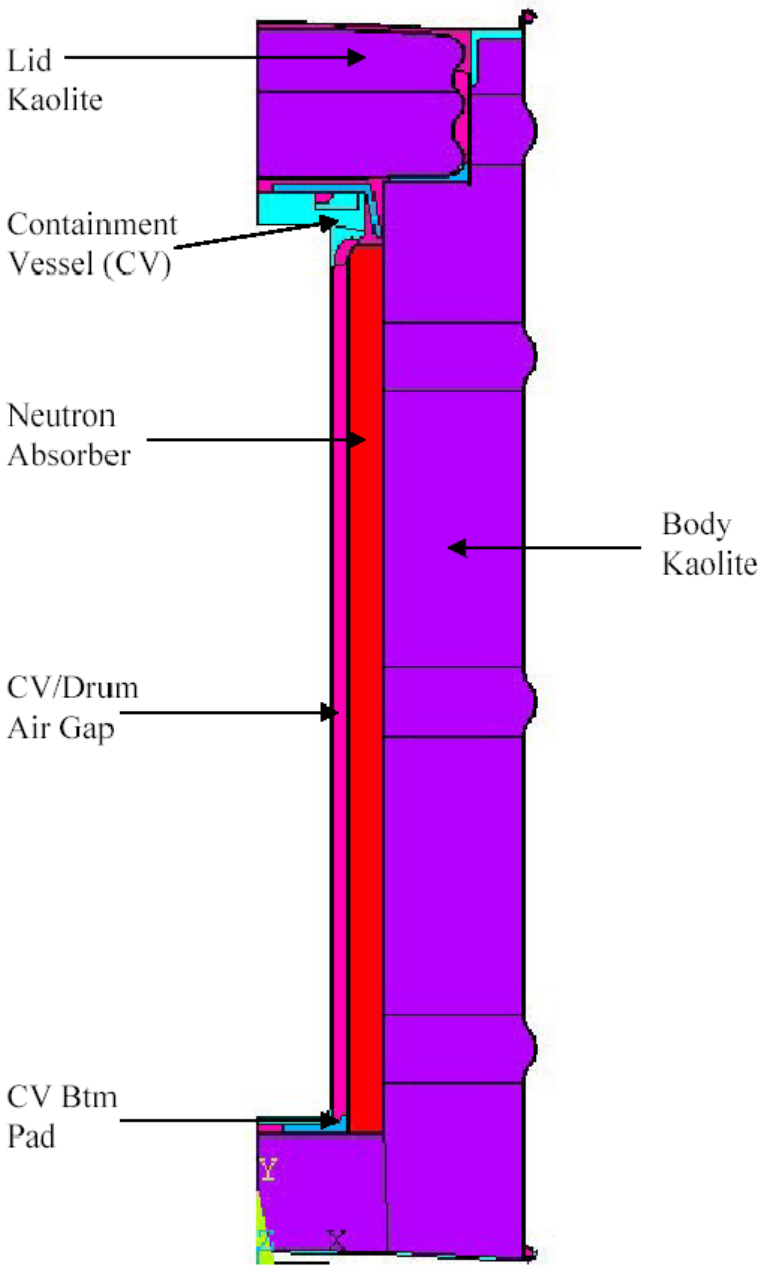


Fig. 3.2. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4.

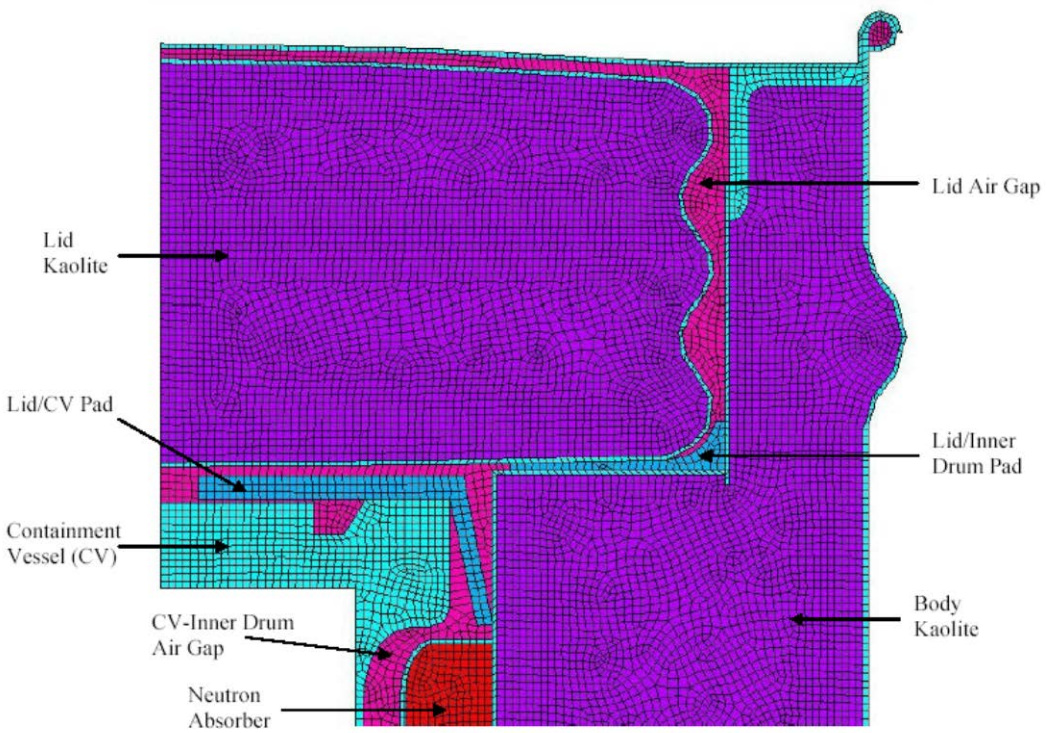


Fig. 3.3. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4 (upper portion detail).

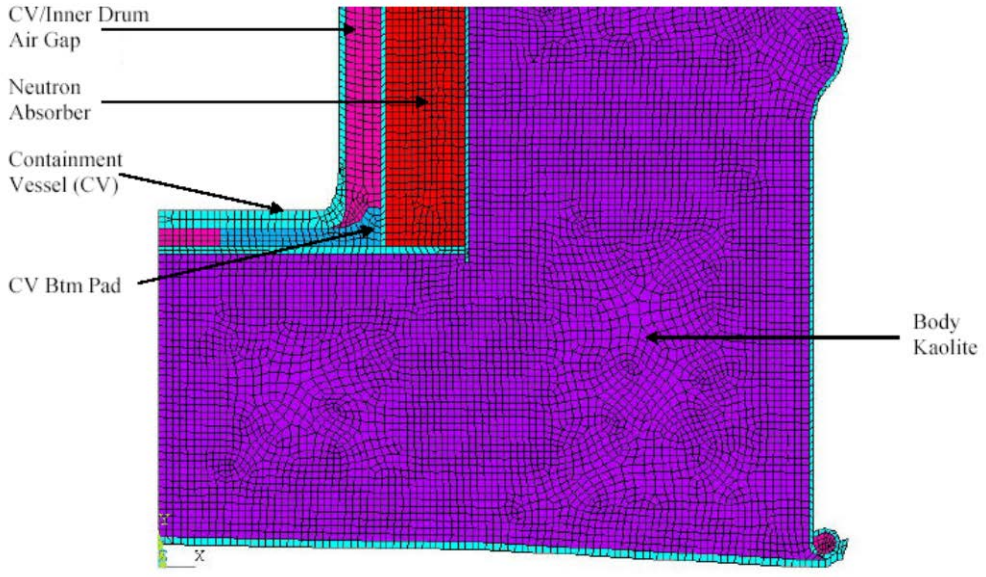


Fig. 3.4. ANSYS axisymmetric finite element model of the ES-3100 shipping container with Cat 277-4 (lower portion detail).

Table 3.12. Maximum "quasi steady-state" temperatures during NCT for the ES-3100 shipping container with various content heat loads—Kaolite density of 19.4 lb/ft^3 and BoroBond4

Node [a]	Location	Maximum "quasi steady-state" temperature, °C (°F) [c]			
		0 W	0.4 W	20 W	30 W
A	CV [d] lid, top, center	88.30 (190.95)	88.62 (191.52)	103.84 (218.91)	111.35 (232.42)
B	CV lid, bottom, center	88.28 (190.90)	88.60 (191.48)	103.90 (219.03)	111.45 (232.62)
C	CV lid, top, outer	88.32 (190.97)	88.63 (191.54)	103.61 (218.50)	111.00 (231.80)
D	CV flange at interface, inner [b]	88.24 (190.83)	88.56 (191.41)	103.87 (218.96)	111.42 (232.55)
E	CV flange at interface, outer [b]	88.25 (190.84)	88.56 (191.41)	103.77 (218.78)	111.27 (232.28)
F	CV flange, bottom, outer	88.24 (190.82)	88.55 (191.39)	103.75 (218.75)	111.25 (232.24)
G	CV shell, mid-height, inner	83.04 (181.47)	83.61 (182.50)	110.50 (230.89)	123.46 (254.23)
H	CV shell, mid-height, outer	83.04 (181.47)	83.61 (182.50)	110.49 (230.88)	123.45 (254.21)
I	CV bottom, outer	83.36 (182.04)	83.75 (182.74)	102.58 (216.64)	111.99 (233.59)
J	CV bottom, center, inner	88.37 (182.07)	83.76 (182.77)	102.70 (216.86)	112.17 (233.91)
K	CV bottom, center, outer	88.37 (181.07)	83.76 (182.77)	102.69 (216.84)	112.15 (233.87)
L	Drum liner, plug cavity, outer	98.72 (209.70)	98.80 (209.85)	102.63 (216.73)	104.58 (220.24)
M	Drum liner, plug cavity, inner	94.43 (201.97)	94.58 (202.24)	101.92 (215.46)	105.65 (222.16)
N	Drum liner, CV flange cavity, outer	89.43 (192.97)	89.63 (193.34)	99.83 (211.70)	105.01 (221.02)
O	Drum liner, CV cavity, mid-height, inner	83.12 (181.62)	83.43 (182.18)	98.63 (209.54)	106.40 (223.52)
P	Drum liner, CV cavity, bottom, inner	83.62 (182.52)	83.96 (183.13)	100.36 (212.65)	108.60 (227.48)
Q	Borobond4, top, outer	88.82 (191.88)	89.04 (192.27)	99.65 (211.38)	105.04 (221.07)
R	Borobond4, mid-height, inner	83.12 (181.62)	83.43 (182.18)	98.63 (209.53)	106.39 (223.51)
S	Borobond4, mid-height, outer	83.03 (181.46)	83.33 (182.00)	97.91 (208.23)	105.36 (221.65)
T	Borobond4, bottom, inner	83.55 (182.39)	83.85 (182.93)	98.58 (209.45)	106.03 (222.86)
U	Borobond4, bottom, outer	83.51 (182.31)	83.80 (182.83)	97.82 (208.07)	104.90 (238.82)
V	Drum plug liner, bottom, center	112.01 (233.62)	112.05 (233.69)	113.95 (237.11)	114.90 (238.82)
W	Drum plug liner, top, center	92.09 (197.77)	92.31 (198.16)	102.93 (217.27)	108.26 (226.87)
X	Drum lid, top, center	118.01 (244.42)	118.03 (244.45)	118.77 (245.79)	119.15 (246.47)
Y	Drum lid, top, outer	107.33 (225.19)	107.34 (225.22)	108.22 (226.80)	108.67 (227.60)
Z	Drum, mid-height, outer	92.27 (198.08)	92.30 (198.14)	93.81 (200.86)	94.58 (202.24)
AA	Drum bottom, outer	91.70 (197.06)	91.74 (197.13)	93.61 (200.49)	94.54 (202.18)
BB	Drum bottom, center	88.82 (191.88)	88.93 (192.07)	93.84 (200.91)	96.30 (205.35)

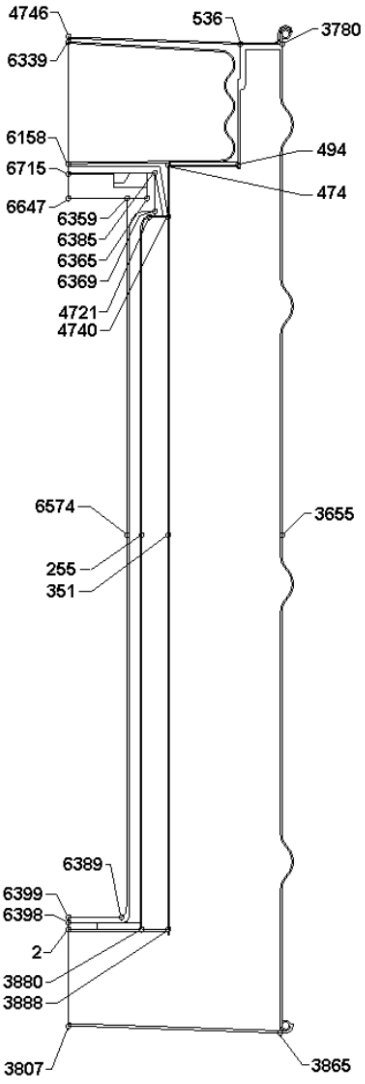
[a] See Fig. 3.1.
[b] Approximate location of the CV O-ring.
[c] Temperatures calculated in DAC-PKG-801699-A001.
[d] CV—containment vessel.

Table 3.13. Maximum "quasi steady-state" temperatures during NCT for the ES-3100 shipping container with various content heat loads—Kaolite density of 30 lb/ft^3 and BoroBond4

Node [a]	Location	Maximum "quasi steady-state" temperature, °C (°F) [c]			
		0 W	0.4 W	20 W	30 W
A	CV [d] lid, top, center	86.56 (187.81)	86.88 (188.38)	102.98 (215.74)	109.59 (229.26)
B	CV lid, bottom, center	86.56 (187.80)	86.88 (188.38)	102.16 (215.90)	109.71 (229.47)
C	CV lid, top, outer	86.54 (187.78)	86.86 (188.34)	101.89 (215.41)	109.31 (228.75)
D	CV flange at interface, inner [b]	86.47 (187.64)	86.79 (188.21)	102.09 (215.77)	109.67 (229.40)
E	CV flange at interface, outer [b]	86.44 (187.59)	86.76 (188.16)	102.00 (215.61)	109.53 (229.15)
F	CV flange, bottom, outer	86.42 (187.56)	86.74 (188.13)	101.99 (215.58)	109.51 (229.12)
G	CV shell, mid-height, inner	81.52 (178.74)	82.09 (179.76)	109.01 (228.21)	121.98 (251.57)
H	CV shell, mid-height, outer	81.52 (178.74)	82.09 (179.76)	109.00 (228.19)	121.97 (251.55)
I	CV bottom, outer	81.32 (178.37)	81.71 (179.08)	100.57 (213.02)	109.99 (229.99)
J	CV bottom, center, inner	81.37 (178.47)	81.77 (179.18)	100.73 (213.31)	110.21 (230.38)
K	CV bottom, center, outer	81.37 (178.47)	81.77 (179.18)	100.72 (213.29)	110.19 (230.34)
L	Drum liner, plug cavity, outer	97.74 (207.93)	97.82 (208.07)	101.65 (214.96)	103.59 (218.47)
M	Drum liner, plug cavity, inner	92.91 (199.23)	93.06 (199.50)	100.40 (212.72)	104.13 (219.43)
N	Drum liner, CV flange cavity, outer	87.69 (189.84)	87.90 (190.21)	98.09 (208.57)	103.27 (217.43)
O	Drum liner, CV cavity, mid-height, inner	81.30 (178.35)	81.61 (178.90)	96.82 (206.27)	104.13 (219.43)
P	Drum liner, CV cavity, bottom, inner	81.52 (178.74)	81.86 (179.35)	98.30 (208.94)	106.56 (223.80)
Q	Borobond4, top, outer	87.36 (189.25)	87.58 (189.64)	98.19 (208.74)	103.57 (218.43)
R	Borobond4, mid-height, inner	81.30 (178.35)	81.61 (178.90)	98.81 (206.26)	104.58 (220.24)
S	Borobond4, mid-height, outer	81.37 (178.46)	81.66 (178.99)	96.24 (205.23)	103.69 (218.64)
T	Borobond4, bottom, inner	81.67 (179.01)	81.98 (179.56)	96.73 (206.12)	104.19 (219.55)
U	Borobond4, bottom, outer	81.78 (179.21)	82.07 (179.72)	96.11 (205.00)	103.23 (217.81)
V	Drum plug liner, bottom, center	111.30 (232.35)	111.34 (232.42)	113.25 (235.85)	114.21 (237.57)
W	Drum plug liner, top, center	90.70 (195.26)	90.92 (195.66)	101.53 (214.76)	106.87 (224.36)
X	Drum lid, top, center	117.74 (243.93)	117.75 (243.96)	118.50 (245.30)	118.88 (245.98)
Y	Drum lid, top, outer	107.04 (224.68)	107.06 (224.71)	107.94 (226.29)	108.39 (227.10)
Z	Drum, mid-height, outer	91.86 (197.36)	91.90 (197.41)	93.42 (200.15)	94.18 (201.53)
AA	Drum bottom, outer	91.00 (195.79)	91.04 (195.86)	92.92 (199.26)	93.87 (200.96)
BB	Drum bottom, center	87.21 (188.97)	87.31 (189.15)	92.26 (198.07)	94.74 (202.54)

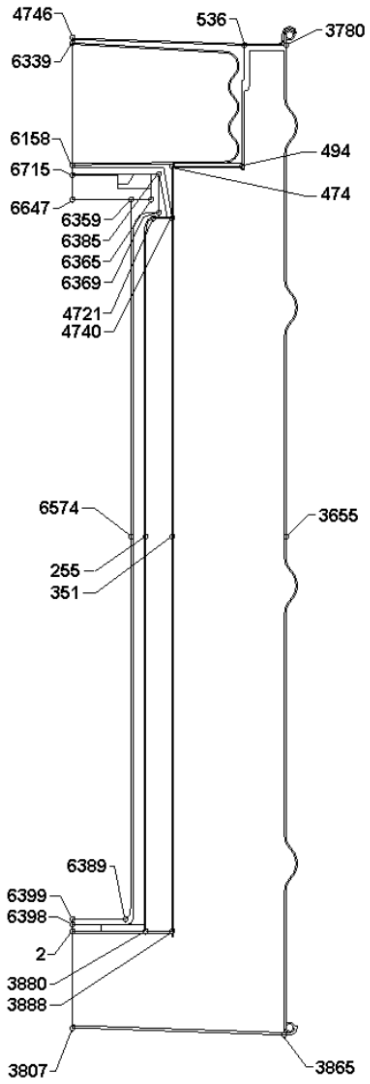
[a] See Fig. 3.1.
[b] Approximate location of the CV O-ring.
[c] Temperatures calculated in DAC-PKG-801699-A001.
[d] CV—containment vessel.

Table 3.14. ES-3100 shipping container maximum steady-state temperatures with Cat 277-4 (no insolation)—Kaolite density of 19.4 lb/ft^3

Node map [a]	Node coordinates (in.)			Maximum temperature [d] (°F)	Maximum temperature [e] (°F)
	No.	r	z	5 W	5 W
	2	0.000	4.505	109.69	140.43
	255	3.180	21.528	108.66	139.54
	351	4.300	21.528	108.16	139.00
	474	4.300	37.535	104.93	135.75
	494	7.325	37.525	103.23	134.06
	536	7.385	42.755	101.81	132.66
	3655[c]	9.185	21.528	102.77	133.57
	3780[c]	9.185	42.755	101.71	132.57
	3807[c]	0.000	0.320	104.39	135.15
	3865[c]	9.185	0.008	102.96	133.76
	3880	3.178	4.505	108.46	139.26
	3888	4.300	4.505	107.99	138.80
	4721	3.500	35.275	106.60	137.42
	4740	4.300	35.275	106.30	137.11
	4746[c]	0.000	43.065	101.82	132.68
	6158	0.000	37.579	106.27	137.05
	6339	0.000	42.859	102.28	133.10
	6359[b]	2.530	36.075	109.38	140.00
	6365[b]	3.425	36.075	109.35	139.96
	6369	3.750	35.525	109.33	139.95
	6385	3.750	37.175	109.21	139.83
	6389	2.310	5.025	111.12	141.81
	6398	0.000	4.775	110.94	141.65
	6399	0.000	5.025	110.94	141.65
	6574	2.530	21.528	115.61	145.99
	6647	0.000	36.075	109.39	140.01
	6715	0.000	37.135	109.36	139.97

[a] See Fig. 7 in DAC-PKG-801940-A001 for details of node locations.
[b] Approximate location of the containment vessel O-ring.
[c] These nodes are at the accessible surfaces of the package (i.e., the drum, drum lid, and drum bottom plate).
[d] Temperatures calculated in DAC-PKG-801940-A001 at 100°F (38°C) ambient temperature for ground transport.
[e] Temperatures calculated in DAC-PKG-801940-A001 at 131°F (55°C) ambient temperature for air transport. The maximum containment vessel temperature reported in DAC-PKG-801940-A001 is 146.11°F. This maximum temperature occurs at a node not reported in this table.

Table 3.15. ES-3100 shipping container maximum "quasi steady-state" temperatures during NCT with various content heat loads and Cat 277-4 (100°F ambient temperature, with insolation)

Node map [a]	Node coordinates (in.)			Maximum "quasi steady-state" temperature [c] (°F)	
	No.	r	z	0 W	5 W
	2	0.000	4.505	180.74	188.26
	255	3.000	21.528	179.61	186.51
	351	4.300	21.528	179.75	186.00
	474	4.300	37.535	202.74	206.02
	494	7.325	37.525	211.30	212.96
	536	7.385	42.755	231.73	232.10
	3655	9.185	21.528	198.09	198.77
	3780	9.185	42.755	230.35	230.64
	3807	0.000	0.320	191.04	193.29
	3865	9.185	0.008	196.66	197.53
	3880	3.178	4.505	180.91	187.34
	3888	4.300	4.505	181.17	187.14
	4721	3.500	35.275	191.41	196.32
	4740	4.300	35.275	192.73	197.32
	4746	0.000	43.065	245.60	245.94
	6158	0.000	37.579	200.32	204.85
	6339	0.000	42.859	238.12	238.81
	6359 [b]	2.530	36.075	190.13	197.36
	6365 [b]	3.425	36.075	190.13	197.32
	6369	3.750	35.525	190.11	197.29
	6385	3.750	37.175	190.23	197.29
	6389	2.310	5.025	180.25	189.10
	6398	0.000	4.775	180.33	189.03
	6399	0.000	5.025	180.33	189.04
	6574	2.530	21.528	179.74	192.42
	6647	0.000	36.075	190.24	197.48
	6715	0.000	37.135	190.26	197.46

[a] See Fig. 7 in DAC-PKG-801940-A001 for details of node locations.
[b] Approximate location of the containment vessel O-ring.
[c] Temperatures calculated in DAC-PKG-801940-A001.

Using the temperatures calculated for the conditions of 10 CFR 71.71(c)(1), Appendix 3.5.1 predicts that the maximum normal operating pressure inside the containment vessel will be 215.24 kPa (31.218 psia). For conservatism and for use in Sects. 2 and 4 during NCT, the maximum gas temperature and the maximum normal operating pressure in the containment vessel are rounded up to 93.33°C (200.0°F), and 215.46 kPa (31.25 psia), respectively. The design absolute pressure of the containment vessel is 801.17 kPa (116.2 psia), and the hydrostatic test pressure is 1135.57 kPa (164.7 psia). Thus, increasing the internal pressure of the containment vessel to a maximum of 215.46 kPa (31.25 psia) during NCT would have no detrimental effect. Stresses generated in the containment vessel at this pressure are insignificant compared to the materials of construction allowable stress. Table 2.20 provides a summary of the pressures and temperatures for NCT. As discussed in Sect. 2.6.1.4, the containment vessel and vessel closure nut stresses for these pressure conditions are below the allowable stress values.

Prior to testing the ES-2M design (a similarly constructed shipping package), each test unit was radiographed to determine the integrity of the Kaolite 1600 impact and insulation material. Following casting of the material inside the drum, some three-dimensional curving cracks were seen in some packages near the top thinner sections from the bottom of the liner to the bottom drum edge. After vibration testing, radiography of the ES-2M TU-4 showed that the lower half of the impact limiter was broken into small pieces (GAB1296-2). To evaluate these findings, TU-4 was reassembled and subjected to HAC sequential testing (GAB1296-2). After vibration and impact testing, many three-dimensional curving cracks were seen around the impact areas, and the inner liner was also visibly deformed. Nevertheless, temperatures at the containment boundary were similar to other packages not subjected to vibration testing prior to HAC testing. No inleakage of water was recorded following immersion. Also, TU-4 of the ES-3100 shipping package was subjected to the full NCT test battery including vibration.

Following these tests, the containment vessel of the ES-2M TU-4 was removed, and a full body helium leak check was performed. The test unit passed the leak-tight criteria in accordance with ANSI N14.5-1997. The containment vessel was then reassembled into the previously tested drum assembly and subjected to the complete HAC testing. Based on the success of this unit and the similar design of the ES-2M, it can be concluded that vibration normally incident to transport does not reduce the effectiveness of the ES-3100 packaging during HAC testing. The ES-3100 has been tested to determine the effectiveness of the package following a sequential NCT 1.2-m (4-ft) drop test and HAC test battery. Throughout all of the vibration and structural testing, the effectiveness of the Kaolite 1600 material as an impact limiter and thermal insulation was not substantially reduced.

Also, in accordance with 10 CFR 71.71(c)(2), the containment vessel pressure must be calculated at −40°C (−40°F). Given the initial conditions of temperature, relative humidity, no silicone rubber or polyethylene bag offgassing, the pressure is calculated as follows:

$$P_1 \text{ @ } 25°C = P_a + P_v + P_{fo},$$

where

P_a = 98.15 kPa (14.236 psia), (Appendix 3.5.1)
P_v = 3.20 kPa (0.464 psia), (Appendix 3.5.1)
P_{fo} = 0. (no offgassing, Appendix 3.5.1)

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 = 98.15 kPa (14.236 psia),
T_1 = 25°C (298.15 K),
T_2 = −40°C (233.15 K),
V_1 = V_2, and

rearranging and solving for P_2,

P_2 = $P_1 (T_2 / T_1)$,
= (98.15)(233.15 / 298.15),
= 76.76 kPa (11.13 psia).

The cold condition for NCT specified in 10 CFR 71.71 is an ambient temperature in still air and shade of −40°C (−40°F). The 35.2 kg (77.60 lb) of HEU contents in the ES-3100 package generates a maximum bounding decay heat load of 5 W. However, in accordance with Nuclear Regulatory Commission (NRC) Regulatory Guide 7.8, the thermal effects of this internal heat source are neglected during evaluation of the package performance at −40°C (−40°F). When exposed to this condition, the package component temperatures will stabilize over 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 EPDM O-rings used in the containment boundary is −40 to 150°C (−40 to 302°F) [Table 3.11] 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 TU-2 to the leak tight criteria stipulated by ANSI N14.5-1997 following compliance testing provides justification of the above statements.

Summarizing 10 CFR 71.43(f), the tests and conditions of NCT shall not substantially reduce the effectiveness of the packaging to withstand HAC sequential testing. The effectiveness of the ES-3100 to withstand HAC sequential testing is not diminished through application of the tests and conditions stipulated in 10 CFR 71.71. The justification for this statement is provided by physical testing of both the ES-2M and ES-3100 test packages. Due to the similarities in design, fabrication, and material used in construction of both the ES-2M and the ES-3100 package, the Kaolite 1600 physical characteristics will hold true for both designs. The integrity of the Kaolite 1600 is not significantly affected by the NCT vibration and 1.2-m (4-ft) drop tests.

3.3.2 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 3.5.1 for the most restrictive containment vessel configurations. For conservatism, the decay heat of 5 W was used for the maximum internal heat load in evaluating the package for NCT. The maximum calculated adjusted internal absolute pressure in the containment vessel with solar insolation and the bounding case parameters is 215.46 kPa (31.25 psia). This pressure incorporates offgassing of the silicone rubber pads, polyethylene bottles, Teflon bottles, and polyethylene bagging and hydrogen gas generation from the radiolysis of water and/or other packing materials. The initial environment inside the containment vessel when assembled is at ambient temperature and pressure with 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 1.3.7.

3.3.3 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 118.86 and 91.93°C (245.94 and 197.48°F) on the surface of the drum and the containment vessel, respectively (Sect. 3.3.1). 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 3.11). 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 M2E801580A002, Appendix 1.3.7). 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 DAC-PKG-801940-A002. The results show that the stresses induced are minimal and do not reduce the effectiveness of the drum assembly. Further discussion of these stresses is provided in Sects. 2.6.1.2 and 2.6.2.

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*. 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 EPDM.

The design temperature range of the containment vessel is −29 to 176.7°C (−20 to 350°F) (DAC-M900000-0003). 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 EPDM O-ring is −40 to 150°C (−40 to 302°F) [Table 3.11] for 1000 h of continuous service.

3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS

3.4.1 Initial Conditions

Six full-scale packages were tested in the sequence shown in Table 2.19. Each ES-3100 test package was subjected to the 1.2-m (4-ft) drop test in accordance with 10 CFR 71.71(c)(5) prior to the sequential HAC tests in accordance with 10 CFR 71.73 (free drop, crush, puncture, thermal, and immersion tests). One of these units (TU-4) had previously completed the tests and conditions stipulated in 10 CFR 71.71(c)(5) through (c)(10), excluding (c)(8). Two different mock-up configurations were used to represent the minimum and maximum proposed shipping weight and to simulate various center of gravity locations. The structural and thermal interface between the mock-up component and the containment vessel was designed to match that of the actual hardware proposed for transport. Based on LS-DYNA drop simulations (DAC-EA-801699-A001 and DAC-EA-801699-A002) the six test units with their associated test weights represent the worst drop orientations for the ES-3100 package. TU-5 used a near replicate of the lightest weight contents for its mock-up component. NCT free-drop, 9-m (30-ft) free drop, 9-m (30-ft) crush and puncture tests were made as specified in 10 CFR 71.71(c)(1), and 73(c)(1) through (c)(3) on all six full-scale test packages prior to thermal testing. The results of this testing are discussed in Sects. 2.7.1, 2.7.2, and 2.7.3. The 1.2-m (4-ft), 9-m (30-ft) drop and crush test orientations were as follows: two tests with the long axis of drum at an oblique angle of 12° to impact surface; a center of gravity over the corner of the drum lid; a drop with the long axis of drum parallel with the impact surface; and a vertical drop on to the drum's lid. The subsequent 40-in. puncture drops were made at various orientations as shown in Table 2.19.

Prior to the thermal test, each test unit was preheated to the maximum temperature extreme in accordance with 10 CFR 71.73(b). Since the containment vessels were initially assembled at ~101.35 kPa (14.7 psia) at 25°C (77°F), the initial internal containment vessel pressure was ~105.70 kPa (15.33 psia) at 38°C (100°F) using the ideal gas law. In accordance with 10 CFR 71.73(b)(1), the internal pressure should be that calculated for the maximum normal operating pressure or the adjusted calculated value of 215.46 kPa (31.25 psia). This slight pressure differential has little or no effect on the thermal test results. The maximum decay heat load of the contents is calculated to be 5 W based on 35.2 kg of HEU. Analysis of the ES-3100 package after thermal HAC tests both with and without the decay heat load has been performed. The maximum projected temperature increase during HAC due to a 5 W heat source without insolation and assuming densities for Kaolite and neutron absorber that result in the largest temperature difference, as calculated in DAC-PKG-801940-A001, would be ~4.56°C (8.20°F) at the containment vessel's top (node 6715), ~4.56°C (8.21°F) at the containment vessel's O-ring (node 6359), ~7.49°C (13.48°F) at the containment vessel's mid body (node 6574), and ~5.28°C (9.50°F) at the containment vessel bottom (node 6399). These temperature differentials are representative for both the Kaolite 1600 densities evaluated.

3.4.2 Fire Test Conditions

Full-scale testing in accordance with 10 CFR 71.73 for HAC was conducted on prototypical packages. Therefore, no analyses were conducted to show compliance with the HAC thermal test. However, analyses were conducted and are discussed in Sect. 3.4.3 to determine the thermal impacts of an internal heat source, application of insolation during cool down, location of crush plate impact on test unit, and thermal capacitance differences between test hardware and proposed shipping hardware.

Full-scale testing of six ES-3100 test units was conducted in accordance with 10 CFR 71.73(c)(4) for HAC. A single full-scale ES-3100 test unit (TU-4) was assembled and subjected to both NCT and to the sequential tests specified in 10 CFR 71.73(c). The furnace used for thermal testing was the No. 3 Furnace at Timken Steel Company in Latrobe, Penn., which is a gas-fired furnace. Oxygen content in stack gases from the furnace were not monitored because it was not anticipated that any of the package's materials of construction were combustible. There was some burning of the silicone pads which are placed between the inner liners and the top plugs of the packages. However, it should be noted that this furnace employs "pulsed" fire burners. This type of burner is unique in that the natural gas flow rate is varied based on furnace controller demands, but the flow of air through the burners is constant, even when no gas is flowing, thereby ensuring a very rich furnace atmosphere capable of supporting any combustion of package materials of construction.

The most significant change to the definition of the HAC thermal test in the current 10 CFR 71 is the requirement for calculation purposes to base convective heat input on "that value which may be demonstrated to exist if the package was exposed to the fire specified." This is not especially significant for this package because it was tested in the gas-fired furnace with burners placed in an attitude which produced a strong convective swirl. Careful examination of the thermal test data indicates that the total heat imparted to the packages was significantly greater than the required total heat specified in 10 CFR 71.73(c)(4). Compliance with ASTM E 2230, *Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material*, was accomplished by the method described in Sect. 7.3 of this standard. This standard is in general agreement with Paragraph 2.2.1 ("Steady-state Method of Compliance") of SG 140.1 entitled *Combination Test/Analysis Method Used to Demonstrate Compliance to DOE Type B Packaging Thermal Test Requirements (30 Minute Fire Test).*

Prior to the beginning of the thermal test, the furnace was characterized for temperature and heat recovery times. The support stand was welded to a large steel plate which had been placed on the floor of the furnace prior to heating. This steel plate acted as the radiating surface at the bottom of the furnace, as well as providing the ability to hold the test stand rigidly in place. Before heating the furnace, workers practiced loading and unloading test packages from the cold furnace to ensure that the furnace door would not remain open >90 s during each loading. In fact, the maximum time the door was open during any loading was 64 s. As discussed in *Test Report of the ES-3100 Package* (ORNL/NTRC-013), six thermocouples were affixed to the drum assembly's exterior surface. Metal retainer clips were welded to the exterior surface to hold the thermocouples in place. The thermocouple tips were inserted underneath the metal clips, and the wire was wrapped around the metal clip. To eliminate any radiant heat exchange between the thermocouples and the furnace walls, the tips and metal clips were covered with a ceramic coating. Three thermocouples were mounted on each of the walls of the furnace, as well as on the furnace floor, on the furnace door, and three thermocouples were mounted on the test stand.

A minimum of 24 h prior to the beginning of all testing, the furnace was turned on with a set-point temperature of 871°C (1600°F). Following each test, the furnace set point was adjusted to 871°C (1600°F) for at least 45 min prior to the beginning of the next test. The furnace control data recorder ran continuously for the entire duration of the preheat cycle test. TU-1 through TU-5 were preheated to >38°C (100°F) by placing the packages in an environmental chamber, which was heated by a torpedo-type kerosene space heater controlled by a mechanical bulb thermostat with a control range of 38 to 93°C (100 to 200°F). The environmental chambers were similar: a welded steel frame with fiberglass insulation panels. Figure 3.5 shows the chamber used for TU-1 through TU-5, which was heated from the bottom with four floor register vents located around the perimeter and a 20.32-cm (8-in.)–diam manual dampened center venting stove pipe.

The set point temperature of the environmental chamber was monitored and adjusted for the duration of the preheat cycle. Initially, the thermostat was set to 66°C (150°F) for ~23 h. The thermostat set point was then reduced to 43°C (110°F) for the remainder of the preheat cycle (24 h). All packages were preheated for at least 47 h. No test package was loaded into the furnace until 15 of the 18 thermocouples monitoring the furnace had a reading of 800°C (1475°F) or higher. All packages were placed in the preheated furnace on the support stand with the long axis positioned horizontally, and the package lid facing toward a furnace side wall (Fig. 3.6). These packages were exposed to the radiation environment for a minimum of 30 min after all functioning furnace thermocouples and at least four of the six test package exterior surface thermocouples reached a temperature of 800°C (1475°F). During the testing of each package, the thermocouple temperature data recorder was set to record every 15 s.

After each test, the furnace was allowed to reheat for a minimum of 45 min after obtaining the set point temperature before testing the next unit. The furnace control temperature data recorder ran continuously for the duration of the preheat. No test package was loaded into the furnace until all functioning thermocouples on the furnace walls and support stand had again reached a temperature of 800°C (1475°F) or higher.

All units were tested in a horizontal attitude with the top end of the package facing to the right side wall of the furnace and the 0° mark on the drum facing the floor of the furnace. The data from each of the thermal tests, as shown in the test report, show that at least four of the six external drum thermocouples reached temperatures well in excess of 800°C (1475°F) and remained above 800°C (1475°F) during the 30-min thermal testing. Similarly, all other surfaces of the furnace, including the support stand, exceeded 800°C (1475°F) during the timed portion of the thermal test. For the test specified in the regulations, regardless of the amount of heat input by convection, radiation, or conduction, the maximum temperature the skin of the package could reach would be 800°C (1475°F). That is, the source of the heat in the regulatory specified test is at 800°C (1475°F). Heat can only be transferred from a hotter source to a colder source. Thus, regardless of the mode of heat transfer, the greatest temperature a specimen exposed to the 10 CFR 71.73(c)(4) thermal test can attain is 800°C (1475°F). Therefore, the fact that these test packages attained temperatures well in excess of 800°C (1475°F) is an excellent indication that the thermal tests performed not only met the requirements of 10 CFR 71.73(c)(4) but actually exceeded them markedly. The results of these tests are provided in the test report (ORNL/NTRC-013).

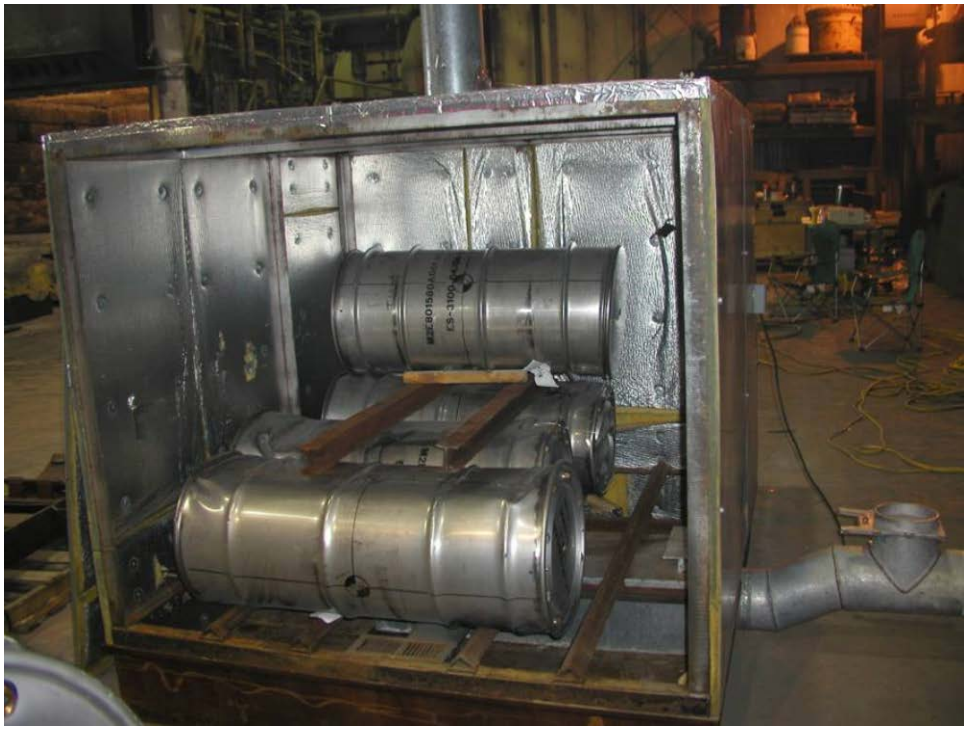


Fig. 3.5. TU-1 through TU-5 preheat arrangement.



Fig. 3.6. Test unit insertion into furnace.

Each test package was removed from the furnace and placed in an area where it was not exposed to artificial cooling (Figs. 3.7 and 3.8). As the furnace door was opened for each test unit, flaming or smoking was visible at the tamper-indicating device (TID) holes in the drum/lid interface. Flaming continued on some of the packages for a short duration; the longest flame duration was 22 min after removal from the furnace. Smoke was also visible from each of the packages and continued after flames were no longer visible. The packages continued to smoke between 12 and 60 min after removal from the furnace. All the packages were allowed to cool naturally to room temperature. The post-thermal testing weights of each unit are summarized in Table 3.16. The drums were disassembled, and the damage was photographed. Each package was visually inspected, and the condition of the package and any observations were recorded.

3.4.3 Maximum Temperatures and Pressure

The six test units previously subjected to both NCT and HAC drop testing were thermally tested in accordance with 10 CFR 71.73(c)(4). To determine the maximum temperatures reached during thermal testing, temperature-indicating patches were placed at various locations throughout the test package at assembly. The temperature range for each patch used is identified in Table 3.17. When the temperature of an indicator was reached, the color would change to black (i.e., blackout temperature). The range of possible blackout temperatures of the patches was from 51.67 to 260°C (125 to 500°F). For TU-1 through TU-5, Table 3.17 defines the number and location of the temperature-indicating patches. A temperature adjustment was evaluated to compensate for conducting the HAC compliance tests with BoroBond4 and substituting Cat 277-4 for the production shipping containers. This adjustment was determined by using an undamaged package and subjecting it to a thermal environment representative of that required by 10 CFR 71.73(c)(4). Based on the analytical results shown in DAC-PKG-801699-A001 and DAC-PKG-801940-A001, the containment vessel in a package using Cat 277-4 would be from 2.5 to 8°F cooler than a package with BoroBond4. Therefore, the results from TU-3 are used without further adjustment.

Since the structural and thermal interface between the various mock-ups and containment vessels is the same as the actual hardware, the use of steel mock-ups to simulate the contents is not expected to affect the results of the thermal test significantly. The total maximum weight of the test packages ranged from 157.4 kg (347 lb) to 203.7 kg (449 lb). The ES-3100 package has a nominal gross shipping weight that ranges from 146.88 kg (323.79 lb) to 187.81 kg (414.05 lb) for the minimum and maximum weight containment vessel configurations shown in Table 2.8, respectively. However, the effect on temperature is evaluated in the following paragraphs due to thermal capacitance differences between the mock-up and the actual contents.



Fig. 3.7. Test unit removal from furnace.



Fig. 3.8. Test unit cool down and monitoring arrangement.

Table 3.16. ES-3100 test package weights before and after 10 CFR 71.73(c)(4) HAC testing

Test Unit	Pre-test [a] weight [kg (lb)]	Post-test [a] weight [kg (lb)]	Thermal test weight loss [kg (lb)]	BoroBond4 or Cat 277-4 original weight [kg (lb)]	Water weight in BoroBond4 or Cat 277-4 [kg (lb)]	Water loss percent d (%)
1	202.3 (446)	202.3 (446)	0.0 (0)	20.7 (45.64) [b]	4.91 (10.82) [c]	0.00
2	202.8 (447)	202.8 (447)	0.0 (0)	20.5 (45.19) [b]	4.86 (10.72) [c]	0
3	203.7 (449)	203.2 (448)	0.45 (1)	20.5 (45.19) [b]	4.87 (10.74) [c]	9.31
4	201.8 (445)	201.4 (444)	0.45 (1)	20.4 (44.97) [b]	4.84 (10.66) [c]	9.38
5	157.4 (347)	156.9 (346)	0.45 (1)	20.6 (45.42) [b]	4.89 (10.77) [c]	9.29

[a] ORNL/NTRC-013.
[b] Weight of BoroBond4 and water obtained from casting data (Barton).
[c] This weight is based on thermogravimetric analysis measurements and calculation showing that the minimum water percent is 23.71%.
[d] All weight loss attributed to loss of water in BoroBond4 or Cat 277-4.

Table 3.17. Thermax temperature-indicating patches for test units

Patch location	Internal surface	External surface	Temperature range [°C (°F)]	Test report figure [a]
Inner liner of drum assembly		17 (Full Range)	52–260 (125–500)	5.30
Top plug weldment		4 (Full Range)	52–260 (125–500)	5.31
Containment vessel body flange	8 (4B & 4C)	8 (4B & 4C)	"B" 77–127 (171–261) "C" 132–182 (270–360)	5.28
Containment vessel body (end cap and cylinder)		5 (B)	"B" 77–127 (171–261)	5.28
Containment vessel sealing lid	4 (B)	4 (B)	"B" 77–127 (171–261)	5.29
Test mock-up components		6 (B)	"B" 77–127 (171–261)	5.26 & 5.27

[a] ORNL/NTRC-013.

In order to predict the maximum temperature for the packaging components during HAC, transient thermal analyses were 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) [DAC-PKG-801940-A001]. 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 various content heat loads up to 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 as previously stated is obtained from their respective steady-state analyses (Table 3.14). 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 (DAC-PKG-801699-A001), 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 various content heat loads up to 30 W using a Kaolite 1600 density of 30 lb/ft^3 and a Cat 277-4 density of 110 lb/ft^3.

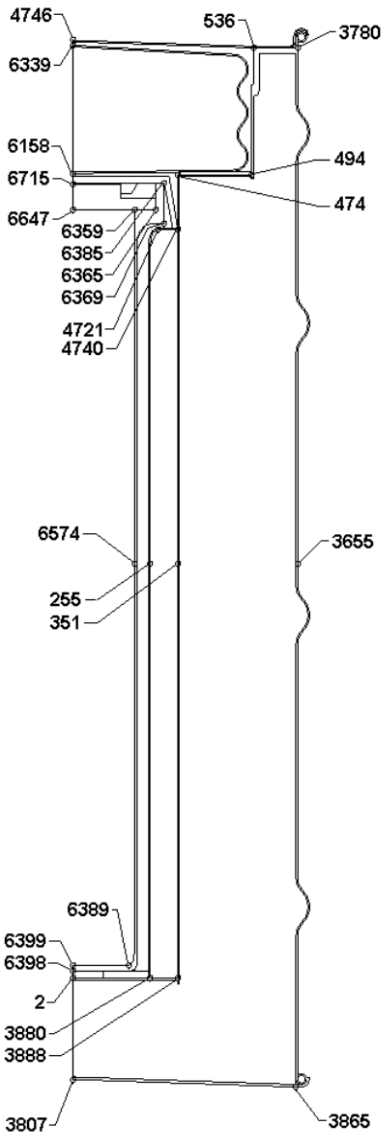
The maximum temperatures calculated for the ES-3100 shipping container for HAC are summarized in Table 3.18 for the analyses using a Kaolite 1600 density of 19.4 lb/ft^3 and a Cat 277-4 density of 100 lb/ft^3. The maximum temperatures calculated for the ES-3100 shipping container for HAC are summarized in Table 3.19 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 3.18).

As previously stated, temperature indicators (patches) were placed on the surface of each containment vessel, inner liner, and mock-up component in TU-1 through TU-5. The blackout temperatures that occurred during thermal testing are recorded for each test unit; the maximum blackout temperatures are listed in Table 3.4. A maximum blackout temperature of 116°C (241°F) was recorded in the vicinity of the O-rings on the containment vessel of TU-5. As discussed below, this temperature will be conservatively adjusted to correlate the test conditions to shipping conditions with decay heat and solar insolation. The blackout temperatures are increased to account for (1) the temperature interval between blackout dots; (2) the ambient temperature of the package prior to insertion into the furnace; (3) the temperature increase due to the effects of applying solar insolation during post-HAC thermal test cool down; (4) the temperature increase due to the decay heat load of the actual contents being shipped; (5) effects of crushing at different locations along the body of the shipping package; (6) thermal capacitance difference in the proposed contents and hardware used during testing; (7) temperature difference occurring when using Borobond4 and Cat 277-4; and (8) temperature difference resulting from variations in Kaolite 1600 and Cat 277-4 material densities.

The initial adjustment for the blackout readings is an increase of 6.11°C (11.0°F) from the patch that blacked out. The highest blackout reading indicates that the actual temperature is somewhere between the highest temperature indicated and the next higher temperature.

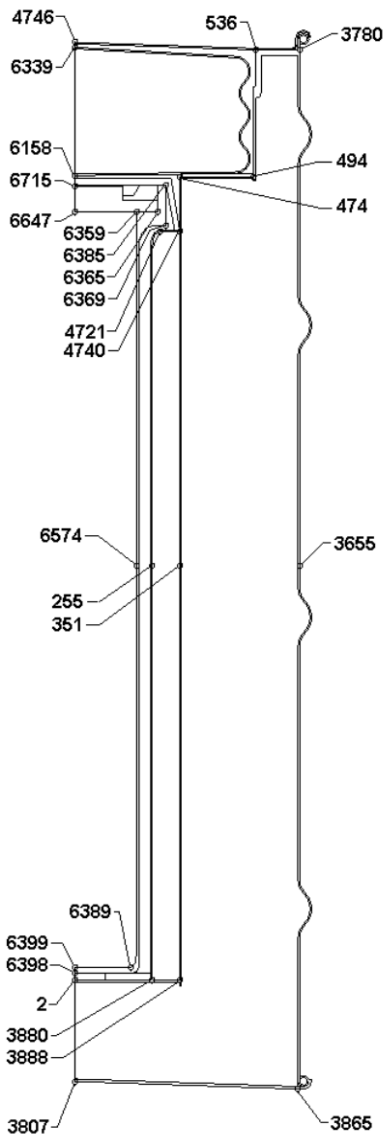
The second adjustment compensates for thermal testing at package soak temperatures less than the maximum temperature of 38°C (100°F). In the case of the ES-3100 package, each test unit was thermally soaked to >38°C (100°F) prior to insertion into the furnace. Therefore, there is no temperature adjustment required.

Table 3.18. ES-3100 package 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 [c] (°F)			
				0 W		5 W	
	No.	r	z	Insolation during cool-down?		Insolation during cool-down?	
				No b	Yes	No	Yes
	2	0.000	4.505	218.57	227.34	226.83	235.47
	255	3.180	21.528	192.62	212.35	200.41	219.88
	351	4.300	21.528	193.97	211.78	201.16	218.55
	474	4.300	37.535	387.76	392.12	391.72	396.07
	494	7.325	37.525	636.45	637.51	638.80	639.87
	536	7.385	42.755	1401.24	1401.24	1401.38	1401.38
	3655	9.185	21.528	1458.92	1458.92	1458.98	1458.98
	3780	9.185	42.755	1455.20	1455.20	1455.24	1455.24
	3807	0.000	0.320	1456.37	1456.37	1456.46	1456.46
	3865	9.185	0.008	1472.23	1472.23	1472.24	1472.24
	3880	3.178	4.505	224.21	231.73	231.44	238.83
	3888	4.300	4.505	229.89	236.49	236.61	243.09
	4721	3.500	35.275	241.99	249.86	247.64	255.45
	4740	4.300	35.275	255.69	262.15	260.99	267.39
	4746	0.000	43.065	1452.75	1452.75	1452.80	1452.80
	6158	0.000	37.579	298.55	302.57	303.83	307.84
	6339	0.000	42.859	1357.12	1357.12	1357.44	1357.44
	6359 [a]	2.530	36.075	221.32	235.09	229.53	243.04
	6365 [a]	3.425	36.075	221.34	235.11	229.52	243.03
	6369	3.750	35.525	221.34	235.11	229.50	243.01
	6385	3.750	37.175	221.74	235.39	229.78	243.17
	6389	2.310	5.025	213.26	223.89	222.83	233.30
	6398	0.000	4.775	213.95	224.48	223.37	233.75
	6399	0.000	5.025	213.95	224.48	223.38	233.75
	6574	2.530	21.528	193.20	214.09	206.59	226.95
	6647	0.000	36.075	221.45	235.19	229.69	243.16
	6715	0.000	37.135	221.54	235.24	229.74	243.18

[a] Approximate location of the containment vessel O-ring.
[b] Baseline case for ΔT comparisons.
[c] Temperatures calculated in DAC-PKG-801940-A001.

Table 3.19. 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 [c] (°F)			
				0 W		5 W	
	No.	r	z	Insolation during cool-down?		Insolation during cool-down?	
				No [b]	Yes	No	Yes
	2	0.000	4.505	208.90	219.11	217.23	227.23
	255	3.180	21.528	186.18	208.50	194.00	216.04
	351	4.300	21.528	186.78	208.11	193.94	214.89
	474	4.300	37.535	359.09	362.05	363.14	366.11
	494	7.325	37.525	594.36	596.62	596.71	598.97
	536	7.385	42.755	1395.15	1395.15	1395.29	1395.29
	3655	9.185	21.528	1456.25	1456.25	1456.31	1456.31
	3780	9.185	42.755	1453.48	1453.48	1453.52	1453.52
	3807	0.000	0.320	1453.70	1453.70	1453.80	1453.80
	3865	9.185	0.008	1471.38	1471.38	1471.39	1471.39
	3880	3.178	4.505	213.14	222.36	220.46	229.47
	3888	4.300	4.505	217.29	225.83	224.12	232.52
	4721	3.500	35.275	230.23	239.26	235.98	244.93
	4740	4.300	35.275	241.51	248.75	246.91	254.07
	4746	0.000	43.065	1449.69	1449.69	1449.76	1449.76
	6158	0.000	37.579	278.41	284.11	283.73	289.44
	6339	0.000	42.859	1339.69	1339.69	1340.05	1340.05
	6359 [a]	2.530	36.075	215.59	229.94	223.79	237.89
	6365 [a]	3.425	36.075	215.59	229.95	223.75	237.87
	6369	3.750	35.525	215.57	229.95	223.72	237.85
	6385	3.750	37.175	215.89	230.22	223.91	238.01
	6389	2.310	5.025	204.68	216.74	214.33	226.16
	6398	0.000	4.775	205.27	217.13	214.76	226.40
	6399	0.000	5.025	205.27	217.13	214.77	226.40
	6574	2.530	21.528	187.66	209.82	201.14	222.75
	6647	0.000	36.075	215.81	230.06	224.03	238.04
	6715	0.000	37.135	215.88	230.12	224.07	238.06

[a] Approximate location of the containment vessel O-ring.
[b] Baseline case for ΔT comparisons.
[c] Temperatures calculated in DAC-PKG-801940-A001.

The third adjustment is a temperature increase to represent the effect of insolation heat flux on the package immediately following the conclusion of the thermal HAC test. Analyses of the ES-3100 package after thermal HAC tests both with and without insolation have been performed (DAC-PKG-801940-A001). Results from these analyses indicate an increase of ~7.47°C (13.44°F) at the containment vessel top (node 6715), ~7.51°C (13.51°F) at the containment vessel O-ring (node 6359), ~11.31°C (20.36°F) at the containment vessel mid body (node 6574), and ~5.76°C (10.37°F) at the containment vessel bottom (node 6399), as a result of applying insolation following HAC thermal testing. These increases are extracted from Tables 3.18 and 3.19. The most pronounced effect of applying the insolation heat flux was that it increased the time required to cool the package to NCT type conditions. Nevertheless, the influence of insolation is included in the adjustments to the blackout temperatures.

The fourth temperature adjustment considered is the temperature increase due to the decay heat load of the actual contents being shipped. A maximum decay heat load of 5 W is calculated as the bounding case for 35.2 kg of HEU. HAC analysis of the ES-3100 package both with and without the decay heat load has been performed, with the results shown in Tables 3.18 and 3.19. The maximum projected temperature increase during HAC due to a 5 W heat source, as calculated in DAC-PKG-801940-A001, would be ~4.56°C (8.20°F) at the containment vessel top (node 6715), ~4.56°C (8.21°F) at the containment vessel O-ring (node 6359), ~7.49°C (13.48°F) at the containment vessel mid body (node 6574), and ~5.28°C (9.50°F) at the containment vessel bottom (node 6399).

The fifth temperature adjustment considered is the temperature increase to the containment vessel based on the location of impact from the 500 kg (1100 lb) crush plate. Based on the differences in location of the crush plate between TU-1 and TU-2, crushing the shipping package with the center of gravity of the plate directly above the containment vessel flange increases the containment vessel temperature on average ~6.11°C (11°F).

The sixth adjustment compensates for the shipment of very small quantities of HEU, rather than the steel mock-ups, and removes the requirement for a minimum content weight. The higher content weight was used for testing to cover the possibility of shipping larger components without retesting. The larger content weight gave conservative structural deformation test results to the drum assembly than would the actual shipping weight. One effect, however, of using the larger test mass could be to reduce the containment vessel's temperature rise during the thermal test because the mock-up acts like a heat sink. In order to evaluate this temperature adjustment, a mock-up of the originally lightest proposed shipment was used in TU-5. The structural and thermal interface between the mock-up components and the containment vessel was designed to match that of the actual shipping hardware, thereby providing the same conductive heat path for thermal testing. As shown by the test results, both the containment vessel and mock-up components of TU-5 recorded higher temperatures than the other test units. This supports the theory that the heavier mock-ups act as heat sinks for the containment vessel. Since the earlier compliance testing, even lower amounts of material are proposed for shipment in the ES-3100. In order to quantify the magnitude of this adjustment, a heat transfer balance is conducted below. This method represents a conservative approach to estimating the adjustment and is not intended to reflect the actual temperature difference. Since the blackouts were recorded on the surface of the mock-up component, adjusted temperatures of 64°C (219°F), 99°C (210°F), and 93°C (199°F) for the top can, middle can, and bottom can are assumed for the following heat transfer equations. The amount of heat absorbed by the mock-up components during the thermal test of TU-5 is calculated as follows:

$$Q = C_{pi} \times (T_{maxi} - T_{mini}) \times W_{Mi}$$

The mockup components for TU-5 consisted of three 10-in.–high steel cans. Two of the upper cans were empty. The bottom can contained 5.9 lb of steel grit. Each individual can weighed ~0.70 lb. Two

temperature-indicating patches were placed around the external mid height diameter of each can ~180° apart. The blackout readings on the top, mid, and bottom cans were 99°C (210°F), 93°C (199°F), and 88°C (190°F), respectively. Each of these readings is increased by either 5 or 6°C (9 or 11°F) due to the accuracy of the patches. Therefore, the top can, middle can, and bottom can and steel grit reached an adjusted temperature of 104°C (219°F), 99°C (210°F), and 93°C (199°F), respectively. Therefore, the mockup contents absorbed ~ 9.476×10^4 J as calculated below:

$$\begin{aligned} Q_A &= \sum C_{pi} \times (T_{maxi} - T_{mini}) \times W_{Mi}, \\ &= 460.5 \times (104 - 37.78) \times (0.318) + 460.5 \times (99 - 37.78) \times (0.318) + 460.5 \\ &\quad \times (93 - 37.78) \times (2.99), \\ &= 94760.2 \text{ J}, \end{aligned}$$

where

Q_A = absorbed heat by mockup contents,
C_{pi} = specific heat of the steel cans and grit,
= 460.5 J/kg-°C (0.11 Btu/lb-°F),

T_{maxi} = recorded mock-up can temperatures,
= 104°C (219°F), (top can)
= 99°C (210°F), (middle can)
= 93°C (199°F), (bottom can and steel grit)

T_{mini} = temperature of preheated test units,
= 37.78°C (100°F),

W_{MI} = mock-up component weights for TU-5,
= 0.318 kg (0.70 lb), (top can)
= 0.318 kg (0.70 lb), (middle can)
= 2.99 kg (6.60 lb). (bottom can and steel grit)

The sixth temperature adjustment caused by adding this 9.476×10^4 J (89.81Btu) of heat from the mockup contents into the containment vessel can then be calculated by using the following equation:

$$\begin{aligned} dT &= Q_A / (C_{pcv} \times W_{cv}), \\ &= 9.476 \times 10^4 \text{ J} / (502.36 \text{ J/kg-°C} \times 14.97 \text{ kg}), \\ &= 12.60°\text{C} (22.68°\text{F}), \end{aligned}$$

where

C_{pcv} = specific heat of the stainless steel containment vessel,
= 502.36 J/kg-°C,

W_{cv} = mass of the empty stainless steel containment vessel,
= 14.97 kg.

The sixth temperature adjustment is 12.60°C (22.68°F).

The seventh temperature adjustment compensates for conducting the HAC compliance tests with BoroBond4 and substituting Cat 277-4 for the production shipping containers. This adjustment is determined by using an undamaged package and subjecting it to a thermal environment representative of that required by 10 CFR 71.73(c)(4). Based on the analytical results shown in DAC-PKG-801699-A001 and DAC-PKG-801940-A001, the containment vessel in a package using Cat 277-4 would be from 2.5°F to 8°F cooler than a package with BoroBond4. Conservatively, the temperatures will not be adjusted due to the neutron poison change.

The eighth and final temperature adjustment compensates for material density variation in the Kaolite 1600 and Cat 277-4 material during HAC compliance tests. Again, this temperature adjustment was predicted for an undamaged package using the finite element method. Based on the analytical results shown in DAC-PKG-801940-A001 (Tables 3.18 and 3.19), the containment vessel temperature was predicted to be ~3.15°C (5.67°F) higher at the containment vessel top (node 6715), ~3.19°C (5.74°F) higher at the containment vessel O-ring (node 6359), ~3.08°C (5.54°F) higher at the containment vessel mid body (node 6574), and ~4.82°C (8.68°F) at the containment vessel's bottom (node 6399) when the lower density values for Kaolite 1600 and the neutron poison were used. Since actual compliance testing was conducted with these densities on the high side, the above adjustments must be added to the containment vessel temperatures. Table 3.20 summarizes the numerous temperature adjustments needed for the containment vessel.

Table 3.20. Predicted temperature adjustments (°F) for containment vessel due to HAC

Node [a]	Analytical temperature adjustments								Total temp adjustment
	1	2	3	4	5	6	7	8	
6715	11.00	0.00	13.44	8.20	11.00	22.68	0.00	5.67	71.99
6359	11.00	0.00	13.51	8.21	11.00	22.68	0.00	5.74	72.14
6574	11.00	0.00	20.36	13.48	11.00	22.68	0.00	5.54	84.06
6399	11.00	0.00	10.37	9.50	11.00	22.68	0.00	8.68	73.23

[a] See Fig. 7 in DAC-PKG-801940-A001 for details of node locations.

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 (TU-5). These adjusted temperatures would not adversely affect the stainless-steel components of the containment vessel. EPDM O-rings are rated for reliable service for a continuous 1000 h at −40 to 150°C (−40 to 302°F) [Table 3.11]. As shown in Fig. 2-24 of the *Parker O-Ring Handbook*, these O-ring materials can survive at the predicted temperature shown in Table 3.21 (313.14°F) for several hundred hours. Because the predicted temperature is only ~6.1°C (11°F) above the continuous service temperature of 150°C (302°F) for the EPDM O-ring, the thermally tested packages with insolation would cool to acceptable limits within 24 h. Therefore, these adjusted temperatures would not adversely affect the containment vessel O-rings.

Table 3.21. Predicted temperatures of the containment vessel due to HAC

Node [a]	Analytical temperature adjustments (°F)	Maximum blackout temperature on TU-5 (°F)	Final predicted temperature (°F)
6715	71.99	261	332.99
6359	72.14	241	313.14
6574	84.06	199	283.06
6399	73.23	210	283.23

[a] See Fig. 7 in DAC-PKG-801940-A001 for 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 40.08°C (72.14°F) for this region, the adjusted average temperature in the first region is 147.58°C (297.64°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 46.70°C (84.06°F) for this region, the adjusted average temperature in the second region is 139.48°C (283.06°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 40.68°C (73.23°F) for this region, the adjusted average temperature in the third region is 134.02°C (273.23°F). Averaging these three temperatures, an average adjusted gas temperature of 140.36°C (284.64°F) is determined for the containment vessel.

As shown in Appendix 3.5.2, the maximum adjusted average gas temperature and pressure in the containment vessel during accident conditions was calculated to be 140.36°C (284.64°F), and 775.37 kPa (112.458 psia), respectively. For conservatism and for use in Sects. 2 and 4, the maximum adjusted average gas temperature and pressure in the containment vessel during accident conditions are rounded up to 140.56°C (285.0°F) and 775.66 kPa (112.50 psia), respectively.

The maximum adjusted temperature on the surface of the containment vessel, adjacent to the O-rings, was 156.19°C (313.14°F). This is well within the design range for the packaging. The full body helium leak test on all test units following thermal testing meets the “leaktight” criteria in accordance with ANSI N14.5-1997. Visual inspection following testing and unloading indicated that no distortion or damage occurred in the containment vessel wall, sealing lid, closure nut, O-rings, or sealing surfaces. No water was 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 TU-6.

The ES-3100 package satisfies the requirements of 10 CFR 71.73 for transport of the 35.2-kg (77.60-lb) arrangements shown in Table 2.8. Section 2.7 has additional details to support this conclusion.

3.4.4 Maximum Thermal Stresses

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 3.4. As shown in Sect. 3.4.3, the maximum temperature for the containment vessel at the O-ring location was adjusted for the ES-3100 package to 156.19°C (313.14°F). Hence, no damage would be expected to the O-rings during HAC.

The test packages were all preheated to >38°C (100°F) prior to being placed in the furnace, which was heated to >800°C (1475°F). As noted in the test report (ORNL/NTRC-013), the temperatures recorded on the containment vessels of TU-1 through TU-5 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 3.4). 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 *ASME Boiler and Pressure Vessel Code*, Sect. III. Thermal stress is defined as a self-balancing stress produced by a nonuniform distribution of temperature (*ASME Boiler and Pressure Vessel Code*, Sect. III, 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 (NB-3213.9). This general stress is further classified (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). 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 (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 six containment vessels were drilled and tapped for full body helium leak testing. All six containment vessels passed the leak rate criteria for leaktightness per ANSI N14.5-1997. The containment vessels were then submerged under a pressure equivalent to 0.9 m (3 ft) of water for 8 h, with no leakage noted (Sect. 2.7.5). Visual inspection following testing and disassembly also indicated that no distortion or damage occurred in the containment vessel wall, sealing lid, closure nut, O-rings, or sealing surfaces. These tests and observations demonstrate that thermal stresses produced during testing did not affect the containment capability of the containment vessel.

3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

The expanded fire test conditions specified in 10 CFR 71.55(f)(1)(iv) for fissile material package designs for air transportation was not conducted. The issue of subcriticality is addressed in Sect. 6 with content mass limits as addressed in Sect. 1 for air transport.

3.5 APPENDICES

3.5.1 Containment Vessel Pressure due to Normal Conditions of Transport for the Proposed Contents

3.5.2 Containment Vessel Pressure due to Hypothetical Accident Conditions for the Proposed Contents

3.5.3 Silicone Rubber Thermal Properties from Therm 1.2 Database

3.5.4 Estimates of Hydrogen Buildup in the ES-3100 Package Containing Highly Enriched Uranium

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Appendix 3.5.1

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. diam by 4.875-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, top can will be empty;

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

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

5. one shipment will contain six cans with external dimension of 3.00-in. diam by 4.75-in. high;

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

7. one shipment will contain three Teflon FEP bottles with external dimensions of 4.69-in. diam by 9.4-in. high;

8. one shipment will contain a brazed assembly of two cans with final external dimensions of 4.25-in. diam by 17.50-in. high. An empty can with external dimensions of 4.25-in. diam by 8.75-in. high will be placed on top or bottom of the 17.50-in.–high can;

9. one shipment will contain fuel rods, or tubes, or plates greater than 17.00 in. in length. These items are bundled together and protected on both ends with an open-ended can with external dimensions of ≤5.0-in. diam by ≤ 8.75-in. high. Total assembly height will be ≤30.5 in. If space is available inside the containment vessel, stainless-steel metal scrubbers will be added on the bottom and top of this assembly or an empty convenience can will be placed on the top or bottom of the assembly;

10. one shipment will contain three cans brazed together with external dimensions of 4.25-in. diam by ~30-in. high; and

11. one shipment will contain closed cans with diameters >4.25 in. In this situation, the void volume inside the loaded containment vessel must be ≥55 $in.^3$ in order to not exceed the previously high pressure prediction for containment vessel arrangement (CVA) 7.

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

1. The highly enriched uranium (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) [25°C (77°F) and 101.35 kPa (14.7 psia)] with air at a maximum relative humidity of 100% for all configurations except for CVA 7. CVA 7 assumes the air is 100% dry.

2. The convenience cans are assumed to not be sealed.

3. Convenience can and bottle geometry does not change during pressure increase inside containment vessel.

4. If metal convenience cans are used, the total amount of polyethylene bagging and lifting slings is limited to 500 g per containment vessel shipping arrangement.

5. The mass of offgassing material (polyethylene bagging or bottles, Teflon bottles, silicone pads, lifting slings) is assumed to be 1490 g for the offgassing evaluation of CVA 7.

6. CVA 11 uses metal cans and, therefore, is limited to 500 g of polyethylene bagging and lifting slings.

The offgassing material limits identified in assumptions 4 and 5 have been established based on the needs of shippers. All configurations are limited to 500 g of polyethylene in the form of bags, slings, and/or bottles. When the requirement to ship material in Teflon bottles arose, the upper limit of 1490 g of offgassing material was established. This limit is a combination of three Teflon bottles (330 g per bottle) and the original 500 g allowance for polyethylene material. These offgassing material limits have been used in calculations pertaining to containment vessel pressure, radioactive material leakage criteria, and criticality control. Therefore, portions of the safety basis for this shipping package have been based on these material limits.

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* (Van Wylen),

> "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* (Van Wylen), the partial pressure of the water vapor at saturation is:

$$\begin{aligned} P_v &= 1.0\ (0.464)\ \text{psia}, \\ &= 0.464\ \text{psia}. \end{aligned}$$

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

$$\begin{aligned} P_a &= P_t - P_v , \\ &= 14.7 - 0.464, \\ &= 14.236\ \text{psia}. \end{aligned}$$

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

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

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:

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

where

V_{ECV} = volume inside an empty containment vessel,
V_{SP} = silicone pad volume,
V_{PB} = polyethylene bagging or lifting sling volume,
V_{SCC} = structural 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.

The bounding case for oxide material contained in 4.25-in–diam cans based on the volumes listed in Table 1 is CVA 1 at 588.46 in.^{3} CVA 1's void volume is the lowest of the volumes shown in Table 1 for configurations that are used to transport the materials in the form of oxide. CVA 2 and CVA 3 have smaller volumes primarily due to the use of can spacers. Can spacers are not required when transporting oxides. To determine the minimum volume for this configuration, the mass limit of 15.13 kg of oxides is used in conjunction with the lowest density oxide of 7.3 kg/L (UO_3). The resulting volume is 15.13 kg / 7.3 kg/L × 1 ft^3 / 28.32 L × 1728 in.^{3} / ft^3 = 126.464 in.^{3} Therefore, the bounding volume for CVA 1 is 588.46 in.^{3} − 126.464 in.^{3} = 462.00 in.^{3}

Table 1. Containment vessel void volume for each CVA

	CVA	V_{ECV} (in.^{3})	V_{SP} [a] (in.^{3})	V_{PB} (in.^{3})	V_{SCC} (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	7.84	0.00	1.02	588.46
2	Five 4.875-high cans Nine silicone pads Three Cat 277-4 spacers Eight can handles	637.18	12.03	30.51	6.47	60.60	1.36	526.21
3	Three 8.75-in.–high cans Two Cat 277-4 spacers Six silicone pads Five can handles	637.18	8.02	30.51	5.14	40.40	0.85	552.26
4	Three 10-in.–high cans Four silicone pads Three can handles	637.18	5.35	30.51	5.56	0.00	0.51	595.26
5	Six 4.75-in.–high nickel cans	637.18	0.00	30.51	12.64	0.00	1.02	593.01
6	Three 4.94-in.–OD polyethylene bottles	637.18	0.00	9.46	21.05	0.00	0.00	606.67
7	Three 4.69-in.–OD Teflon FEP bottles	637.18	0.00	30.51	27.95	0.00	0.00	578.72
8	One 17.5-in.–high can loaded One 8.75-in.–high can empty Three silicone pads Two can handles	This configuration is bounded by CVA 3						
9	Two open-ended cans One empty convenience can with height ≤ 8.75-in. Three silicone pads Two can handles	This configuration is bounded by CVA 4 b						
10	Three 10-in. cans brazed together Two silicone pads One can handle	This configuration is bounded by CVA 4						
11	Closed convenience cans with diameters greater or equal to 4.25-in. Seven silicone pads							54.25 (min.)

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] Although CVA 9 may slightly exceed the height of the combined three 25.4 cm (10 in.) can height (CVA 4), the open-ended cans and contents produce a larger void volume and thereby lower overall pressure inside the containment vessel.

Only CVA 7 can accommodate the uranyl nitrate crystals (UNX) held in the Teflon bottles. CVA 7 is limited to 9.17 kg of the uranyl nitrate hexahydrate crystals and 11.9 kg of uranyl nitrate trihydrate crystals (see Appendix 3.5.4). For the bounding pressure calculation, the smallest resulting free volume in CVA 7 is then 578.72 − 11.9 kg / 2.81 kg/L × 1 ft^3 / 28.32 L × 1728 in.^{3} / ft^3 = 578.72 in.^{3} − 258.4 in.^{3} = 320.32 in.^{3}

The bounding case for all materials contained in cans with a diameter >4.25 in. is determined by not exceeding the maximum predicted HAC pressure previously determined for CVAs 1 and 7. A minimum void volume of 54.25 in.^{3} in the containment vessel has been calculated. This value is conservatively rounded up to 55 in.^{3}

Using the above molar equations and bounding volumes, the number of moles for water vapor and dry air in the vessel for CVAs 1, 7, and 11 are 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-mol· R)	T_{amb} (R)	n_v (lb-mol)	n_a (lb-mol)
1	14.236	0.464	462.00	1545.32	537	2.1527E-05	6.6047E-04
7	14.700 [a]	0.000 [a]	320.32	1545.32	537	0.0000E+00	4.7285E-04
11	14.236	0.464	54.25	1545.32	537	2.5278E-06	7.7556E-05

[a] This represents a worst case set of conditions due to the later addition of water vapor from efflorescence of the UNX crystals.

II. Molar quantity determination due to offgassing for each containment vessel arrangement

The maximum temperature calculated for the containment vessel is 91.93°C (197.48°F). This temperature is assumed to be constant throughout the containment vessel and contents. Therefore, the polyethylene bags, polyethylene bottles, Teflon FEP bottles, 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 170°C (338°F) conducted by the Y-12 Development Division, the amount of gas (V_{bo} and V_{po}) generated due to offgassing of the polyethylene bags and bottles, and silicone rubber can pads at any temperature is estimated by first determining the offgassing 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 offgassing occurred in the polyethylene bags and bottles, or silicone rubber pad material as documented in Y/DZ-2585. The data showed that the Teflon FEP material offgassing volume per unit mass (V_{tf}) was conservatively assumed to be 0.25 cm^3/g@STP (Y/DZ-2720). These values are used to determine the offgassing volumes as shown below:

$V_{po} = W_p \times 0.0 / 16.387$ (in.^{3}) (offgassing volume of silicone rubber pads)

$V_{bo} = W_b \times 0.0 / 16.387$ (in.^{3}) (offgassing volume of polyethylene bags and bottles or lifting sling)

$V_{tf} = W_{tf} \times 0.25 / 16.387$ (in.^{3}) (offgassing volume of Teflon bottles)

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

$$n_{io} = \frac{P_v \times V_i}{R_u \times T_{amb} \times 12}.$$

A summary of the results obtained using the above equations for the bounding CVA is presented in Tables 3, 4, and 5.

Table 3. Molar quantity of gas generated due to the silicone rubber pad offgassing [a]

CVA	W_p (g)	V_{po} ($in.^3$)	P_V (psia)	R_u (ft-lb/lb-mol·R)	T_{amb} (R)	n_{po} (lb-mol)
1	186.74	0.00	14.7	1545.32	537	0.0000E+00
7	0.00	0.00	14.7	1545.32	537	0.0000E+00
11	186.74	0.00	14.7	1545.32	537	0.0000E+00

[a] Silicone rubber pad weight determined from Table 2.8.

Table 4. Molar quantity of gas generated due to the polyethylene bag, sling and bottle offgassing

CVA	W_b (g)	V_{bo} ($in.^3$)	P_V (psia)	R_u (ft-lb/lb-mol·R)	T_{amb} (R)	n_{bo} (lb-mol)
1	500.00	0.00	14.7	1545.32	537	0.0000E+00
7	500.00	0.00	14.7	1545.32	537	0.0000E+00
11	500.00	0.00	14.7	1545.32	537	0.0000E+00

Table 5. Molar quantity of gas generated due to the Teflon bottle offgassing

CVA	W_{tf} (g)	V_{tf} ($in.^3$)	P_V (psia)	R_u (ft-lb/lb-mol·R)	T_{amb} (R)	n_{tf} (lb-mol)
7	990.00	15.10	14.7	1545.32	537	2.2296E-05

III. Gas generation due to radiolysis of water

Buildup of hydrogen gas (H_2) and oxygen gas (O_2) in the ES-3100 containment vessel due to radiolysis is incorporated into the pressure calculation by assuming that 5 mol % of the free volume is hydrogen gas. Since each mole of H2 generated is accompanied by 0.5 mol of O_2, the concentration of H_2 will reach 5 mol % when volume of H_2 is 0.05405 times the initial void volume (see Sect. 3.5.4.8 of Appendix 3.5.4). Using the ideal gas law, the number of gas moles of hydrogen in the volume at standard temperature and pressure is:

$$n_r = \frac{P_v \times V_r}{R_u \times T_{amb} \times 12},$$

where

n_r = individual molar quantity for hydrogen and oxygen gas;
V_r = volume of gas assumed generated by radiolysis.

A summary of the results for hydrogen and oxygen generation due to radiolysis using the above equation is presented in Table 6.

Table 6. Molar quantity of oxygen and hydrogen gas generation due to radiolysis

CVA	V_v (in.^{3})	V_h (in.^{3})	P_v (psia)	R_u (ft-lb/lb-mol· R)	T_{amb} (R)	n_{r-H2} (lb-mol)	n_{r-O2} (lb-mol)
1	462.00	24.97	14.7	1545.32	537.0	3.6861E-05	1.8430E-05
7	320.32	17.31	14.7	1545.32	537.0	2.5558E-05	1.2779E-05
11	54.25	2.93	14.7	1545.32	537.0	4.3285E-06	2.1643E-06

IV. Molar quantity of gas generated due to the efflorescence nature of the uranyl nitrate crystals

The UNX crystals in any hydrated state will decompose and lose water molecules at the temperature shown in Table 3.3 [197.48°F (91.93°C)]. The partial pressure of water vapor in this mixture is conservatively estimated to be the saturated vapor pressure (P_{sv}) of water at 197.48°F or 10.9117 psia. Using the ideal gas law, the molar quantity of water vapor (nv) in this volume at the maximum containment vessel temperature and the saturated vapor pressure is:

$$n_v = \frac{P_{sv} \times V_v}{R_u \times T_{cv} \times 12},$$

$$= (10.9117 \times 320.32) / (1545.32 \times 12 \times 657.48),$$
$$= 2.8668 \times 10^{-4} \text{ lb-mol},$$

where

n_v = molar quantity for water vapor;
V_v = void volume of containment vessel;
T_{cv} = maximum temperature of containment vessel; and
P_{sv} = interpolated saturated vapor pressure of water at temperature from *Fundamental of Classical Thermodynamic* (Van Wylen), Table A.1.1, p. 650.

V. Total pressure due to offgassing and NCT temperatures inside the containment vessel

The total pressure of the mixture at 91.93°C (197.48°F), P_T, for the bounding CVA is the sum of each of the previously calculated molar quantities. Table 7 summarizes the molar constituents and total pressure of each bounding CVA. The following equation is used to calculated the final containment vessel pressure:

$$P_{91.93°C} = (\sum n_i \times R \times T \times 12) / V_{GMV},$$

where

n_i = individual molar quantity for each gas,

T = average gas temperature,
= 91.93°C (197.48°F),

V_{GMV} = V_v = gas mixture volume.

Table 7. Total pressure inside the containment vessel at 91.93°C (197.48°F) [a]

CVA	n_a [b] (lb-mol)	n_v [b] (lb-mol)	n_{po} [b] (lb-mol)	n_{bo} [b] (lb-mol)	n_{tf} [b] (lb-mol)	n_{H2} [b] (lb-mol)	n_{O2} [b] (lb-mol)	n_T [b] (lb-mol)	P_T (psia)
1	6.6047E-04	2.1527E-05	0.0000E+00	0.0000E+00	0.0000E+00	3.6862E-05	1.8431E-05	7.3729E-04	19.457
7	4.7285E-04	2.8668E-04 [c]	0.0000E+00	0.0000E+00	2.2296E-05	2.5558E-05	1.2779E-05	8.2016E-04	31.218
11	7.7556E-05	2.5278E-06	0.0000E+00	0.0000E+00	0.0000E+00	4.3285E-06	2.1643E-06	8.6577E-05	19.457

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] n_a—molar quantity of dry air in the gas mixture;
n_v—molar quantity of water vapor in the gas mixture;
n_{po}—molar quantity of gas due to offgassing of the silicone rubber pads;
n_{bo}—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
n_{tf}—molar quantity of gas due to offgassing of the Teflon bottles;
n_{H2}—molar quantity of hydrogen gas due to radiolysis of water;
n_{O2}—molar quantity of oxygen gas due to radiolysis of water; and
n_T—total molar quantity in the gas mixture.

[c] This value is the molar quantity of water vapor generated from the efflorescence of UNX crystals.

VI. Total pressure at −40°C (−40°F)

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

VII. Maximum containment vessel pressure differential in accordance with air transport guidance

The methodology used to determine the maximum pressure differential for air transport in accordance with TS-R-1, Paragraph 618 incorporates the following assumptions.

1. The three containment vessel arrangements previously discussed in this appendix will be evaluated.

2. Evaluation will be conducted at the maximum containment vessel temperature shown in Table 3.14 for air transport.

3. Maximum containment vessel temperature was determined using an ambient temperature of 55°C, self-heating of the package contents, and no insolation.

4. Maximum pressure differential is the maximum normal operating pressure (MNOP) plus 95 kPa.

A value of 146.11°F was determined and documented in DAC-PKG-801940-A001 and is used as an average temperature of the containment vessel. The molar quantity results shown in Table 8 will be evaluated at this temperature as shown in Table 9. The molar values shown in Table 8 for CVA 7 are very conservative because the water vapor molar quantity includes water vapor generated from the efflorescence of UNX crystals. UNX crystals will not be transported by air.

Table 8. Total molar quantities inside the containment vessel [a]

CVA	n_a [b] (lb-mol)	n_v [b] (lb-mol)	n_{po} [b] (lb-mol)	n_{bo} [b] (lb-mol)	n_{tf} [b] (lb-mol)	n_{H2} [b] (lb-mol)	n_{O2} [b] (lb-mol)	n_T [b] (lb-mol)
1	6.6047E-04	2.1527E-05	0.0000E+00	0.0000E+00	0.0000E+00	3.6862E-05	1.8431E-05	7.3729E-04
7	4.7285E-04	2.8668E-04 [c]	0.0000E+00	0.0000E+00	2.2296E-05	2.5558E-05	1.2779E-05	8.2016E-04
11	7.7556E-05	2.5278E-06	0.0000E+00	0.0000E+00	0.0000E+00	4.3285E-06	2.1643E-06	8.6577E-05

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] n_a—molar quantity of dry air in the gas mixture;
n_v—molar quantity of water vapor in the gas mixture;
n_{po}—molar quantity of gas due to offgassing of the silicone rubber pads;
n_{bo}—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
n_{tf}—molar quantity of gas due to offgassing of the Teflon bottles;
n_{H2}—molar quantity of hydrogen gas due to radiolysis of water;
n_{O2}—molar quantity of oxygen gas due to radiolysis of water; and
n_T—total molar quantity in the gas mixture.

[c] This value is the molar quantity of water vapor generated from the efflorescence of UNX crystals.

Therefore, the maximum differential pressure (P_{DIFF}) generated under air transport conditions is the maximum pressure calculated in Table 9 plus 95 kPa (13.78 psi). This pressure differential will be used in Table 2.21a to evaluate the containment vessel structural integrity for air transport.

Table 9. Containment vessel MNOP at 63.39°C (146.11°F)

CVA	n_T (lb-mol)	P_{MNOP} (psia)	P_{DIFF} (psig)
1	7.3729E-04	17.937	31.717
7	8.2016E-04	28.778	42.558
11	8.6577E-05	17.937	31.717

Appendix 3.5.2

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;

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 two can spacers;

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

5. one shipment will contain six nickel cans with external dimensions of 3.00-in. diam by 4.75-in. high;

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

7. one shipment will contain three Teflon FEP bottles with external dimensions of 4.69-in. diam by 9.4-in. high;

8. one shipment will contain a brazed assembly of two cans with final external dimensions of 4.25-in. diam by 17.50-in. high. An empty can with external dimensions of 4.25-in. diam by 8.75-in. high will be placed on top or bottom of the 17.50-in.–high can;

9. one shipment will contain fuel rods, or tubes, or plates greater than 17.00 in. in length. These items are bundled together and protected on both ends with an open-ended can with external dimensions of ≤5.0-in. diam by ≤ 8.75-in. high. Total assembly height will be ≤30.5 in. If space is available inside the containment vessel, stainless-steel metal scrubbers will be added on the bottom and top of this assembly or an empty convenience can will be placed on the top or bottom of the assembly;

10. one shipment will contain three cans brazed together with external dimensions of 4.25-in. diam by ~30-in. high; and

11. one shipment will contain closed cans with diameters >4.25 in. In this situation, the void volume inside the loaded containment vessel must be ≥55 $in.^3$ in order to not exceed the previously high pressure prediction for containment vessel arrangement (CVA) 7.

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 [25°C (77°F)] and at the maximum normal operating pressure (see Table 7 of Appendix 3.5.1).

2. The convenience cans are assumed to not be sealed.

3. Convenience can and bottle geometry does not change during pressure increase inside containment vessel.

4. If metal convenience cans are used, the total amount of polyethylene bagging and lifting slings is limited to 500 g per containment vessel shipping arrangement.

5. The mass of offgassing material (polyethylene bagging or bottles, Teflon bottles, silicone pads, lifting slings) is assumed to be 1490 g for the offgassing evaluation of CVA 7.

6. Hydrogen and oxygen molar quantities calculated in Appendix 3.5.1 are conservatively added to the gas mixture for HAC.

7. The contribution in pressure generated by the efflorescence of uranyl nitrate crystals (UNX) is incorporated into the results for CVA 7.

8. CVA 11 uses metal cans and, therefore, is limited to 500 g of polyethylene bagging and lifting slings.

The offgassing material limits identified in assumptions 4 and 5 have been established based on the needs of shippers. All configurations are limited to 500 g of polyethylene in the form of bags, slings, and/or bottles. When the requirements to ship material in Teflon bottles arose, the upper limit of 1490 g of offgassing material was established. This limit is a combination of three Teflon bottles (990 g) and the original 500 g allowance for polyethylene material. These offgassing material limits have been used in calculations pertaining to containment vessel pressure, radioactive material leakage criteria, and criticality control. Therefore, portions of the safety basis for this shipping package have been based on these material limits.

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 bottles, silicone rubber pads, and Teflon bottles) 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

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

$$n_{MNOP} = \frac{P_T \times V_v}{R_u \times T_{amb} \times 12} \ (molar\ equation) .$$

Using P_T from Table 1 and the molar equation, the total number of moles is summarized in Table 2.

Table 1. Total pressure inside the containment vessel at 91.93°C (197.48°F) [a]

CVA	n_a [b] (lb-mol)	n_v [b] (lb-mol)	n_{po} [b] (lb-mol)	n_{bo} [b] (lb-mol)	n_{tf} [b] (lb-mol)	n_{H2} [b] (lb-mol)	n_{O2} [b] (lb-mol)	n_T [b] (lb-mol)	P_T (psia)
1	6.6047E-04	2.1527E-05	0.0000E+00	0.0000E+00	0.0000E+00	3.6862E-05	1.8431E-05	7.3729E-04	19.457
7	4.7285E-04 [c]	2.8668E-04 [c]	0.0000E+00	0.0000E+00	2.2296E-05	2.5558E-05	1.2779E-05	8.2016E-04	31.218
11	7.7556E-05	2.5278E-06	0.0000E+00	0.0000E+00	0.0000E+00	4.3285E-06	2.1643E-06	8.6577E-05	19.457

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] n_a—molar quantity of dry air in the gas mixture;
n_v—molar quantity of water vapor in the gas mixture;
n_{po}—molar quantity of gas due to offgassing of the silicone rubber pads;
n_{bo}—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
n_{tf}—molar quantity of gas due to offgassing of the Teflon bottles;
n_{H2}—molar quantity of hydrogen gas due to radiolysis of water;
n_{O2}—molar quantity of oxygen gas due to radiolysis of water; and
n_T—total molar quantity in the gas mixture.

[c] For CVA 7, using 100% dry air at containment vessel closure and the saturated vapor pressure at temperature for the water vapor constituent, the highest pressure is generated.

Table 2. Molar summary at MNOP and 25°C (77°F)

CVA	P_T (psia)	V_V ($in.^3$)	R_u (ft-lb/lb-mol·R)	T_{amb} (R)	n_{MNOP} (lb-mol)
1	19.457	462.00	1545.32	537	9.0270E-04
7	31.218	320.32	1545.32	537	1.0042E-03
11	19.457	54.25	1545.32	537	1.0600E-04

II. Molar quantity determination due to offgassing 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 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 40.08°C (72.14°F) for this region (Sect. 3.4.3), the adjusted average temperature in the first region is 147.58°C (297.64°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 46.70°C (84.06°F) for this region (Sect. 3.4.3), the adjusted average temperature in the second region is 139.48°C (283.06°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 40.68°C (73.23°F) for this region (Sect. 3.4.3), the adjusted average temperature in the third region is 134.02°C

(273.23°F). Averaging these three temperatures, an average adjusted gas temperature of 140.36°C (284.64°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 170°C (338°F) conducted by the Y-12 Development Division (Y/DZ-2585), the amount of gas generated due to offgassing of the silicone rubber can pads, the polyethylene bags and bottles, and the Teflon FEP bottles at 140.36°C (284.64°F), (V_{po}, V_{bo}, and V_{tf}) is estimated by first determining the offgassing volume per unit mass at temperature and multiplying that by the total mass of the bags, bottles, slings, 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/g @STP for the polyethylene bagging and bottles, and silicone rubber pads, respectively, were taken from the curves for the offgassing volume per unit mass as documented in Y/DZ-2585. The data showed that the Teflon FEP material offgassing volume per unit mass (V_{tf}) was conservatively assumed to be 0.25 cm^3/g@STP (Y/DZ-2720). These values are used to determine the offgassing volume as shown below:

$V_{po} = W_p \times 0.8 / 16.387\ (in.^3)$ (offgassing volume of silicone rubber pads)

$V_{bo} = W_b \times 7.0 / 16.387\ (in.^3)$ (offgassing volume of polyethylene bags, bottles, and lifting sling)

$V_{tf} = W_{tf} \times 0.25 / 16.387\ (in.^3)$ (offgassing bottles of Teflon FEP bottles)

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

$$n_i = \frac{P_v \times V_i}{R_u \times T_{amb} \times 12}.$$

A summary of the results obtained using the above equations for CVAs 1, 7, and 11 is presented in Tables 3, 4, and 5.

Table 3. Molar quantity of gas generated due to the silicone rubber pad offgassing [a]

CVA	W_p (g)	V_{po} ($in.^3$)	P_V (psia)	R_u (ft-lb/lb-mol·R)	T_{amb} (R)	n_{po} (lb-mol)
1	186.74	9.12	14.7	1545.32	537	1.3458E-05
7	0.00	0.00	14.7	1545.32	537	0.0000E+00
11	186.74	9.12	14.7	1545.32	537	1.3458E-05

[a] Silicone rubber pad weight determined from Table 2.8.

Table 4. Molar quantity of gas generated due to polyethylene bag, sling, and bottle offgassing

CVA	W_b (g)	V_{bo} (in.^{3})	P_V (psia)	R_u (ft-lb/lb-mol·R)	T_{amb} (R)	n_{bo} (lb-mol)
1	500.00	213.58	14.7	1545.32	537	3.1529E-04
7	500.00	213.58	14.7	1545.32	537	3.1529E-04
11	500.00	213.58	14.7	1545.32	537	3.1529E-04

Table 5. Molar quantity of gas generated due to the Teflon FEP bottle offgassing

CVA	W_{tf} (g)	V_{tf} (in.^{3})	P_V (psia)	R_u (ft-lb/lb-mol·R)	T_{amb} (R)	n_{tf} (lb-mol)
7	990.00	15.10	14.7	1545.32	537	2.2296E-05

III. Gas generation due to radiolysis of water

Buildup of hydrogen gas (H_2) and oxygen gas (O_2) in the ES-3100 containment vessel due to radiolysis is incorporated into the pressure calculation by assuming that 5 mol % of the free volume is hydrogen gas. Since each mole of H2 generated is accompanied by 0.5 mol of O_2, the concentration of H_2 will reach 5 mol % when volume of H_2 is 0.05405 times the initial void volume (see Sect. 3.5.4.8 of Appendix 3.5.4). Using the ideal gas law, the number of gas moles of hydrogen in the volume at standard temperature and pressure is:

$$n_r = \frac{P_v \times V_r}{R_u \times T_{amb} \times 12},$$

where

n_r = individual molar quantity for hydrogen and oxygen gas,
V_r = volume of gas assumed generated by radiolysis.

A summary of the results for hydrogen and oxygen generation due to radiolysis using the above equation is presented in Table 6.

Table 6. Molar quantity of oxygen and hydrogen gas generation due to radiolysis

CVA	V_v (in.^{3})	V_h (in.^{3})	P_v (psia)	R_u (ft-lb/lb-mol·R)	T_{amb} (R)	n_{r-H2} (lb-mol)	n_{r-O2} (lb-mol)
1	462.00	24.97	14.7	1545.32	537.0	3.6861E-05	1.8430E-05
7	320.32	17.31	14.7	1545.32	537.0	2.5558E-05	1.2779E-05
11	54.25	2.93	14.7	1545.32	537.0	4.3285E-06	2.1643E-06

IV. Molar quantity of gas generated due to the efflorescence nature of the uranyl nitrate crystals

The UNX crystals in any hydrated state will decompose and lose water molecules at the average gas temperature shown in Sect. 3.4.3 [140.36°F (284.64°C)]. The partial pressure of water vapor in this mixture is conservatively estimated to be the saturated vapor pressure (P_{sv}) of water at 284.64°F or 52.964 psia. Using the ideal gas law, the molar quantity of water vapor (n_v) in this volume at the maximum containment vessel temperature and the saturated vapor pressure is:

$$\begin{aligned} n_v &= (P_{sv} \times V_v) / (R_u \times T_{cv} \times 12); \\ &= (52.964)(320.32) / (1545.32 \times 12 \times 744.64); \\ &= 1.2286 \times 10^{-3} \text{ lb-mol;} \end{aligned}$$

where

n_v = individual molar quantity for water vapor;
V_v = void volume of containment vessel;
T_{cv} = average gas temperature inside the containment vessel; and
P_{sv} = interpolated saturated vapor pressure of water at temperature from *Fundamental of Classical Thermodynamic* (Van Wylen), Table A.1.1, p. 650.

V. Total pressure due to offgassing and HAC temperatures inside the containment vessel with efflorescence of uranyl nitrate crystals

The total pressure of the mixture at 140.36°C (284.64°F), P_T, for each CVA is the sum of each of the previously calculated molar quantities. Table 7 summarizes the molar constituents and total pressure of each CVA. The following equation is used to calculate the final containment vessel pressure:

$$P_{140.36°C} = (\sum n_i \times R \times T \times 12) / V_{GMV},$$

where

n_i = individual molar quantity for each gas,

T = average gas temperature,
= 140.36°C (284.64°F),

V_{GMV} = V_v,
= gas mixture volume.

Table 7. Total pressure inside the containment vessel at 140.36°C (284.64°F) with efflorescence [a]

CVA	n_{MNOP} [b] (lb-mol)	n_{po} [b] (lb-mol)	n_{bo} [b] (lb-mol)	n_{tf} [b] (lb-mol)	n_{r-H2} [b] (lb-mol)	n_{r-O2} [b] (lb-mol)	n_{CE-WV} [b, c] (lb-mol)	n_T [b] (lb-mol)	P_T (psia)
1	9.0270E-04	1.3458E-05	3.1529E-04	0.0000E+00	3.6862E-05	1.8431E-05	0.0000E+00	1.2867E-03	38.459
7	1.0042E-03	0.0000E+00	3.1529E-04	2.2296E-05	2.5558E-05	1.2779E-05	1.2286E-03	2.6087E-03	112.458
11	1.0600E-04	1.3485E-05	3.1529E-04	0.0000E+00	4.3285E-06	2.1643E-06	0.0000E+00	4.4127E-04	112.318

[a] This assumes that the internal convenience cans, polyethylene or Teflon FEP bottles, and Cat 277-4 spacer cans are not sealed.

[b] n_{MNOP}—molar quantity of the gas mixture at maximum normal operating pressure at standard temperature [25°C (77°F)];
n_{po}—molar quantity of gas due to offgassing of the silicone rubber pads;
n_{bo}—molar quantity of gas due to offgassing of the polyethylene bags, bottles, and lifting sling;
n_{tf}—molar quantity of gas due to offgassing of the Teflon bottles;
n_{r-H2}—molar quantity of hydrogen gas due to radiolysis of water;
n_{r-O2}—molar quantity of oxygen gas due to radiolysis of water;
n_{CE-WV}—molar quantity of water vapor due to efflorescence of UNX crystals; and
n_T—total molar quantity in the gas mixture.

[c] Efflorescence of UNX crystals as water vapor.

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Appendix 3.5.3

Silicone Rubber Thermal Properties from Therm 1.2 Database

The thermal properties for silicone rubber used in the thermal analyses of the ES-3100 shipping container were obtained from the Therm 1.2 Thermal Properties Database by R. A. Bailey. Since Therm 1.2 is not a publicly available program, screen captures from Therm 1.2 of the data for silicone rubber are presented in Figs. 1 and 2 in English and SI units, respectively.

```
                  silicone rubber, medium k (see ref 5)
         ------------------------------------------------------------
         Density                              .04696548   lb/in**3
         Specific Heat                        .3          Btu/lb°F
         Conductivity                         .01612725   Btu/hr in°F
         Maximum Material Temp             545.0          °F
         silicone rubber, medium k (see ref 5)
         ------------------------------------------------------------
References:
    fleming p           private collection of plastics data          1968
                        materials engr  matl selector issue          1967
                        metals handbook  8th ed                      1961
    moyer j             private collection of thermal data           1968
Material properties quality
    Density                 -  Good data, or no way of estimating quality.
    Specific Heat           -  Poor or conflicting data.  Used best or average.
    Conductivity            -  Poor or conflicting data.  Used best or average.
    Transition Temperature  -  Good data, or no way of estimating quality.
    Latent Heat             -  No data.  Made no estimate.
    Specific Heat Tables    -  No data.  Made no estimate.
    Conductivity Tables     -  No data.  Made no estimate.
```

Fig. 1. Silicone rubber thermal properties from Therm 1.2 (English units).

```
         silicone rubber, medium k (see ref 5)
         ------------------------------------------------------------
         Density                          1300.0          kg/m**3
         Specific Heat                    1255.2          J/kg°K
         Conductivity                         .33472      J/sec m°K
         Maximum Material Temp             558.15         °K
         silicone rubber, medium k (see ref 5)
         ------------------------------------------------------------
References:
    fleming p           private collection of plastics data           1968
                        materials engr  matl selector issue           1967
                        metals handbook  8th ed                       1961
    moyer j             private collection of thermal data            1968
Material properties quality
    Density                 -  Good data, or no way of estimating quality.
    Specific Heat           -  Poor or conflicting data.  Used best or average.
    Conductivity            -  Poor or conflicting data.  Used best or average.
    Transition Temperature  -  Good data, or no way of estimating quality.
    Latent Heat             -  No data.  Made no estimate.
    Specific Heat Tables    -  No data.  Made no estimate.
    Conductivity Tables     -  No data.  Made no estimate.
```

Fig. 2. Silicone rubber thermal properties from Therm 1.2 (SI units).

Appendix 3.5.4

Estimates of Hydrogen Buildup in the ES-3100 Package Containing Highly Enriched Uranium

3.5.4.0 Summary

Table 3.5.4.1 below indicates that the ES-3100 package with Containment Vessel Arrangement 1 (CVA 1, see Appendix 3.5.1) and a 15.13-kg load of uranium oxide with 3 wt % water, will generate 5 mol % of hydrogen in the void space of the containment vessel in ~1.5 years (18 months). With CVA 7, a load of 4.75 kg of uranyl nitrate hexahydrate crystals [UO2(NO3)2·XH2O, X = 6, 21.6 wt % water] or a load of 6.70 kg of uranyl nitrate trihydrate crystals (X=3, 12.1 wt % water) will generate 5 mol % of hydrogen in ~1.2 years (15 months). With CVA 7, a load of 9.17 kg of hexahydrate crystals will generate 5 mol % in ~0.46 years (5.6 months) while a load of 11.90 kg of trihydrate crystals will generate 5 mol % in ~0.49 years (5.8 months).

Table 3.5.4.1 Summary of load weights and shipment durations

Weight (kg)	Water		Time to 5 mol % hydrogen (y/month)
	X	wt %	
Oxides [CVA 1] [a]			
15.13	UO_2	3.0	1.51/18.2
15.13	U_3O_8	3.0	1.51/18.1
15.13	UO_3	3.0	1.49/17.9
$UO_2(NO_3)_2 \cdot XH_2O$ [CVA 7] [b]			
4.75	6	21.64	1.20/14.4
6.70	3	12.13	1.22/14.6
9.17	6	21.64	0.464/5.6
11.90	3	12.13	0.486/5.8

[a] CVA 1 consists of six steel cans (see Sect. 3.1.4.1).
[b] CVA 7 consists of three Teflon bottles (see Sect. 3.1.4.1).

3.5.4.1 Introduction

There is a concern that hydrogen gas (H_2) could build up to dangerous levels in the ES-3100 package. Consequently, it is necessary to estimate the combination of shipping weight and transit time that limits the H_2 concentration in the package to 5 mol % (established as a limit for the purposes of this analysis). The H_2 can be generated by radiolysis and/or chemical reaction involving any material containing hydrogen. Of the anticipated materials to be shipped, the only chemical reaction would be metal reacting with water (or water vapor) to form H_2 and a metal oxide. It will be shown that radiolysis of water is the major source of H_2 for uranium oxides and uranyl nitrate crystals.

The materials that may be shipped in the ES-3100 include highly enriched uranium (HEU) in the form of uranium oxide (UO_3, U_3O_8, and UO_2) and uranyl nitrate crystals [UNX or $UO_2(NO_3)_2 \cdot XH_2O$]. The water associated with oxides ranges from 0 to 3 wt % (Sect. 1.2.2). The water in UNX ranges from X = 0 to X = 6 (0 to 21.6 wt %). The molecular weights of uranyl nitrate [$UO_2(NO_3)_2$] and H_2O are 391 and 18 g/mol, respectively, so the fraction of water in UN6 is $6 \times 18 / (391 + 6 \times 18) = 0.216$. There is no liquid water (sorbed or interstitial) associated with any of the other contents. However, the air in the void

spaces of the package contains water vapor (humidity). It will be shown that the maximum amount of H_2 from humidity is below 5 mol %.

3.5.4.2 Initial hydrogen in convenience containers

It was suggested that convenience containers stored for a long period of time could accumulate significant amounts of H_2 in the containers before being placed in the ES-3100. The convenience containers are Teflon bottles for UNX, and cans or polyethylene bottles for other materials. An estimate of the accumulated H_2 is given in this section.

The ES-3100 has several containment vessel arrangements (CVAs, see Appendix 3.5.1, Table 1) for the convenience containers. CVA 7 consists of three Teflon bottles and is the only arrangement for UNX. CVAs 5 (nickel alloy cans) and 6 (polyethylene bottles) can only be used for oxides while the remaining CVAs (steel cans) may be used for oxides or metal. The bounding arrangement for oxides is CVA 1 (6 steel cans) because it has the smallest free volume (588.45 $in.^3$, see Appendix 3.5.1, Table 1).

The H_2 generated in a container can leak out through tiny spaces in imperfect lids and by permeation or diffusion through the walls of the container. The largest leaks are through the lids but these are difficult to characterize. Consequently, this calculation conservatively considers only permeation and diffusion through the cylindrical surfaces. Because permeation is usually a faster mechanism than diffusion and is more likely with plastics, the permeation model was used for the Teflon bottles. Since metals are not very permeable, the diffusion model was used for the cans.

The rate of gas loss through permeation is based on an equation in *Perry's Chemical Engineers' Handbook* (p. 6-39, Eq. 6-170). The resulting expression is

$$d(n_P) / dt = -P_T \times \Delta P \times A_T / \tau_T \times \rho_G \times (1 + \Delta P / P_0),$$

where

n_P = the amount of gas in the three Teflon bottles, mol;
t = time, y;
P_T = the permeability of H_2 through Teflon, $cm^2/y \cdot Pa$;
ΔP = the pressure increase over the initial value, Pa;
A_T = the cylindrical area of three Teflon bottles (each is 4.69-in. diam × 9.4-in. tall) 2682.8 cm^2 (Y/HDPO/03-43);
τ_T = the thickness of each bottle, 0.13 cm (Y/HDPO/03-43);
ρ_G = the molar density of an ideal gas at 25°C and 1 atm, 4.087×10^{-5} mol/cm^3;
P_0 = the initial pressure in the bottles, 101,325 Pa (1 atm); and

$1 + \Delta P / P_0$ corrects the gas density for the pressure increase.

The permeability of H_2 through Teflon at 25°C is 3.12×10^{-5} $cm^2/y \cdot Pa$ (equivalent to 9.89×10^{-8} $cm^2/s \cdot Bar$ (*Parker O-Ring Handbook*, Table 3-24, p.3-30).

At steady state, the permeation rate is balanced by the gas generation rate.

$$1.5 \times d(n_{H2}) / dt = P_T \times \Delta P \times A_T / \tau_T \times \rho_G \times (1 + \Delta P / P_0),$$

$$\rightarrow \Delta P \times (1 + \Delta P / P_0) = [1.5 \times d(n_{H2}) / dt] / [P_T \times A_T / \tau_T \times \rho_G],$$

where

$d(n_{H2}) / dt$ = the H_2 generation rate, 0.01379 mol/y for 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$ (see Sect. 3.5.4.7);
1.5 = a factor to account for the oxygen released with the hydrogen.

As an example for 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$, the above expression for ΔP with the above parameters is $\Delta P = \{[1.5 \times 0.01379 \text{ mol/y}] / [3.12 \times 10^{-5} \text{ cm}^2/\text{y} \cdot \text{Pa} \times (2682.8 \text{ cm}^2 / 0.13 \text{ cm}) \times 4.087 \times 10^{-5} \text{ mol/cm}^3]\} / (1 + \Delta P / 101{,}325 \text{ Pa})$. $\Delta P = 779.5$ Pa satisfies the above expression.

The steady-state mole fraction and H_2 amount are

$$f_{H2B} = (2 / 3) \times \Delta P / (P_0 + \Delta P),$$
$$n_{H2B} = f_{H2B} \times V_B \times \rho_G \times (1 + \Delta P / P_0) = V_B \times \rho_G \times (2 / 3) \times \Delta P / P_0,$$
$$V_B = 6840 - Wt_{UNX} / \rho_{UN6},$$

where

f_{H2B} = the mole fraction of H_2 in the bottles;
n_{H2B} = the amount of H_2 in the three bottles, mol;
2 / 3 = a factor to account for the fact that 1 / 3 of the pressure increase is due to oxygen;
V_B = the free volume of the 3 bottles, cm^3 [5149.6 cm^3 for 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$];
6840 = the empty void volume of three Teflon bottles, 6840 cm^3 (Y/HDPO/03-43);
Wt_{UNX} = the total weight of UNX in the containers, g;
ρ_{UN6} = the theoretical density of UN6 and, lacking data for other UNX hydrates, is also applied to all the hydrates, 2.81 g/cm^3 (CRC Handbook, p. 4-94).

For the example of 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$, the above equation becomes

$$n_{H2B} = 5149.6 \text{ cm}^3 \times 4.087 \times 10^{-5} \text{ mol/cm}^3 \times (2 / 3) \times 779.5 \text{ Pa} / 101{,}325 \text{ Pa},$$
$$= 0.001079 \text{ mol.}$$

The rate of H_2 loss through diffusion is based on an equation in *Perry's Chemical Engineers' Handbook* (p. 5-47, Eq. 5-189). The resulting expression is

$$d(n_{H2C}) / dt = -D \times \Delta C \times A_D / \tau_D,$$

where

n_{H2C} = the amount of H_2 in the 6 cans, mol;
$d(n_{H2C}) / dt$ = the rate of H_2 lost through diffusion from the 6 cans, mol/y;
D = the diffusivity, cm^2/y;
ΔC = the H_2 concentration increase over the initial value, mol/cm^3;
A_D = the cylindrical area of six steel cans, (each is 4.25-in. diam × 4.88-in. tall, see Sect. 1, Fig. 1.4), 2522.2 cm^2;
τ_D = the thickness of the can (assumed to be 0.012 in.), 0.0305 cm.

At steady state, the diffusion rate is balanced by the H_2 generation rate.

$$d(n_{H2}) / dt = D \times \Delta C \times A_D / \tau_D \rightarrow \Delta C$$
$$= [d(n_{H2}) / dt] / [D \times A_D / \tau_D]$$

The steady-state H_2 amount and mole fraction are

$$n_{H2C} = V_C \times \Delta C,$$
$$f_{H2C} = (V_C \times \Delta C) / (V_C \times \rho_G) = \Delta C / \rho_G,$$
$$V_C = V_0 - Wt_{OX} / \rho_{OX},$$

where

f_{H2C} = the mole fraction of H_2 in the cans;
V_C = the free volume in 6 cans, cm^3 (5001.3 cm^3 for 15,130 g of U_3O_8);
V_0 = the free volume of the 6 empty cans, 6806.8 cm^3;
Wt_{OX} = the total weight of uranium oxides in the containers, g;
ρ_{OX} = the theoretical density of uranium oxides, 7.3 g/cm^3 for UO_3, 8.38 for U_3O_8, and 10.97 for UO_2 (CRC Handbook, p. 4-94).

H_2 diffusion is discussed at http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/03_babu_transfer.pdf, p. 42 (Sudarsanam 2005). There is a wide range of values for diffusivity at room temperatures and a suggested value of $\sim 5 \times 10^{-7}$ cm^2/s (15.8 cm^2/y) is probably a low number for plain steel without welds or rough surfaces. This is the value used for calculating the diffusion loss rate of H_2 from the cans.

For 15,130 g of U_3O_8, the value of $d(n_{H2}) / dt$ is 0.01185 mol/y (see Sect. 3.5.4.7). ΔC = 0.01185 mol/y / [15.8 cm^2/y × 2522.2 cm^2 / 0.0305 cm] = 9.078E-09 mol/cm^3. The amount of H_2 in the 6 cans is n_{H2C} = 5001.3 cm^3 × 9.078E-09 mol/cm^3 = 4.540E-05 mol.

The above analysis assumed the material to be shipped is distributed equally to the maximum number of convenience containers for the specified CVAs (3 bottles for CVA 7 and 6 cans for CVA 1). If the material can be packed into fewer convenience containers, the amount of initial H_2 would be less. The expressions for C and n_{H2C} indicate that n_{H2C} is proportional to $V_C / A_D = (V_0 - Wt_{OX} / \rho_{OX}) / A_D$. If the empty volume and surface area of a single can is v and a, respectively, the above proportionality becomes $(Nc \times v - Wt_{OX} / \rho_{OX}) / (Nc \times a) = v / a - Wt_{OX} / (Nc \times a \times \rho_{OX})$ where Nc is the number of cans (1 to 6). As Nc increases, $Wt_{OX} / (Nc \times a \times \rho_{OX})$ decreases so that less is subtracted from v / a. The result is increasing n_{H2C}.

3.5.4.3 Hydrogen generation by chemical reaction with water

Metals can combine with the oxygen in water to release H_2. The only source of water for metals is the humidity of the air in the void spaces of the package. The air is assumed to be at 25°C, 1 atm (101.325 kPa) and 100% relative humidity. The vapor pressure of water at 25°C is 3.1690 kPa (CRC Handbook, p. 6-8), so the initial concentration of water vapor is 3.1690 / 101.325 = 0.031 mol fraction. Since 1 mol of water vapor produces 1 mol of H_2 and the oxygen is bound up as solid metal oxides, this reaction does not change the total gas pressure. Therefore, if all the water vapor reacts with the metal, the maximum concentration of H_2 is also 0.031 mol fraction, which is below the 5 mol % limit.

3.5.4.4 Radiation energy calculations

The radiation energy that drives radiolysis can be estimated from the decay rate and maximum decay energy of each radionuclide that makes up the HEU compounds (oxides and crystals). The bounding information to calculate these terms and the results are given in Table 3.5.4.2. It should be noted that the transuranic concentration can be much higher for HEU metal.

Table 3.5.4.2. Radiation energy calculations

Nuclide	$Wt\%_n$ [a]	MW_n [b] (g/mol)	T_{Hn} [b] (y)	α_{Mn} [b] (MeV)	D_{Rn} [c] [atms/(g y)]	Nuclide contr [c] [MeV/(gU y)]
^{232}U	4.00E-06	232.0371	6.89E+01	5.414	2.61E+19	5.65E+12
^{233}U	6.00E-01	233.0396	1.59E+05	4.909	1.13E+16	3.32E+14
^{234}U	2.00E+00	234.0409	2.45E+05	4.856	7.28E+15	7.07E+14
^{235}U	5.49E+01	235.0439	7.04E+08	4.679	2.52E+12	6.48E+12
^{236}U	4.00E+01	236.0456	2.34E+07	4.569	7.56E+13	1.38E+14
^{238}U	0.00E+00	238.0508	4.46E+09	4.185	3.93E+11	0.00E+00
Transur	4.00E-03			5.476 [d]	4.73E+17	1.04E+14
^{237}Np	2.50E+00	237.0482	2.14E+06	4.957	8.23E+14	1.02E+14
Total	1.00E+02					1.395E+15

[a] Wt % from Appendix 4.5.1 (Table 1). Maximum transuranic for compounds is 40 µg/gU and 0.60 MBq/gU activity.
[b] MW is molecular weight; T_H is half life; and α is the maximum energy emitted (*CRC Handbook of Chemistry and Physics*, pp. 11-140 and 11-141).
[c] D_R is decay rate, and Nuclide Contr is the contribution of each nuclide to the total rate of decay energy.
[d] Transuranic α assumed to be equal to ^{246}Cm.

The decay rate per gram of the n^{th} radionuclide is

$$D_{Rn} = [\ln(2) / T_{Hn}] \times A_N / MW_n ;$$
$$= \text{the decay rate of the } n^{th} \text{ radionuclide, atoms/y;}$$

T_{Hn} = half life of the n^{th} radionuclide, y;
A_N = Avogadro's number, 6.022×10^{23} molecules/mol;
MW_n = the molecular (atomic) weight of the n^{th} radionuclide, g/mol.

All the radionuclides in Table 3.5.4.2 are primarily α emitters, and the total rate of radiation dose is given as

$$D_E = \sum_{n=1}^{N} \frac{Wt\%_n \times D_{Rn} \times \alpha_{Mn}}{100} ,$$

where

D_E = the total rate of decay energy per gram of uranium, Mev/(gU y);
$Wt\%_n$ = the weight percent of the n^{th} radionuclide in the uranium;
α_{Mn} = the α energy emitted in the decay of the n^{th} radionuclide, MeV; and
N = the total number of radionuclides.

The above calculation of D_E for HEU is 1.395×10^{15} MeV/(gU y).

3.5.4.5 Hydrogen generation by radiolysis of polyethylene

Almost all the radiation energy from HEU is due to alpha particles with energies of 4–5 MeV (Table 3.5.4.2). These particles are not very penetrating and will only deposit their energy into materials that are in intimate contact with the uranium atoms (i.e., the water of hydration in uranyl nitrate crystals and the water associated with the oxides). The polyethylene is in the form of bottles and bags that

surround the uranium and the only alpha particles that reach the polyethylene come from the outer range of alpha particle penetration within the HEU.

Equations 1.9 and 1.10 on p. 9 in *Handbook of Radioactivity Analysis* approximate the range of alpha particle penetration in air, and other materials for α energy in the range of 4 to 7 MeV. These are combined to give the following expression for calculating the range in HEU (metal, oxide, or crystals).

$$R = 9.6 \times 10^{-7} \times \alpha_{MA}^{3/2} \times (MW_A)^{½} / \rho,$$

where

R = the range of alpha particle penetration in the HEU, m;
α_{MA} = the average α energy emitted by the HEU, ~4.9 MeV (Table 3.5.4.2);
MW_A = the average molecular weight of the HEU, ~235.5 g/mol (Table 3.5.4.2); and
ρ = the density of the HEU, g/cm^3.

The range increases with decreasing ρ, and the smallest value for ρ is ~1.5 g/cm^3. {The smallest approximate bulk density of HEU oxide, *Cost-Effectiveness of Utilizing Surplus Depleted Uranium (DU)*, [WM-4009]}. The resulting range is 1.07×10^{-4} m.

The radius of a polyethylene bottle is 0.0627 m [4.94-in. diam (Table 2.10), configuration designated as CVA 6]. If the HEU oxide fills the bottle, the alpha particles generated in the outer range come from the HEU between 0.0627 and $(0.0627 - 1.07 \times 10^{-4}$ m). For an infinite cylinder, the fraction of the total radiation within this range is $[(0.0627)^2 - (0.0627 - 1.07 \times 10^{-4})^2] / (0.0627)^2 = 0.00339$. Half of this radiation would be directed toward the center of the cylinder, and much of the outward-directed portion would be absorbed passing through the HEU. Consequently, the radiation absorbed by the polyethylene would be much less than 1% of that absorbed by the water, and the H_2 generated in the polyethylene would be correspondingly less than that generated in the water.

3.5.4.6 Hydrogen generation by radiolysis of water

Assuming an infinite amount of water is available, the radiolytic hydrogen generation rate is given by the following expression (based on NUREG/CR-6673, p. 31, Eq. 4.7):

$$d(n_{H2}) / dt = (D_H / 100) \times [G(H_2) / A_N],$$

where

n_{H2} = the amount of hydrogen generated, mol;
t = time, y;
D_H = the decay energy absorbed by the water, eV/y; and
$G(H_2)$ = a radiolytic hydrogen generation factor for alpha radiation in water, molecules H_2/100 eV absorbed by water.

3.5.4.7 Radiolytic hydrogen generation factors for alpha radiation in water

A bounding value for $G(H_2)$ with alpha radiation is 1.6 molecules H_2/100 eV absorbed by water (NUREG/CR-6673, p. 12, Table 3.1). However, 2003 experimental data from Oak Ridge National Laboratory suggest lower $G(H_2)$ values [*Alpha Radiolysis of Sorbed Water on Uranium Oxides and Uranium Oxyfluorides* (ORNL/TM-2003/172) and *Water Sorption and Radiolysis Studies for Neptunium Oxides* (ORNL/TM-2003/194)]. Table 3.5.4.3 lists the $G(H_2)$ values derived from these experiments. The largest of the ORNL values (1.02) is used for the hydrogen generation calculations.

Table 3.5.4.3. $G(H_2)$ values derived from alpha radiolysis experiments

Sample description	$e^-(H_2O)$	e^-(rem)	f_{H2O}	Gf	molecules/100 eV		
					G'(gas) [a]	G'(H_2)	G(H_2)
Icenhour and Toth, ORNL/TM-2003/172, 2003							
Fig. 3.3. Samp A-2-2, UO_3, 10% H_2O, 350°C	0.0556	0.3689	0.1000	0.1309	0.1507	0.1005	0.77
Fig. 3.5. Samp A-4-1 U_3O_8, 2% H_2O, 650°C	0.0111	0.4000	0.0200	0.0270	0.0113	0.0075	0.28
Icenhour et al., ORNL/TM-2003/194, 2004							
Fig. 4.12. Samp Al 3, NpO_2, 8% H_2O, 650°C	0.0444	0.3728	0.0800	0.1065	0.1100	0.0733	0.69
Fig. 4.11. Samp Al 2, NpO_2, 1% H_2O, 650°C	0.0056	0.4012	0.0100	0.0137	0.0210	0.0140	1.02
Fig. 4.13. Samp Al 4, NpO_2, 1% H_2O, 800°C	0.0056	0.4012	0.0100	0.0137	0.0060	0.0040	0.29
Fig. 4.14. Samp Al 5, NpO_2, 0.5% H_2O, 650°C	0.0028	0.4032	0.0050	0.0068	0.0043	0.0029	0.42

[a] G'(gas) for ORNL/TM-2003/172 is based on a measured slope in Fig. 3.3 or 3.5. For ORNL/TM-2003/194, the values are listed on Figs. 4.11–4.14.

The G'(gas) value is the initial slope of the gas yield (mmol/g material) versus the decay energy (MGy) converted to units of molecules of gas per 100 eV. G'(gas) for ORNL/TM-2003/172 is based on a measured slope in Fig. 3.3 or 3.5 while the values for ORNL/TM-2003/194 are listed on Figs. 4.11 through 4.14. Figure 3.5.4.1 is from ORNL/TM-2003/172 (p. 9, Fig. 3.5) with lines added to outline the initial slope and facilitate reading values. From Fig. 3.5.4.1, the gas yield difference along the slope is $0.023 - (-0.0005) = 0.0235$ millimol/g or $0.0235 \times A_N / 1000 = 1.42 \times 10^{19}$ molecules/g. The decay energy difference along the slope is 20.0 MGy or $20.0 \times 6.24 \times 10^{21} = 1.25 \times 10^{23}$ eV (6.24×10^{21} eV/g = 1 MGy). Therefore, G'(gas) is $1.42 \times 10^{19} / 1.25 \times 10^{23}) \times 100 = 0.0113$ molecules gas/100 eV. It is assumed the gas is due to the decomposition of H_2O and has a molar composition of 2/3 H_2 and 1/3 oxygen (O_2). The derived G'(H_2) is 2/3 of the G'(gas) value or 0.00756 molecules H_2/100 eV decay energy.

The radiation calculated in Table 3.5.4.2 is the decay energy rather than the energy absorbed by the water associated with the material. The energy absorbed by the associated water, D_H, is approximately equal to the decay energy, D_E, multiplied by the fraction of electrons associated with the water or

$$Gf = e^-(H_2O) / e^-(mat),$$

where

$$e^-(mat) = \sum_{i=1}^{I} e^-(mat_i);$$

Gf = the fraction of electrons associated with the water;
$e^-(H_2O)$ = the number of electrons associated with the water, electrons/molecule;
e^-(mat) = the total number of electrons associated with the molecular species; electrons/molecule;
$e^-(mat_i)$ = the contribution of the i^{th} molecular species to e^-(mat); and
I = the total number of molecular species.

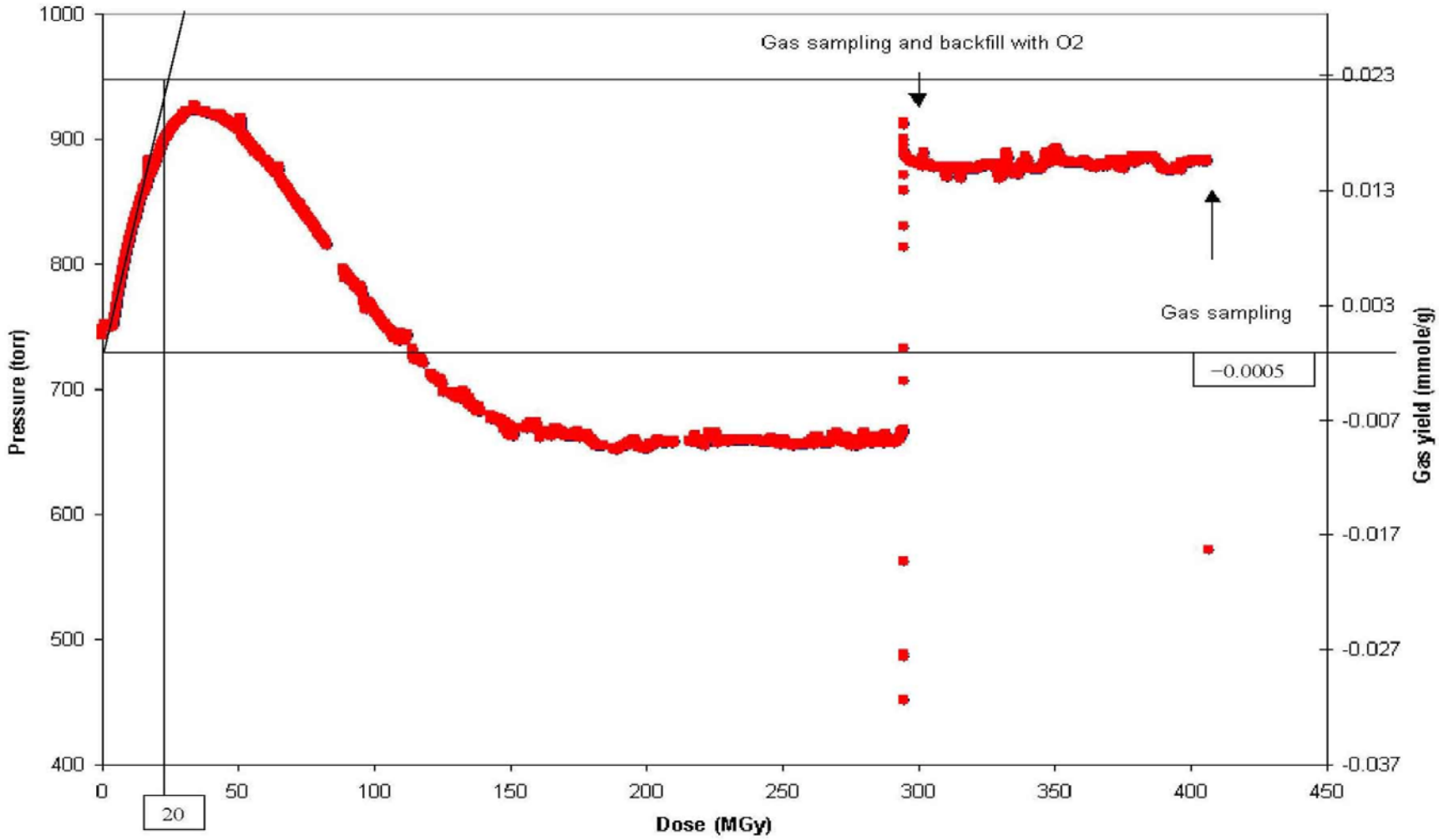


Fig. 3.5.4.1. Pressure and gas yield as a function of dose.

Note: Based on Fig. 3.5 in *Alpha Radiolysis of Sorbed Water on Uranium Oxides and Uranium Oxyfluorides* (ORNL/TM-2003/172), Sample A-4-1 (5.64 g U_3O_8 with 2 wt % H_2O, spiked with 0.0249 g ^{244}Cm).

The energy absorbed by the water is

$$D_H = Gf \times D_E,$$

and

$$G'(H_2) = Gf \times G(H_2) \rightarrow G(H_2) = G'(H_2) / Gf.$$

Two methods to calculate Gf are reported in *Calculation of Hydrogen Generation Rates for Storage of Post-KIS Oxide in 9975 Shipping Containers* (Calculation No. N-CLC-K-00219, p. 9 and 10). In the more rigorous of the two methods, Gf is estimated from the material stoichiometry and molecular weights. Using this more rigorous method, $e^-(mat_i)$ is calculated as

$$e^-(mat_i) = f_i \times \sum_{i=1}^{J} \frac{n_{i,j} \times Z_{i,j}}{MW_i},$$

where

f_i = the weight fraction of the i^{th} molecular species,
MW_i = the molecular weight of the i^{th} species,
$n_{i,j}$ = the number of moles of the j^{th} element in the i^{th} species,
J = the total number of elements in the i^{th} species, and
$Z_{i,j}$ = the atomic number of the j^{th} element in the i^{th} species.

According to the preceding equation, the expression for the number of electrons associated with the water is

$$e^-(H_2O) = f_{H2O} \times 10 / (16 + 2) = f_{H2O} \times 0.5556.$$

A mixture of water and U_3O_8 (assuming all the uranium is ^{235}U) is

$$e^-(mat) = f_{H2O} \times 0.5556 + f_{U3O8} \times (3 \times 92 + 8 \times 8) / (3 \times 235 + 8 \times 16) = f_{H2O} \times 0.5556 + f_{U3O8} \times 0.4082$$

where

f_{H2O} = the weight fraction of water and

f_{U3O8} = the weight fraction of U_3O_8
= $1 - f_{H2O}$ if no other material is present.

A $G'(H_2)$ value of 0.00756 molecules H_2/100 eV decay energy is derived from the experiment by Icenhour and Toth with a U_3O_8 sample (5.64 g) containing 2% water and spiked with 0.0249 g ^{244}Cm (ORNL/TM-2003/172, p. 7, Table 3.1). The mass of ^{244}Cm can be neglected, so the calculation of $G(H_2)$ for this sample is $e^-(H_2O) = 0.02 \times 0.5556 = 0.0111$; $e^-(mat) = 0.0111 + 0.98 \times 0.4082 = 0.4111$; $Gf = 0.0111 / 0.4111 = 0.0270$; and $G(H_2) = 0.00756 / 0.0270 = 0.280$ molecules H_2/100 eV absorbed by the water. Since the largest of the ORNL values (1.02) is used for the hydrogen generation calculations, the $G'(H_2)$ value for any other water content is the corresponding value of $Gf \times 1.02$.

To calculate Gf for $UO_2(NO_3)_2 \cdot XH_2O$, the two components are $UO_2(NO_3)_2$ and H_2O, where f_{H2O} is

$$f_{H2O} = X \times (2 + 16) / [235 + 2 \times 16 + 2 \times (14 + 3 \times 16) + X \times (2 + 16)],$$
$$= 1 / [1 + 391 / (X \times 18)],$$

$$e^-(mat) = f_{H2O} \times 0.5556 + f_{UN2O8} \times (92 + 8 \times 8 + 2 \times 7) / (391),$$
$$= f_{H2O} \times 0.5556 + f_{UN2O8} \times 0.4348,$$

f_{UN2O8} = the weight fraction of $UO_2(NO_3)_2 = 1 - f_{H2O}$.

The following example calculations are for U_3O_8 with 3% H_2O and $UO_2(NO_3)_2 \cdot XH_2O$ with X = 6 (f_{H2O} = 0.2164, Sect. 3.5.4.1). The $e^-(H_2O)$ and $e^-(mat)$ values for the U_3O_8 are 0.0300 × 0.5556 = 0.0167 and 0.0167 + 0.9700 × 0.4082 = 0.4126, respectively. The resulting Gf and $G'(H_2)$ values for the U_3O_8 are 0.0167 / 0.4126 = 0.0404 and 0.0404 × 1.02 = 0.0412, respectively. The corresponding values for $UO_2(NO_3)_2 \cdot 6H_2O$ are $e^-(H_2O)$ = 0.2164 × 0.5556 = 0.1202, $e^-(mat)$ = 0.1202 + 0.7836 × 0.4348 = 0.4609, Gf = 0.1202 / 0.4609 = 0.2608, and $G'(H_2)$ = 0.2608 × 1.02 = 0.2661.

The equation for the H_2 generation rate ($d(n_{H2})/dt$, mol H_2/y) is given in Sect. 3.5.4.6. The emitted radiation rate is 1.395×10^{21} eV/[GU Y] (1.395E+15 MeV/[gU y], Table 3.5.4.2). The uranium content of U_3O_8 with 3% H_2O is (1 − 0.0300) × 3 × 235 / (3 × 235 + 8 × 16) = 0.8209 gU/g and $UO_2(NO_3)_2 \cdot 6H_2O$ is 235 / (235 + 2 × 16 + 2 × [14 + 3 × 16] + 6 × (2 + 16) = 0.4709 gU/g. For 15,130 g of U_3O_8 with 3% H_2O, $d(n_{H2}) / dt = 15{,}130 \times 0.8209 \times 1.39 \times 10^{21} \times 0.0412 / (100 \times 6.022 \times 10^{23}) = 0.01185$ mol H_2/y. For 4750 g of $UO_2(NO_3)_2 \cdot 6H_2O$, $d(n_{H2}) / dt = 4750 \times 0.4709 \times 1.39 \times 10^{21} \times 0.2661 / (100 \times 6.022 \times 10^{23}) = 0.0137$ mol H_2/y.

3.5.4.8 Time to reach 5 mol %

The time at which the H_2 concentration in the void space of the package reaches 5 mol % depends on the H_2 generation rate and the initial amount of gas in the void space. This void space includes the internal void space within the convenience containers and the void space in the containment vessel outside the convenience containers. It is assumed that the convenience containers are open to the containment vessel and all the gases initially present, and subsequently generated, are mixed in this void space.

The initial amount of gas in the void space is given by

$$n_I = V_{VT} \times \rho_G,$$
$$V_{VT} = V_{BT} - Wt / \rho,$$

where

n_I = the initial amount of gas in the containment vessel void space, mol;
V_{VT} = the void volume of the loaded containment vessel, cm^3;
V_{BT} = the void volume of the containment vessel with empty convenience containers, 9,643.0 cm^3 (588.45 $in.^3$) and 9,483.5 cm^3 (578.72 $in.^3$) for CVA 1 and CVA 7, respectively (Appendix 3.5.1, Table 1);
Wt = the total load weight (Wt_{UNX} or Wt_{OX}), g;
ρ = the density of the load material (ρ_{UNX} or ρ_{OX}).

Since each mole of H_2 generated is accompanied by 0.5 mol of O_2, the concentration of H_2 will reach 5 mol % when

$$(n_{H2GN} + n_{H2I}) / (1.5 \times n_{H2GN} + n_I) = 0.05 \text{ or } n_{H2GN} = 0.05405 \times n_I - 1.08108 \times n_{H2I},$$

where

n_{H2GN} = the amount of H_2 generated after the containment vessel is loaded, mol,
n_{H2I} = the initial amount of H_2 in the convenience containers when the containment vessel is loaded (= n_{H2B} or n_{H2C}), mol.

As an example, 15,130 g of U_3O_8 (ρ is 8.38 g/cm^3) in a CVA 1 configuration will result in a loaded void volume (V_{VT}) of 9643.0 − 15130 / 8.38 = 7837.5 cm^3. The initial amount of gas (n_I) is 7837.5 cm^3 × 4.087 × 10^{-5} mol/cm^3 = 0.32035 mol. The initial amount of H_2 in the convenience containers (n_{H2I}) is 4.5402E-05 mol (Sect. 3.5.4.2) so n_{H2GN} = 0.05405 × 0.32035 − 1.08108 × 4.54E-05 = 0.017267 mol.

3.5.4.9 Hydrogen buildup

The buildup of H_2 in the containment vessel can be expressed as

$$\frac{d(n_{H2GN})}{dt} = \frac{d(n_{H2})}{dt} - L_{MH2},$$

where

L_{MH2} = the permeation loss rate of H_2 through the main O-ring of the containment vessel, mol /y.

Parker O-Ring Handbook (Sect. 3.12.1, p. 3-21) gives the following expression for the permeation loss of H_2 through an O-ring:

L_{VH2} = $0.7 \times F \times D \times P \times Q \times (1 - S)^2$;
= the permeation loss rate of H_2 through the O-ring, std cm^3 H_2/s;

F = the permeability of hydrogen through the O-ring material (ethylene propylene, Table 3.10) at 38°C, 28.9E-08 std cm^3 H_2/(cm s bar) [*Parker O-Ring Handbook*, Table 3-24, p. 3-29];
D = the inside diameter of the O-ring, 5.359 in. (Drawing M2E801580A013, Appendix 1.3.7);
P = the pressure differential across the seal, psi;
S = the fraction of the O-ring cross-section reduced by squeezing the ring in the gland, 0.15 to 0.21 (Sect. 4.1.1), 0.21 conservatively selected;
Q = a factor depending on S (ring is lubricated, Table 3.10), 0.72 (*Parker O-Ring Handbook*, Fig. 3-11, p. 3-21);
L_{MH2} = L_{VH2} multiplied by (3600 s/h × 24 h/d × 365.25 d/y) and divided by 22,414 std cm^3/mol.

The pressure increase in the containment vessel is given by

P = $1.5 \times n_{H2GN} / n_I \times P_i$,
P_i = the initial pressure of the gas in the containment vessel, 14.7 psia.

If the initial pressure is equal to the ambient pressure (the usual situation), the pressure differential across the seal is equal to P.

If all of the above terms are combined, the expression for $d(n_{H2GN}) / dt$ becomes

$$\frac{d(n_{H2GN})}{dt} = \frac{d(n_{H2})}{dt} - \frac{k \times n_{H2GN}}{n_I},$$

$$\begin{aligned} k &= 0.7 \times F \times D \times 1.5 \times P_i \times Q \times (1 - S)^2 \times (3600 \times 24 \times 365.25) / 22414, \\ &= 0.01512 \text{ mol/y}. \end{aligned}$$

The solution to the above differential equation is

$$n_{H2GN} = [d(n_{H2}) / dt] \times n_I / k \times [1.0 - \exp(-k \times t / n_I)],$$

and the time when n_{H2GN} reaches $0.05405 \times n_I - 1.08108 \times n_{H2I}$ is

$$t = -\text{Ln}(1.0 - [0.05405 \times n_I - 1.08108 \times n_{H2I}] \times k / [d(n_{H2}) / dt \times n_I]) \times n_I / k.$$

As an example, the time for the 15,130 g of U_3O_8 is $-\text{Ln}(1.0 - 0.017267 \text{ mol} \times 0.01512 \text{ mol/y} / [0.01185 \text{ mol/y} \times 0.32035 \text{ mol}]) \times 0.32035 \text{ mol} / 0.01512 \text{ mol/y} = 1.51$ y.

As shown in Table 3.5.4.2, the bounding value of the decay energy (D_E) is 1.39×10^{15} MeV/(gU y). The energy per gram of material is the product of $D_E \times$ the fraction of uranium in the material. The fraction of uranium in UO_2 with $f_{H2O} = 0.03$ (3% water) is $(1 - 0.03) \times 235 / (235 + 2 \times 16) = 0.85375$ gU/g material. Similarly, the fractions in U_3O_8 and UO_3 are 0.82095 and 0.80548, respectively. The corresponding fraction in crystals is $235 / [235 + 2 \times 16 + 2 \times (14 + 3 \times 16) + X \times (2 + 16)] = 0.47094$ gU/g material for X = 6 [$UO_2(NO_3)_2 \cdot 6H_2O$] and 0.52809 for X = 3 [$UO_2(NO_3)_2 \cdot 3H_2O$]. The decay energies are 1.19×10^{15} MeV/y g material for UO_2 with 3% H_2O, 1.15×10^{15} for U_3O_8, 1.12×10^{15} for UO_3, 6.57×10^{14} for $UO_2(NO_3)_2 \cdot 6H_2O$, and 7.37×10^{14} for $UO_2(NO_3)_2 \cdot 3H_2O$.

Table 3.5.4.4 summarizes the calculations for the time to reach 5 mol % H_2 in the void space of the containment vessel, as a function of the total weight of the material in the containers (Wt). The total amount of H_2 in the void space is the sum of the initial H_2 plus the added H_2 while the total gas in the void space is the sum of the initial gas plus 1.5 times the added H_2. The 1.5 factor accounts for the O_2 generated with the H_2. For 15.13 kg of U_3O_8 with 3% H_2O, the time to reach 5 mol % H_2 in the void space is 1.5 years or 18.2 months. At that time, the total amount of H_2 in the void space is 0.00005 + 0.01820 = 0.01825 mol while the total gas in the void space is 0.33777 + 1.5 × 0.01820 = 0.36507 mol.

Table 3.5.4.4. Summary of calculation results

Weight (kg)	Density (g/cm^3)	Void volume (cm^3)	Gas amounts (mol)			Water content		Material uranium content (gU/g)	Annual radiation rate [a]	Gf	G'(H_2) [b]	n_{H2} rate (mol/y)	Time to 5 % (y/mo)
			Initial total	Initial H_2	Added H_2	X	(wt %)						
U Oxides (UO_2) [CVA 1]													
15.13	10.97	8263.8	0.33777	0.00005	0.018202		3.0	0.85375	1.19E+15	0.04075	0.04156	0.01243	1.5/18.2
U Oxides (U_3O_8) [CVA 1]													
15.13	8.38	7837.5	0.32035	0.00005	0.017267		3.0	0.82095	1.15E+15	0.04040	0.04120	0.01185	1.5/18.1
U Oxides (UO_3) [CVA 1]													
15.13	7.30	7570.4	0.30943	0.00004	0.016681		3.0	0.80548	1.12E+15	0.04023	0.04104	0.01158	1.5/17.9
$UO_2(NO_3)_2 \cdot XH_2O$ [CVA 7]													
4.75	2.81	7793.1	0.31853	0.00108	0.016051	6.00	21.64	0.47094	6.57E+14	0.26087	0.26609	0.01379	1.2/14.4
6.70	2.81	7099.2	0.29017	0.00085	0.014766	3.00	12.13	0.52809	7.37E+14	0.15000	0.15300	0.01254	1.2/14.6
9.17	2.81	6220.2	0.25424	0.00144	0.012189	6.00	21.64	0.47094	6.57E+14	0.26087	0.26609	0.02661	0.46/5.6
11.90	2.81	5248.6	0.21453	0.00088	0.010647	3.00	12.13	0.52809	7.37E+14	0.15000	0.15300	0.02227	0.49/5.8

[a] Units are MeV/(g y).
[b] Units are molecules H_2/100 eV.

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4. CONTAINMENT

Design analysis, full-scale testing, and similarity of the ES-3100 prototypes have been used to demonstrate that the ES-3100 package with highly enriched uranium (HEU) is in compliance with the applicable containment requirements of Title 10 Code of Federal Regulations, Part 71 (10 CFR 71). The containment requirements of 10 CFR 71.51 are shown in Table 4.1. A bounding load case has been established for the ES-3100 package, and it assumes that the maximum HEU content is 35.2 kg (Sect. 1.2.2.6) with a decay heat load of 5 W (Sect. 3.1.2). This decay heat load and the volumes established for the convenience cans, polyethylene bagging, spacers, silicone rubber pads, and the containment vessel void volume are discussed in Sect. 3.1.2 and Appendix 3.5.1. Sections 2 and 3 of this safety analysis report for packaging (SARP) also examine the effects of the lightest weight HEU content [2.77 kg (6.11 lb)]. Section 3.4.3 also examines the conservative effects of shipping no contents inside the containment vessel but including the maximum decay heat load for the proposed contents. The evaluations in Sects. 2, 3, and 4 have demonstrated that the ES-3100 shipping package with HEU content weight ranging from 0 kg (0 lb) to 35.2 kg (77.60 lb) meets the containment requirements specified in 10 CFR 71 for all conditions of transport. A summary of the containment boundary design and fabrication acceptance basis is given in Table 4.2. No credit is taken for the various convenience cans' ability to protect the HEU contents from being released.

Table 4.1. Containment requirements of transport for Type B packages [a]

Condition	Allowable release rate
Normal Conditions of Transport (NCT)	$R_N = 10^{-6}$ A_2 per hour = 2.78×10^{-10} A_2 per second
Hypothetical Accident Conditions (HAC)	$R_A = A_2$ in 1 week = 1.65×10^{-6} A_2 per second For ^{85}Kr, a value of 10 A_2 in 1 week is used

[a] From ANSI N14.5-1997, Sects. 5.4.1 and 5.4.2, and 10 CFR 71.51(a)(1) and (a)(2).

Table 4.2. Summary of the containment vessel design and fabrication acceptance basis

Weight (empty, nominal)	15.10 kg (33.29 lb)
Temperature at loading (air fill, average)	25°C (77°F)
Pressure at loading (air fill, average)	101.35 kPa (14.70 psia)
Hydrostatic pressure test	1034 ± 34 kPa (150 ± 5) gauge
Leakage rate testing [a]	
Acceptance leakage rate test, air (or equivalent)	
Containment boundary [b]	$L_T \leq 1 \times 10^{-7}$ ref-cm^3/s
Fabrication verification of O-ring seal [c]	$L_T \leq 1 \times 10^{-4}$ ref-cm^3/s
Preshipment, air [d]	$L_T \leq L_R$ or no detected leakage when tested to a sensitivity of 1×10^{-3} ref-cm^3/s

[a] L_T is the maximum allowable test leakage rate for a set of testing conditions.
[b] Acceptance leakage testing of the containment boundary includes fabrication, periodic (within 12 months of use), and maintenance testing. According to Subclause 2.1 of ANSI N14.5-1997, *leaktight* is defined as an air leakage rate of 1×10^{-7} ref-cm^3/s; under the same conditions, this air leakage rate is ~ equal to a helium leakage rate of 2×10^{-7} cm^3/s.
[c] Performed at initial fabrication on the fully assembled containment vessel with both O-rings installed to demonstrate the functionality of the leak-test port and sealing capability of the outer O-ring (Appendix 1.3.3).
[d] L_R as defined in ANSI N14.5-1997, Subclause 6.2, is the more restrictive reference air leakage rate based on the allowable leakage rate for both NCT and HAC.

The analysis documented in Appendix 4.5.1 was conducted to establish the upper limit for the total activity and the maximum number of A_2s proposed for transport in the ES-3100 package. The maximum activity [7.2554×10^{-1} TBq (19.6092 Ci)] of the contents occurs 10 years after initial fabrication. When the maximum activity-to-A_2 value (4.7528×10^{3}) is reached at ~70 years from material fabrication, the corresponding activity is 7.2456×10^{-1} TBq (19.5827 Ci). These values have been determined using a maximum of 35.2 kg of HEU with isotopic weight percents as shown in Table 4.3. By applying the maximum weight percents of isotopes ^{233}U, ^{234}U, ^{236}U and by incorporating the traces of ^{232}U and the transuranic isotopes, the maximum activity, minimum A_2 value, and the minimum leakage requirements were determined for the proposed contents and are summarized in Tables 4.4, 4.5, and 4.6. The mass and isotopic concentrations used for the proposed content do not take into consideration limits based on shielding and subcriticality.

Table 4.3. Isotopic mass and weight percent for the HEU contents [a]

Nuclide	Weight percent	Mass (g)
U-232	0.000004	0.001408
U-233	0.600000	211.200000
U-234	2.000000	704.000000
U-235	54.819996	19,296.638592
U-236	40.000000	14,080.000000
U-238	0.000000	0.000000
Transuranic	0.080000 [b]	28.160000
Np-237	2.500000	880.000000
Total	**100.000000**	**35,200.000000**

[a] Weight percent values of individual isotopes are those that generate the largest activity within the allowable ranges presented in Sect. 1.2.2.

[b] The transuranic weight percent of 0.080000 applies to ground transport only. The maximum transuranic weight percent in contents transported by air will be 0.004000.

Table 4.4. Activity, A_2 value, and number of A_2 proposed for transport

Year	Fast absorption			Medium absorption			Slow absorption		
	Activity (TBq)	A_2 (TBq)	Act / A_2	Activity (TBq)	A_2 (TBq)	Act / A_2	Activity (TBq)	A_2 (TBq)	Act / A_2
0	7.197E-01	1.5289E-04	4.707E+03	7.1974E-01	1.5253E-04	4.7185E+03	7.1974E-01	1.5148E-04	4.751E+03
5	7.251E-01	1.5399E-04	4.709E+03	7.2507E-01	1.5363E-04	4.7197E+03	7.2507E-01	1.5257E-04	4.752E+03
10	7.255E-01	1.5408E-04	4.709E+03	7.2554E-01	1.5372E-04	4.7199E+03	7.2554E-01	1.5267E-04	4.752E+03
20	7.254E-01	1.5404E-04	4.709E+03	7.2538E-01	1.5368E-04	4.7200E+03	7.2538E-01	1.5263E-04	4.752E+03
30	7.251E-01	1.5399E-04	4.709E+03	7.2514E-01	1.5363E-04	4.7200E+03	7.2514E-01	1.5258E-04	4.752E+03
40	7.249E-01	1.5394E-04	4.709E+03	7.2494E-01	1.5358E-04	4.7201E+03	7.2494E-01	1.5254E-04	4.753E+03
50	7.248E-01	1.5390E-04	4.709E+03	7.2478E-01	1.5355E-04	4.7202E+03	7.2478E-01	1.5250E-04	4.753E+03
60	7.247E-01	1.5387E-04	4.709E+03	7.2465E-01	1.5352E-04	4.7203E+03	7.2465E-01	1.5247E-04	4.753E+03
70	7.246E-01	1.5385E-04	4.710E+03	7.2456E-01	1.5349E-04	4.7206E+03	7.246E-01	1.5245E-04	4.7528E+03

Table 4.5. Regulatory leakage criteria for NCT [a]

Verification activity	Fast absorption		Medium absorption		Slow absorption	
	$L_{RN - air}$ (ref-cm^3/s)	$L_{RN - He}$ (cm^3/s)	$L_{RN - air}$ (ref-cm^3/s)	$L_{RN - He}$ (cm^3/s)	$L_{RN - air}$ (ref-cm^3/s)	$L_{RN - He}$ (cm^3/s)
Design	1.3916E-04	1.7141E-04	1.3884E-04	1.7104E-04	1.3792E-04	1.6996E-04

[a] The procedure used to calculate the above criteria is shown in Appendix 4.5.2. This data has been extracted from Table 1 in Appendix 4.5.2.

Table 4.6. Containment vessel verification tests criteria for NCT

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 ORNL/NTRC-013
Design verification of containment vessel boundary (helium)	$L_T \leq 2.0 \times 10^{-7}$ cm^3/s	See ORNL/NTRC-013
Verification leakage testing		
Fabrication, periodic, and maintenance (helium)	$L_T \leq 2.0 \times 10^{-7}$ cm^3/s	Y51-01-B2-R-140 (Appendix 8.3.1) or equivalent
Fabrication verification of O-ring seal (air)	$L_T \leq 1.0 \times 10^{-4}$ ref-cm^3/s	Tested at initial fabrication in accordance with the supplier's approved procedure as required by Appendix 1.3.3
Preshipment (air)	$L_T \leq L_R$ or no detected leakage when tested to a sensitivity of 1×10^{-3} ref-cm^3/s	Y51-01-B2-R-074 (Appendix 7.5.2) or equivalent

The initial composition of the content contains several isotopes of uranium (Sect. 1.2.2). As a result of radioactive decay, the ingrowth of uranium daughter products occurs, and these concentrations of daughter products will vary with time. The uranium isotopes and daughter products are considered a mixture of radionuclides, and the method for determining the mixture's A_2 value in Section IV, Appendix A, 10 CFR 71 is applied. The A_2 value for the most conservative set of contents defined in Sect. 1.2.2 has been calculated in Appendix 4.5.1. Since the HEU can be in the form of oxides (U_3O_8-Al, UO_2-Mg, UO_2-ZrO_2, UO_2, UO_3, and U_3O_8), uranyl nitrate crystals (UNX), metal or alloy, research reactor fuel elements and components, or compounds, the calculation of the mixture's A_2 used the various uranium isotopic A_2 values for fast, medium, and slow lung absorption criteria shown in Table A-1 of Appendix A of 10 CFR 71.

The mass and material compositions analyzed in this section of the SARP are not limited by the combustible gas requirements stated in NUREG-1609, Sect. 4.5.2.3, which requires the applicant to demonstrate that any combustible gases generated in the package during a period of one year do not exceed 5% (by volume) of the free gas volume in any confined region of the package. No credit should

be taken for getters, catalysts, or other recombination devices. The analysis conducted in Appendix 3.5.4 evaluates the different packaging arrangements for the generation of hydrogen gas due to the radiolysis of water vapor, free water, interstitial water, polyurethane bags, and polyurethane or Teflon bottles. By limiting the mass and the material distribution as shown in Appendix 3.5.4, the combustible gas concentration limit stated in NUREG-1609 is not exceeded. These limits are further shown in Tables 1.3 and 1.3a. Getters, catalysts, or other recombination devices are not employed in any of the containment vessel packaging arrangements. The analysis conducted in Appendix 3.5.1 predicts the maximum normal operating pressure inside the containment vessel for the various packaging arrangements and masses discussed previously. This appendix also includes the hydrogen gas generation predicted by Appendix 3.5.4.

4.1 DESCRIPTION OF THE CONTAINMENT SYSTEM

As shown in Table 4.4, the number of A_2s proposed for shipping exceeds 3000. In accordance with NUREG 1609, the containment vessel is a Category I vessel. 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, Div. 1, Subsection NB and Sect. IX.

4.1.1 Containment Boundary

The containment boundary consists of the vessel's body, lid assembly, and inner O-ring (Sect. 1.2.1.5, Fig. 1.3). Only the inner O-ring is considered part of the boundary. The outer O-ring is provided to allow a post-assembly verification leak check. Two methods of fabrication may be used to fabricate the containment vessel body as shown on Drawing M2E801580A012 (Appendix 1.3.7). 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 0.254 cm (0.100 in.). Each of these pieces is joined with full-penetration circumferential weld as shown on sheet 2 of Drawing M2E801580A012 (Appendix 1.3.7). The weld filler material conforms to Sect. II, Part C, of the *ASME Boiler and Pressure Vessel Code.* All full-penetration welds are dye penetrant and radiographically inspected in accordance with Sect. III, Div. 1, Subsection NB-5000, of the *ASME Boiler and Pressure Vessel Code*. The top flange is machined to match the schedule 40 stainless-steel 5-in. pipe, to provide two concentric half-dovetailed 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 flow forming 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. Final machining of the top flange area is identical 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 1.3.7). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.3.7) 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 an external retaining ring made from Type 302 stainless steel. A

weld is used to seal around a plug that is inserted inside the hole used for machining the pathway for leak testing between the O-rings. Since this plug and weld are outside the containment boundary, the weld is not important to safety. However, it is important to operation because its sealing capability is needed to properly conduct the preshipment leak test. This weld is addressed in Paragraph 3.4 of the containment vessel equipment specification (JS-YMN3-801580-A001, Appendix 1.3.3). In this specification, the weld is inspected visually and using dye penetrant. The requirements of NB-5110 and NB-5350 of the *ASME Boiler and Pressure Vessel Code* also apply. The sealing lid is further machined to accept a ⅜-in.-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 lid assembly, with the O-rings in place on the body, are joined together by torquing the closure nut and sealing lid assembly to 162.7 ± 6.78 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. This torquing of the closure nut represents the positive fastening device used to satisfy the requirements of 10 CFR 71.43(c). The effectiveness of this closure system has been demonstrated by the NCT and HAC tests, which show that the complete containment system, including welds and O-ring seals, meet the leaktight criterion as defined in ANSI N14.5-1997 after the conclusion of the test series documented in ORNL/NTRC-013.

10 CFR 71.73(c) requires that the package containment vessel be immersed in 15 m (50 ft) of water, which is equivalent to an external pressure differential of 150 kPa (21.7 psi). The design analyses (DAC-M900000-0003) show that this vessel is conservatively rated for the 150-kPa (21.7-psi) external pressure differential requirement, as well as for an internal pressure differential of 699.82 kPa (101.5 psig). A summary of the containment boundary design and acceptance basis is given in Table 4.2.

The ES-3100 package has no connections, fittings, valves, tapped holes, or other devices that penetrate the containment boundary; therefore, the package does not allow continuous venting during transport. The leak test port on the containment vessel lid accesses the annulus between the two O-rings. Since the outer O-ring is not considered to be part of the containment boundary, this leak test port does not penetrate the containment boundary. Therefore, the requirements of 10 CFR 71.43(e) and (h) are not applicable.

The containment vessel O-rings (Drawings M2E801580A013 and M-801580-0013, Appendix 1.3.7) are manufactured from ethylene propylene diene monomer (EPDM) in accordance with Equipment Specification SPC-M801580-0002 (Appendix 1.3.9).

The EPDM O-rings are rated for continuous service as a static face seal in the temperature range of −40 to 150°C (−40 to 302°F) [*Parker O-Ring Handbook*, Fig. 2-24]. Tests conducted by Los Alamos National Laboratory (LANL) on a similar compound used as a static face seal, are documented in *SAFKEG 2863B Tests for Verification of O-ring Performance* (TR 96/12/20). The material compound for the LANL tests was certified to ASTM D 2000 as M3BA610A14B13F17. The ES-3100 package O-rings are also certified to ASTM D 2000 as M3BA712A14B13F17. The class of material in the LANL test is identical except that the durometer and tensile strengths are somewhat less than those of the ES-3100 package. Each material was tested in accordance with ASTM D 2137 for brittleness at −40°C (−40°F) without failure. The leak test fixture, as reported in TR 96/12/20, provided a maximum compression of 25.7% in a static face seal configuration. The compression range provided by the flange and lid design of the ES-3100 package is 14.8 to 20.8% or 0.051 to 0.076 cm (0.020 to 0.030 in.) compression due to

the half-dovetail design. Furthermore, *Parker O-Ring Handbook* states that the minimum squeeze for all seals, regardless of cross-section, should be ~0.018 cm (0.007 in.). Since the minimum compression is 0.051 cm (0.020 in.) and the flange and lid with the closure nut have nearly identical coefficient of thermal expansion, the sealing performance at −40°C (−40°F) should not be degraded. Therefore, the performance of the ES-3100 O-rings should be representative of those documented in TR 96/12/20. These tests demonstrated that the O-rings were leaktight over the temperature range of −40 to 205°C (−40 to 401°F), which is greater than the operating temperature range of −40 to 156.19°C (−40 to 313.14°F) of the ES-3100 containment vessel (Table 3.5). In addition to component testing, an ES-3100 full-scale test unit [Test Unit (TU)-2] was chilled to ≤ −40°C and later subjected to an NCT drop test and the entire HAC test battery. The containment vessel was leak tested and achieved "leaktight" status. Therefore, the continuous service temperature rating of the EPDM O-ring has been verified by testing.

4.1.2 Special Requirements for Plutonium

The HEU contents have only trace amounts of the transuranic isotopes. Therefore, the requirements in 10 CFR 71.63 and 71.74 are not applicable.

4.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT

Title 10 CFR 71.51(a)(1) specifies that there shall be no loss or dispersal of radioactive contents as demonstrated to a sensitivity of 10^{-6} A_2 per hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging. The initial composition of the HEU contains several isotopes of uranium and transuranic contributors (Table 4.3). As a result of radioactive decay, uranium, transuranics, and daughter product isotopes are present in the HEU contents at varying concentrations depending on the length of decay time. The HEU, with its isotopes and daughter isotopes and contributions from unknown transuranic isotopes, qualifies as a mixture for A_2 determination (Appendix A of 10 CFR 71). The A_2 value and the maximum content activity-to-A_2 value ratio for this mixture have been calculated for several different decay times (Table 4.4). As calculated in Appendix 4.5.1, the A_2 value [1.5245×10^{-4} TBq (4.1203×10^{-3} Ci)] and the maximum content activity-to-A_2 ratio (4.7528×10^{3}) used to qualify this package occurs at ~70 years of decay. As previously stated, these values have been determined using a bounding case maximum of 35.2 kg of HEU with isotopic weight percent values as shown in Table 4.3. The specified composition is a very conservative upper bound achieved by using the maximum weight percent values for the higher specific activity isotopes (^{232}U, ^{233}U, ^{234}U, and ^{236}U), including contributions from other transuranics and ^{237}Np.

The maximum activity, minimum A_2, and minimum leakage requirements were determined for this worst case scenario and are presented in Tables 4.4 and 4.5. These masses and isotopic concentrations were used for the proposed contents without regard to limits established based on shielding and subcriticality considerations. The actual mass limits affirmed for this shipping package are established in Sect. 1 (Tables 1.3, 1.3a, and 1.3b). The analyses conducted in Appendix 4.5.2 assume that the total mass of uranium for each component is available for release as an aerosol (worst case). From experimental tests, the maximum aerosol density containing uranium particulate was reported in "Leakage of Radioactive Powders from Containers" (Curren and Bond) to be 9.0×10^{-6} g/cm^3. This aerosol density is used to calculate the total activity concentration in ANSI N14.5-1997, Sect. B.15, Examples 13, 27, and 29.

The containment criteria for the ES-3100 package will be leaktight (defined in paragraph 2.1 of ANSI N14.5-1997 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 the design and fabrication containment verification of the ES-3100 leakage rate testing.

The design, fabrication, maintenance, and periodic leakage rate limit is 1×10^{-7} ref-cm^3/s air (or equivalent). Preshipment leakage rate testing, which demonstrates correct assembly of the containment vessel, shall be performed to the acceptance criterion of either (1) a leakage rate of not more than the reference air leakage rate, L_R, or (2) no detected leakage when tested to a sensitivity of at least 10^{-3} ref-cm^3/s (ANSI N14.5-1997, Subclause 7.6.4). The preshipment, fabrication, and maintenance 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. In addition to these leakage tests, Subclause 7.5.2 of ANSI N14.5-1997 states that the periodic leakage rate testing shall be conducted within 12 months prior to each shipment. Testing of the ES-3100 and EPDM O-rings, documented in RP 801580-0022, *ES-3100 Containment Vessel (CV) O-rings Life Extension Testing*, provides the justification to extend the periodic leakage rate testing frequency to 24 months. Therefore, the periodic leakage rate testing specified in Chapter 8 shall be conducted in accordance with ANSI N14.5-1997 except for the frequency. These leakage rates are not dependent on filters or mechanical cooling.

The complete design verification testing of the ES-3100 package for NCT was conducted on test unit TU-4. Since the containment vessel was assembled at ambient conditions, the pressure was nominally 101.35 kPa (14.70 psia) at 25°C (77°F). In accordance with 10 CFR 71.71(b), the initial pressure inside each containment vessel should be the maximum normal operating pressure (MNOP). As calculated in Appendix 3.5.1 and rounded up, the bounding case MNOP is 114.11 kPa (16.55 psia). The stresses at the MNOP are insignificant compared to the allowable stresses (Tables 2.21 and 2.21a). O-ring grooves are designed and fabricated in accordance with guidance from the *Parker O-Ring Handbook*. In accordance with Fig. 3-2 of the *Parker O-Ring Handbook*, the durometer of the O-ring, and the tolerance gap from the production drawings, the O-ring should be able to withstand ~800 psig before anti-extrusion devices are required. Therefore, conducting a compliance test with the MNOP in the containment vessel will have little, if any, effect on the results.

Following the design verification testing of paragraphs 10 CFR 71.71(c)(5) through 71.71(c)(10) excluding 71.71(c)(8), TU-4 was subjected to the sequential testing of paragraphs 10 CFR 71.73(c)(1) through (c)(4). Upon removal of the containment vessel from the drum assembly, the cavity between the O-rings was leak checked. This unit recorded a leak rate between the O-rings of 2.4773×10^{-5} ref-cm^3/s.

Following the O-ring leak test, the entire containment boundary of TU-4 was helium leak tested to a value $\leq 2 \times 10^{-7}$ cm^3/s, thereby verifying a leak-tight boundary. The leak-test procedure followed to verify this criterion is documented in the ES-3100 test report (ORNL/NTRC-013). The maximum recorded helium leakage rate for this containment vessel was 2.0×10^{-7} cm^3/s after 20 min of testing. Visual inspection following the testing indicated that neither the vessel body, the O-rings, the seal areas, nor the vessel lid assembly were damaged during the tests. Pictures taken of the containment vessel top following testing showed that the closure nut had rotated a maximum of 0.15 cm (0.060 in.) from its original radial position obtained during assembly. Based on the pitch of the closure nut, this rotation

translates into only 0.0013 cm (0.0005 in.) decompression of the O-rings. This compares to the original nominal compression of 0.064 cm (0.025 in.). Therefore, O-ring compression was maintained during compliance testing. Based on these results, the ES-3100 package meets and exceeds the containment criteria specified in 10 CFR 71.51 for NCT when used to ship the contents described in the introductory section of this chapter.

Following fabrication, the containment vessel undergoes hydrostatic pressure testing to 1034 kPa (150 psi) gauge. The hydrostatic test is conducted before the final leakage test. Following the hydrostatic pressure test, and prior to conducting the leakage test, the containment vessel and O-ring cavity must be thoroughly dried. Each vessel is then leak tested with helium to 2×10^{-7} cm^3/s. In accordance with *ASME Boiler and Pressure Vessel Code*, Sect. V, Subsection A, Article 10, Appendix IX, "Helium Mass Spectrometer Test—Hood Technique," a system response time must be established to determine the helium leak testing duration. The fabricators of this package used the *ASME Boiler and Pressure Vessel Code* approach and determined that the system response time for their setup of this containment vessel was ~15 s. To ensure that the leak detector steady-state (equilibrium) response is reached, the helium leak test duration was established at 2 min (8 × system response time). This test ensures the containment vessel's integrity (walls, welds, inner O-ring seal) as delivered for use in accordance with paragraph 6.3.2 of ANSI N14.5-1997.

Following placement of the HEU content inside the containment vessel and joining the body and lid assembly, the volume between the containment vessel's O-ring seals is typically evacuated and leak checked using the pressure rise air leak test prescribed in Sect. 7.1.2.1. The acceptance criterion for preshipment leakage rate testing shall be either (1) a leakage rate of not more than the reference air leakage rate, L_R, or (2) no detected leakage rate when tested to a sensitivity of at least 10^{-3} ref-cm^3/s. This ensures that each containment vessel has been properly assembled in accordance with paragraph 7.6.4 of ANSI N14.5-1997.

The design verification tests were conducted following compliance tests in accordance with 10 CFR 71.71 and 71.73. The effectiveness of this closure system has been demonstrated by the NCT and HAC tests, which show that the complete containment system, including welds and O-ring seals, meet the leaktight criterion as defined in ANSI N14.5-1997 after the conclusion of the test series documented in ORNL/NTRC-013.

4.3 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS

Requirements. A Type B package, in addition to satisfying the requirements of paragraphs 10 CFR 71.41 through 71.47, must be designed, constructed, and prepared for shipment so under the tests specified in Sect. 71.73 ("Hypothetical Accident Conditions"), there would be no escape of ^{85}Kr exceeding 10 A_2 in one week, no escape of other radioactive material exceeding a total amount A_2 in one week, and no external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in.) from the external surface of the package.

Analysis. Calculations have been conducted in Appendix 4.5.2 to determine the regulatory leakage criteria to satisfy the above requirements. The results are shown in Table 4.7. These analyses assume that the total mass of uranium for each component is available for release as an aerosol (worst case). From experimental tests, the maximum aerosol density containing uranium particulate was reported by Curren and Bond to be 9.0×10^{-6} g/cm^3. This aerosol density is used to calculate the total activity concentration in ANSI N14.5-1997, Sect. B.15, Examples 13, 27, and 29. Design leakage rate verification testing of the containment boundary (Table 4.8) was conducted on TU-1 through TU-6 and documented in the test report (ORNL/NTRC-013). Since each containment vessel was assembled at ambient conditions, the pressure was nominally 101.35 kPa (14.70 psi) at 25°C (77°F). In accordance with 10 CFR 71.73(b), for these tests, the initial pressure inside each containment vessel should be the maximum normal operating pressure. As shown in Tables 2.21 and 2.21a, the stresses at the maximum normal operating pressure are insignificant compared to the allowable stresses. Therefore, conducting compliance testing with nominal pressure in the containment vessel would have little, if any, effect on the results. During the structural and thermal tests conducted on the ES-3100 for HAC, the drum experienced plastic deformation, and the insulation and impact limiter material experienced some deterioration, as anticipated (Sect. 2.7). The containment vessels did not exhibit any signs of damage and passed post-test leak tests and the subsequent 10 CFR 71.73(c)(5)–specified 0.9-m (3-ft) water immersion tests except for TU-6. TU-6 was subjected to the test specified in 10 CFR 71.73(c)(6). After completion of this test, the containment vessel was removed and the 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 TU-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 TU-1 through TU-5 were helium leak tested using the procedure shown in the test report (ORNL/NTRC-013). 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 TU-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 21 min of testing on TU-4 as documented in Sect. 5.2.2 of ORNL/NTRC-013. TU-2 and TU-5 displayed some unusual pulsing action during leak testing. The root cause of these oscillatory leak rates has not been determined. However, it is postulated that the seal around the machined port in the lid that is used for helium leak checking the test units was the cause of this unusual pattern. In accordance with the *ASME Boiler and Pressure Vessel Code*, Sect. V, Subsection A, Article 10, Appendix IX, "Helium Mass Spectrometer Test – Hood Technique," a system response time must be established to determine the helium leak testing duration. The fabricators of this package used this *ASME Boiler and Pressure Vessel Code* approach and determined that the system response time for their leak test setup with this containment vessel was ~15 s. To ensure that the leak detector steady-state (equilibrium) response is reached, the helium leak test duration was established at 2 min (8 × system response time). Since the helium leakage rates observed at NTRC (ORNL/NTRC-013), using a configuration similar to the fabricator's test arrangement, remained below the ANSI N14.5-1997 leak tight value for ~10 min, it was determined that the test duration was adequate and the units were leaktight. 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 in Sect. 5.2.2 of ORNL/NTRC-013. 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.

Table 4.7. Regulatory leakage criteria for HAC [a]

Verification activity	Fast absorption		Medium absorption		Slow absorption	
	$L_{RA\text{ - air}}$ (ref-cm^3/s)	$L_{RA\text{ - He}}$ (cm^3/s)	$L_{RA\text{ - air}}$ (ref-cm^3/s)	$L_{RA\text{ - He}}$ (cm^3/s)	$L_{RA\text{ - air}}$ (ref-cm^3/s)	$L_{RA\text{ - He}}$ (cm^3/s)
Design	2.3879E-01	2.3551E-01	2.3824E-01	2.3497E-01	2.3663E-01	2.3341E-01

[a] The procedure used to calculate the above criteria is shown in Appendix 4.5.2.

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 ORNL/NTRC-013
Design verification of containment vessel boundary (helium)	$L_T \leq 2.0 \times 10^{-7}$ cm^3/s	See ORNL/NTRC-013

The 35.2 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 SARP.

4.4 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 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. With the exception of the periodic leakage rate testing frequency discussed below, the requirements of ANSI N14.5-1997 are used for all stages of containment demonstration for the ES-3100 leakage rate testing (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 equivalent). Preshipment leakage rate testing, which demonstrates correct assembly of the containment vessel, shall be performed to the acceptance criterion of either (1) a leakage rate of not more than the reference air leakage rate, L_R, or (2) no detected leakage when tested to a sensitivity of at least 10^{-3} ref-cm^3/s (ANSI N14.5-1997, Subclause 7.6.4). The preshipment, fabrication, and maintenance 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. In addition to these leakage tests,

Subclause 7.5.2 of ANSI N14.5-1997 states that the periodic leakage rate testing shall be conducted within 12 months prior to each shipment. Testing of the ES-3100 and EPDM O-rings, documented in RP 801580-0022, provides the justification to extend the periodic leakage rate testing frequency to 24 months. Therefore, the periodic leakage rate testing specified in Chapter 8 shall be conducted in accordance with ANSI N14.5-1997 except for the frequency. 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. TU-4's containment vessel was subjected to both the NCT and HAC tests. TU-1 through TU-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 35.2 kg of HEU in the containment vessel.

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4.5 APPENDICES

4.5.1 Determination of A_2 for the ES-3100 Package with HEU Contents

4.5.2 Calculation of the ES-3100 Containment Vessel's Regulatory Reference Air Leakage Rates

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Appendix 4.5.1

Determination of A_2 for the ES-3100 Package with HEU Contents

Introduction

The containment criteria for radioactive, fissile material packages are given in 10 CFR 71.51(a)(1) for Normal Conditions of Transport (NCT) [$\leq 10^{-6}$ A_2/h] and in 71.51(a)(2) for Hypothetical Accident Conditions (HAC) [$\leq A_2$ in a week]. The A_2 value for this mixture of radioisotopes must be determined to establish the content containment criteria and to determine the maximum release quantity that is allowed by the regulations. These values for a mixture of isotopes are determined by the methodology given in 10 CFR 71, Appendix A, "Determination of A_1 and A_2," Sect. IV. The results of these analyses are used to demonstrate compliance of the ES-3100 package with the containment requirements of 10 CFR 71.

Scope

The A_2 value of the highly enriched uranium (HEU) content to be shipped is evaluated based on the mass and weight percents of HEU shown in Table 1 and defined in Sect. 1.2.2. The weight percents shown in Table 1 are the ones that generate the largest activity within the allowable ranges presented in Sect. 1.2.2. Incorporating the new 10 CFR 71 A_2 values for the uranium isotopes, three different categories have been established based on the absorption rate of the uranium isotopes. The fast lung absorption, medium lung absorption, and slow lung absorption categories are addressed in subsequent sections. By applying the maximum weight percents of isotopes ^{232}U, ^{233}U, ^{234}U, ^{236}U and by incorporating the traces of ^{237}Np and the transuranic isotopes, the maximum activity, minimum A_2 value, and the minimum leakage requirements were determined for each category of absorption for the HEU contents. The mass and isotopic concentrations used for the proposed content do not take into consideration limits based on shielding and subcriticality.

Table 1. Isotopic mass and weight percent for the HEU contents [a]

Nuclide	Weight percent	Mass (g)
U-232	0.000004	0.001408
U-233	0.600000	211.200000
U-234	2.000000	704.000000
U-235	54.819996	19,296.638592
U-236	40.000000	14,080.000000
U-238	0.000000	0.000000
Transuranic	0.080000 [b]	28.160000
Np-237	2.500000	880.000000
Total	**100.000000**	**35,200.000000**

[a] Weight percents values of individual isotopes are those that generate the largest activity within the allowable ranges presented in Sect. 1.2.2.

[b] The transuranic weight percent of 0.080000 applies to ground transport only. The maximum transuranic weight percent in contents transported by air will be 0.004000.

According to 10 CFR 71, Appendix A, parent and daughter nuclides are considered to be a mixture of different nuclides than those of the parent nuclide. The radioactive decay of uranium [refer to the decay chains presented by Dr. David C. Kocher, *Radioactive Decay Data Tables* (DOE/TIC-11026)] creates isotopes that will accumulate enough activity to exceed their respective criteria for limited quantities (49 CFR 173.425, Table 4, "Activity Limits for Limited Quantities, Instruments, and Articles") and for Type A quantities of radionuclides (10 CFR 71, Table A-1, "A_1 and A_2 Values for Radionuclides"). Furthermore, the A_2 value for the mixture will change over time as a result of radioactive decay. The analysis below shows that the A_2 value for this mixture reaches a minimum at initial fabrication, increases to the 10^{th} year, and declines through the 70^{th} year.

Analysis

Mass Tables. The mass and weight fractions for HEU isotopes used in the containment calculations are presented in Table 1. For conservatism, a small quantity of ^{232}U is assumed in this material at fabrication.

ORIGEN-S Results. The source terms of the isotopes in the mixtures were evaluated using the ORIGEN-S computer program (NUREG/CR-0200). The mass values for the parent and daughter products are presented in Table 2 for the time interval of 0–70 years. Contributions from the transuranics and ^{237}Np are held constant at each time interval during the 70-year evaluation.

The A_2 value of each mixture was calculated using the procedure shown in Tables 3, 4, and 5 for the above time intervals. The 70^{th} year of decay represents the smallest value of A_2 and the maximum activity-to-A_2 value ratio (the smallest maximum allowable leakage rate within the time interval examined). A summary of the content activity and the A_2 value of the various configurations for the above time interval is given in Table 6.

From Sect. 1.2.2, the activity and mass concentrations for the transuranics are 1.2×10^{7} Bq/gU and 800 µg/gU (ground transport only), respectively. Using a maximum uranium mass of 35.2 kg, the mass of transuranics is calculated to be 28.160 g and the activity is calculated to be 4.2240×10^{-1} TBq. Dividing this activity by the mass results in a specific activity of 1.5×10^{-2} TBq/g. In accordance with 10 CFR 71, Appendix A, Table A-3 for "contents with no relevant data," an A_2 value of 9.0×10^{-5} TBq is obtained.

Section 1.2.2 gives a maximum concentration for Np-237 of 0.025 g/gU. Using a maximum uranium mass of 35.2 kg, the mass of Np-237 is calculated to be 880 g. This value is used in Tables 3, 4, and 5 for the Np-237 contents.

Results

The containment criteria analysis indicates that the HEU contents must be shipped in a Type B material package since their activities are greater than the A_2 value. The smallest A_2 value of 1.5245×10^{-4} TBq (4.1203×10^{-3} Ci) in conjunction with the maximum activity-to-A_2 value ratio of 4,752.8 occurs after ~70 years of decay for the assumed maximum 35.2 kg of HEU.

Table 2. Mass values of parent and daughter products for 35.2 kg of HEU

Isotope	0 years	5 years	10 years	20 years	30 years	40 years	50 years	60 years	70 years
Pb-210	0.0000E+00	1.4150E-10	1.0912E-09	8.1664E-09	2.5555E-08	5.6672E-08	1.0349E-07	1.6896E-07	2.5274E-07
Pb-212	0.0000E+00	1.8163E-08	2.0275E-08	1.8867E-08	1.7037E-08	1.5488E-08	1.3996E-08	1.2672E-08	1.1475E-08
Bi-210	0.0000E+00	8.7296E-14	6.7302E-13	5.0054E-12	1.5770E-11	3.4918E-11	6.3923E-11	1.0419E-10	1.5558E-10
Bi-212	0.0000E+00	1.7178E-09	1.9149E-09	1.7882E-09	1.6192E-09	1.4643E-09	1.3277E-09	1.2024E-09	1.0884E-09
Po-210	0.0000E+00	2.4077E-12	1.8586E-11	1.3798E-10	4.3507E-10	9.6448E-10	1.7670E-09	2.8653E-09	4.2944E-09
Rn-222	0.0000E+00	1.4150E-12	5.6602E-12	2.2598E-11	5.0829E-11	9.0112E-11	1.4080E-10	2.0205E-10	2.7526E-10
Ra-223	0.0000E+00	6.5223E-12	2.4700E-11	8.9922E-11	1.8428E-10	2.9910E-10	4.3032E-10	5.7311E-10	7.2362E-10
Ra-224	0.0000E+00	1.5770E-07	1.7600E-07	1.6474E-07	1.4925E-07	1.3489E-07	1.2207E-07	1.1053E-07	1.0011E-07
Ra-225	0.0000E+00	2.1120E-08	4.5619E-08	9.1238E-08	1.3686E-07	1.8227E-07	2.2810E-07	2.7245E-07	3.1891E-07
Ra-226	0.0000E+00	2.2035E-07	8.8000E-07	3.5200E-06	7.8848E-06	1.4010E-05	2.1894E-05	3.1469E-05	4.2803E-05
Ra-228	0.0000E+00	2.0557E-13	6.8992E-13	2.0557E-12	3.6186E-12	5.2378E-12	6.8710E-12	8.5184E-12	1.0166E-11
Ac-225	0.0000E+00	1.6896E-08	3.0835E-08	6.1670E-08	9.2506E-08	1.2313E-07	1.5396E-07	1.8459E-07	2.1542E-07
Ac-227	0.0000E+00	4.6119E-09	1.7541E-08	6.3486E-08	1.3025E-07	2.1226E-07	3.0489E-07	4.0523E-07	5.1136E-07
Ac-228	0.0000E+00	2.5062E-17	8.4198E-17	2.5062E-16	4.4070E-16	6.3923E-16	8.3917E-16	1.0391E-15	1.2404E-15
Th-227	0.0000E+00	1.0710E-11	4.0716E-11	1.4762E-10	3.0296E-10	4.9206E-10	7.0819E-10	9.4168E-10	1.1906E-09
Th-228	0.0000E+00	3.0694E-05	3.4214E-05	3.1962E-05	2.9005E-05	2.6189E-05	2.3795E-05	2.1542E-05	1.9430E-05
Th-229	0.0000E+00	6.3360E-03	9.0394E-03	1.8058E-02	2.7034E-02	3.6115E-02	4.4986E-02	5.4067E-02	6.3149E-02
Th-230	0.0000E+00	9.7856E-03	1.9501E-02	3.9072E-02	5.8573E-02	7.8144E-02	9.7856E-02	1.1686E-01	1.3658E-01
Th-231	0.0000E+00	7.8537E-08	7.8537E-08	7.8537E-08	7.8537E-08	7.8537E-08	7.8537E-08	7.8537E-08	7.8537E-08
Th-232	0.0000E+00	2.0416E-03	4.0973E-03	8.1946E-03	1.2292E-02	1.6333E-02	2.0416E-02	2.4640E-02	2.8723E-02
Th-234	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Pa-231	0.0000E+00	9.3396E-05	1.8698E-04	3.7435E-04	5.6153E-04	7.4678E-04	9.3396E-04	1.1211E-03	1.3064E-03
Pa-233	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
U-232	1.4080E-03	1.3376E-03	1.2742E-03	1.1546E-03	1.0447E-03	9.4618E-04	8.5747E-04	7.7581E-04	7.0259E-04
U-233	2.1120E+02	2.1119E+02	2.1119E+02	2.1118E+02	2.1117E+02	2.1116E+02	2.1116E+02	2.1115E+02	2.1114E+02
U-234	7.0400E+02	7.0399E+02	7.0398E+02	7.0396E+02	7.0394E+02	7.0392E+02	7.0390E+02	7.0388E+02	7.0386E+02
U-235	1.9297E+04	1.9297E+04	1.9297E+04	1.9297E+04	1.9297E+04	1.9297E+04	1.9297E+04	1.9297E+04	1.9297E+04
U-236	1.4080E+04	1.4080E+04	1.4080E+04	1.4080E+04	1.4080E+04	1.4080E+04	1.4080E+04	1.4080E+04	1.4080E+04
U-238	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Trans.	2.8160E+01	2.8160E+01	2.8160E+01	2.8160E+01	2.8160E+01	2.8160E+01	2.8160E+01	2.8160E+01	2.8160E+01
Np-237	8.8000E+02	8.8000E+02	8.8000E+02	8.8000E+02	8.8000E+02	8.8000E+02	8.8000E+02	8.8000E+02	8.8000E+02
Total	**3.5200E+04**	**3.5200E+04**	**3.5200E+04**	**3.5200E+04**	**3.5200E+04**	**3.5200E+04**	**3.5200E+04**	**3.5200E+04**	**3.5200E+04**

Table 3. A_2 value calculation for 35.2 kg HEU for fast absorption uranium at 70 years

Isotope	Mass at 70 years (g)	Specific activity (TBq/g)	Activity (TBq)	A_2 (TBq)	f(i) (TBq/TBq)	f(i) / A_2 (1/TBq)
Pb-210	2.5274E-07	2.8000E+00	7.0767E-07	5.0000E-02	9.7669E-07	1.9534E-05
Pb-212	1.1475E-08	5.1000E+04	5.8523E-04	2.0000E-01	8.0770E-04	4.0385E-03
Bi-210	1.5558E-10	4.6000E+03	7.1567E-07	6.0000E-01	9.8773E-07	1.6462E-06
Bi-212	1.0884E-09	5.4000E+05	5.8774E-04	6.0000E-01	8.1116E-04	1.3519E-03
Po-210	4.2944E-09	1.7000E+02	7.3005E-07	2.0000E-02	1.0076E-06	5.0379E-05
Rn-222	2.7526E-10	5.7000E+03	1.5690E-06	4.0000E-03	2.1654E-06	5.4136E-04
Ra-223	7.2362E-10	1.9000E+03	1.3749E-06	7.0000E-03	1.8975E-06	2.7108E-04
Ra-224	1.0011E-07	5.9000E+03	5.9065E-04	2.0000E-02	8.1518E-04	4.0759E-02
Ra-225	3.1891E-07	1.5000E+03	4.7837E-04	4.0000E-03	6.6022E-04	1.6505E-01
Ra-226	4.2803E-05	3.7000E-02	1.5837E-06	3.0000E-03	2.1858E-06	7.2859E-04
Ra-228	1.0166E-11	1.0000E+01	1.0166E-10	2.0000E-02	1.4031E-10	7.0153E-09
Ac-225	2.1542E-07	2.1000E+03	4.5238E-04	6.0000E-03	6.2435E-04	1.0406E-01
Ac-227	5.1136E-07	2.7000E+00	1.3807E-06	9.0000E-05	1.9055E-06	2.1173E-02
Ac-228	1.2404E-15	8.4000E+04	1.0419E-10	5.0000E-01	1.4380E-10	2.8761E-10
Th-227	1.1906E-09	1.1000E+03	1.3097E-06	5.0000E-03	1.8075E-06	3.6151E-04
Th-228	1.9430E-05	3.0000E+01	5.8290E-04	1.0000E-03	8.0449E-04	8.0449E-01
Th-229	6.3149E-02	7.9000E-03	4.9888E-04	5.0000E-04	6.8852E-04	1.3771E+00
Th-230	1.3658E-01	7.6000E-04	1.0380E-04	1.0000E-03	1.4326E-04	1.4326E-01
Th-231	7.8537E-08	2.0000E+04	1.5707E-03	2.0000E-02	2.1679E-03	1.0839E-01
Th-232	2.8723E-02	4.0000E-09	1.1489E-10	UNLIMITED	1.5857E-10	--
Pa-231	1.3064E-03	1.7000E-03	2.2209E-06	4.0000E-04	3.0651E-06	7.6628E-03
U-232	7.0259E-04	8.3000E-01	5.8315E-04	1.0000E-02	8.0483E-04	8.0483E-02
U-233	2.1114E+02	3.6000E-04	7.6010E-02	9.0000E-02	1.0491E-01	1.1656E+00
U-234	7.0386E+02	2.3000E-04	1.6189E-01	9.0000E-02	2.2343E-01	2.4825E+00
U-235	1.9297E+04	8.0000E-08	1.5438E-03	UNLIMITED	2.1306E-03	--
U-236	1.4080E+04	2.4000E-06	3.3792E-02	UNLIMITED	4.6638E-02	--
Transuranic	2.8160E+01	1.5000E-02	4.2240E-01	9.0000E-05	5.8298E-01	6.4775E+03
Np-237	8.8000E+02	2.6000E-05	2.2880E-02	2.0000E-03	3.1578E-02	1.5789E+01
Total Mass =	**3.5200E+04**	**$\sum$ Act. =**	**7.2456E-01**		**$\sum$ f(i) / A_2 =**	**6.4998E+03**

$$A_2\ (\text{mixture}) = \frac{1}{\sum \text{f(i)}/A_2} = \frac{1}{6.4998 \times 10^3\ (1/\text{TBq})} = 1.5385 \times 10^{-4}\ \text{TBq}$$

Table 4. A_2 value calculation for 35.2 kg HEU for medium absorption uranium at 70 years

Isotope	Mass at 70 years (g)	Specific activity (TBq/g)	Activity (TBq)	A_2 (TBq)	f(i) (TBq/TBq)	f(i) / A_2 (1/TBq)
Pb-210	2.5274E-07	2.8000E+00	7.0767E-07	5.0000E-02	9.7669E-07	1.9534E-05
Pb-212	1.1475E-08	5.1000E+04	5.8523E-04	2.0000E-01	8.0770E-04	4.0385E-03
Bi-210	1.5558E-10	4.6000E+03	7.1569E-07	6.0000E-01	9.8775E-07	1.6463E-06
Bi-212	1.0884E-09	5.4000E+05	5.8773E-04	6.0000E-01	8.1115E-04	1.3519E-03
Po-210	4.2944E-09	1.7000E+02	7.3005E-07	2.0000E-02	1.0076E-06	5.0379E-05
Rn-222	2.7526E-10	5.7000E+03	1.5690E-06	4.0000E-03	2.1655E-06	5.4137E-04
Ra-223	7.2362E-10	1.9000E+03	1.3749E-06	7.0000E-03	1.8975E-06	2.7108E-04
Ra-224	1.0011E-07	5.9000E+03	5.9064E-04	2.0000E-02	8.1517E-04	4.0759E-02
Ra-225	3.1891E-07	1.5000E+03	4.7837E-04	4.0000E-03	6.6022E-04	1.6505E-01
Ra-226	4.2803E-05	3.7000E-02	1.5837E-06	3.0000E-03	2.1858E-06	7.2859E-04
Ra-228	1.0166E-11	1.0000E+01	1.0166E-10	2.0000E-02	1.4030E-10	7.0151E-09
Ac-225	2.1542E-07	2.1000E+03	4.5239E-04	6.0000E-03	6.2437E-04	1.0406E-01
Ac-227	5.1136E-07	2.7000E+00	1.3807E-06	9.0000E-05	1.9055E-06	2.1173E-02
Ac-228	1.2404E-15	8.4000E+04	1.0420E-10	5.0000E-01	1.4381E-10	2.8762E-10
Th-227	1.1906E-09	1.1000E+03	1.3097E-06	5.0000E-03	1.8075E-06	3.6151E-04
Th-228	1.9430E-05	3.0000E+01	5.8291E-04	1.0000E-03	8.0451E-04	8.0451E-01
Th-229	6.3149E-02	7.9000E-03	4.9888E-04	5.0000E-04	6.8852E-04	1.3770E+00
Th-230	1.3658E-01	7.6000E-04	1.0380E-04	1.0000E-03	1.4326E-04	1.4326E-01
Th-231	7.8537E-08	2.0000E+04	1.5707E-03	2.0000E-02	2.1679E-03	1.0839E-01
Th-232	2.8723E-02	4.0000E-09	1.1489E-10	UNLIMITED	1.5857E-10	--
Pa-231	1.3064E-03	1.7000E-03	2.2209E-06	4.0000E-04	3.0651E-06	7.6628E-03
U-232	7.0259E-04	8.3000E-01	5.8315E-04	7.0000E-03	8.0484E-04	1.1498E-01
U-233	2.1114E+02	3.6000E-04	7.6009E-02	2.0000E-02	1.0490E-01	5.2452E+00
U-234	7.0386E+02	2.3000E-04	1.6189E-01	2.0000E-02	2.2343E-01	1.1172E+01
U-235	1.9297E+04	8.0000E-08	1.5437E-03	UNLIMITED	2.1306E-03	--
U-236	1.4080E+04	2.4000E-06	3.3792E-02	2.0000E-02	4.6638E-02	2.3319E+00
Transuranic	2.8160E+01	1.5000E-02	4.2240E-01	9.0000E-05	5.8298E-01	6.4775E+03
Np-237	8.8000E+02	2.6000E-05	2.2880E-02	2.0000E-03	3.1578E-02	1.5789E+01
Total Mass =	**3.5200E+04**	**∑ Act. =**	**7.2456E-01**		**∑ f(i) / A2 =**	**6.5149E+03**

$$A_2\ (\text{mixture}) = \frac{1}{\sum \text{f(i)}/A_2} = \frac{1}{6.5149 \times 10^3\ (1/\text{TBq})} = 1.5349 \times 10^{-4}\ \text{TBq}$$

Table 5. A_2 value calculation for 35.2 kg HEU for slow absorption uranium at 70 years

Isotope	Mass at 70 years (g)	Specific activity (TBq/g)	Activity (TBq)	A_2 (TBq)	f(i) (TBq/TBq)	f(i) / A_2 (1/TBq)
Pb-210	2.5274E-07	2.8000E+00	7.0766E-07	5.0000E-02	9.7668E-07	1.9534E-05
Pb-212	1.1475E-08	5.1000E+04	5.8524E-04	2.0000E-01	8.0771E-04	4.0386E-03
Bi-210	1.5558E-10	4.6000E+03	7.1569E-07	6.0000E-01	9.8775E-07	1.6463E-06
Bi-212	1.0884E-09	5.4000E+05	5.8773E-04	6.0000E-01	8.1115E-04	1.3519E-03
Po-210	4.2944E-09	1.7000E+02	7.3005E-07	2.0000E-02	1.0076E-06	5.0379E-05
Rn-222	2.7526E-10	5.7000E+03	1.5690E-06	4.0000E-03	2.1655E-06	5.4137E-04
Ra-223	7.2362E-10	1.9000E+03	1.3749E-06	7.0000E-03	1.8975E-06	2.7108E-04
Ra-224	1.0011E-07	5.9000E+03	5.9064E-04	2.0000E-02	8.1517E-04	4.0759E-02
Ra-225	3.1891E-07	1.5000E+03	4.7837E-04	4.0000E-03	6.6022E-04	1.6505E-01
Ra-226	4.2803E-05	3.7000E-02	1.5837E-06	3.0000E-03	2.1858E-06	7.2859E-04
Ra-228	1.0166E-11	1.0000E+01	1.0166E-10	2.0000E-02	1.4030E-10	7.0151E-09
Ac-225	2.1542E-07	2.1000E+03	4.5239E-04	6.0000E-03	6.2437E-04	1.0406E-01
Ac-227	5.1136E-07	2.7000E+00	1.3807E-06	9.0000E-05	1.9055E-06	2.1173E-02
Ac-228	1.2404E-15	8.4000E+04	1.0420E-10	5.0000E-01	1.4381E-10	2.8762E-10
Th-227	1.1906E-09	1.1000E+03	1.3097E-06	5.0000E-03	1.8075E-06	3.6151E-04
Th-228	1.9430E-05	3.0000E+01	5.8291E-04	1.0000E-03	8.0451E-04	8.0451E-01
Th-229	6.3149E-02	7.9000E-03	4.9888E-04	5.0000E-04	6.8852E-04	1.3770E+00
Th-230	1.3658E-01	7.6000E-04	1.0380E-04	1.0000E-03	1.4326E-04	1.4326E-01
Th-231	7.8537E-08	2.0000E+04	1.5707E-03	2.0000E-02	2.1679E-03	1.0839E-01
Th-232	2.8723E-02	4.0000E-09	1.1489E-10	UNLIMITED	1.5857E-10	--
Pa-231	1.3064E-03	1.7000E-03	2.2209E-06	4.0000E-04	3.0651E-06	7.6628E-03
U-232	7.0259E-04	8.3000E-01	5.8315E-04	1.0000E-03	8.0484E-04	8.0484E-01
U-233	2.1114E+02	3.6000E-04	7.6009E-02	6.0000E-03	1.0490E-01	1.7484E+01
U-234	7.0386E+02	2.3000E-04	1.6189E-01	6.0000E-03	2.2343E-01	3.7238E+01
U-235	1.9297E+04	8.0000E-08	1.5437E-03	UNLIMITED	2.1306E-03	--
U-236	1.4080E+04	2.4000E-06	3.3792E-02	6.0000E-03	4.6638E-02	7.7730E+00
Transuranic	2.8160E+01	1.5000E-02	4.2240E-01	9.0000E-05	5.8298E-01	6.4775E+03
Np-237	8.8000E+02	2.6000E-05	2.2880E-02	2.0000E-03	3.1578E-02	1.5789E+01
Total Mass =	**3.5200E+04**	**$\sum$ Act. =**	**7.2456E-01**		**$\sum$ f(i) / A_2 =**	**6.5594E+03**

$$A_2\ (\text{mixture}) = \frac{1}{\sum \text{f(i)}/A_2} = \frac{1}{6.5594 \times 10^3\ (1/\text{TBq})} = 1.5245 \times 10^{-4}\ \text{TBq}$$

Table 6. Activity, A_2 value, and activity-to-A_2 ratio for the enriched uranium contents

Year	Activity (TBq)	A_2-Mixture (TBq)			Activity/A_2		
		Fast	Medium	Slow	Fast	Medium	Slow
0	7.1974E-01	1.5289E-04	1.5253E-04	1.5148E-04	4707.57	4718.68	4751.39
5	7.2507E-01	1.5399E-04	1.5363E-04	1.5257E-04	4708.55	4719.59	4752.38
10	7.2554E-01	1.5408E-04	1.5372E-04	1.5267E-04	4708.85	4719.88	4752.34
20	7.2538E-01	1.5404E-04	1.5368E-04	1.5263E-04	4709.04	4720.07	4752.54
30	7.2514E-01	1.5399E-04	1.5363E-04	1.5258E-04	4709.01	4720.04	4752.52
40	7.2494E-01	1.5394E-04	1.5358E-04	1.5254E-04	4709.24	4720.28	4752.46
50	7.2478E-01	1.5390E-04	1.5355E-04	1.5250E-04	4709.42	4720.16	4752.66
60	7.2465E-01	1.5387E-04	1.5352E-04	1.5247E-04	4709.50	4720.23	4752.74
70	7.2456E-01 [a]	1.5385E-04	1.5349E-04	1.5245E-04 [a]	4709.52	4720.57	4752.77 [a]

[a] The A_2, total activity, and activity-to-A_2 ratio values used in Appendix 4.5.2.

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Appendix 4.5.2

Calculation of the ES-3100 Containment Vessel's Regulatory Reference Air Leakage Rates

Introduction

The ES-3100 leak-testing requirements of the containment boundary are based on the smallest maximum allowable leakage rate generated from the maximum uranium content defined in Table 4.3. Section 5 of ANSI N14.5-1997 defines the maximum allowable leakage rate based on the maximum allowable release rate. These leakage rates, L_N and L_A, are the maximum allowable O-ring seal leakage rates for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The worst-case maximum allowable leakage rates are used to calculate an equivalent leakage hole diameter following ANSI N14.5-1997, Appendix B, for each condition of transport. This leakage hole diameter is used to calculate a reference air and a helium leakage rate for leak testing. A bounding mass for the highly enriched uranium (HEU) content of 35.2 kg is used in this calculation to certify the ES-3100 package for shipment. The maximum allowable leakage rates are calculated using this maximum content mass in a much more dispersive form (oxide powder) at the highest calculated pressures and temperatures. This appendix shows the procedure used to calculate the leak criteria for the uranium constituents in the "slow lung absorption" group. Table 1 shows the results of using this procedure for fast, medium, and slow absorption uranium constituents as a function of decay time.

HEU Content

Calculate R_N and R_A: (Table 4.1)

The maximum allowable release rate is based on using A_2.

$A_2 = 1.5245 \times 10^{-4}$ TBq, (4.1203×10^{-3} Ci). [Table 6 (Appendix 4.5.1)]

The containment requirements for NCT and HAC are:

$R_N = A_2 \times 10^{-6}$ TBq/h,
$= A_2 \times 2.78 \times 10^{-10}$ TBq/s, [ANSI N14.5-1997 (Eq. 1)]
$= 1.5245 \times 10^{-4} \times 2.78 \times 10^{-10}$ TBq/s,
$= 4.2382 \times 10^{-14}$ TBq/s, (1.1455×10^{-12} Ci/s).

$R_A = A_2$ (TBq/week),
$= A_2 \times 1.65 \times 10^{-6}$ (TBq/s), [ANSI N14.5-1997 (Eq. 2)]
$= 1.5245 \times 10^{-4} \times 1.65 \times 10^{-6}$ TBq/s,
$= 2.5155 \times 10^{-10}$ TBq/s, (6.7986×10^{-9} Ci/s). (or limited to 10 A_2/week of ^{85}Kr)

Following ANSI N14.5-1997, the medium aerosol activity must be calculated to determine the leakage rates.

m = total nuclide mass in the package available for release (g),
TotA = total activity in the package available for release (TBq),
TSA = total specific activity in the package available for release (TBq/g).

Table 1. Regulatory leakage criteria for 35.2 kg of HEU

Years from fabrication		NCT		HAC	
		$L_{RN\text{ - air}}$ (ref-cm^3/s)	$L_{RN\text{ - He}}$ (cm^3/s)	$L_{RA\text{ - air}}$ (ref-cm^3/s)	$L_{RA\text{ - He}}$ (cm^3/s)
Fast absorption	0	1.3922E-04	1.7148E-04	2.3889E-01	2.3560E-01
	5	1.3918E-04	1.7144E-04	2.3883E-01	2.3555E-01
	10	1.3918E-04	1.7143E-04	2.3882E-01	2.3554E-01
	20	1.3918E-04	1.7143E-04	2.3881E-01	2.3553E-01
	30	1.3917E-04	1.7143E-04	2.3881E-01	2.3553E-01
	40	1.3917E-04	1.7143E-04	2.3880E-01	2.3552E-01
	50	1.3917E-04	1.7142E-04	2.3880E-01	2.3552E-01
	60	1.3916E-04	1.7142E-04	2.3879E-01	2.3551E-01
	70	1.3916E-04	1.7141E-04	2.3879E-01	2.3551E-01
Medium absorption	0	1.3890E-04	1.7111E-04	2.3833E-01	2.3507E-01
	5	1.3887E-04	1.7107E-04	2.3827E-01	2.3501E-01
	10	1.3886E-04	1.7106E-04	2.3827E-01	2.3500E-01
	20	1.3886E-04	1.7106E-04	2.3826E-01	2.3499E-01
	30	1.3886E-04	1.7106E-04	2.3826E-01	2.3499E-01
	40	1.3885E-04	1.7105E-04	2.3825E-01	2.3499E-01
	50	1.3885E-04	1.7105E-04	2.3825E-01	2.3498E-01
	60	1.3885E-04	1.7105E-04	2.3824E-01	2.3498E-01
	70	1.3884E-04	1.7104E-04	2.3824E-01	2.3497E-01
Slow absorption	0	1.3796E-04	1.7001E-04	2.3670E-01	2.3348E-01
	5	1.3793E-04	1.6997E-04	2.3665E-01	2.3342E-01
	10	1.3792E-04	1.6997E-04	2.3664E-01	2.3342E-01
	20	1.3792E-04	1.6997E-04	2.3664E-01	2.3342E-01
	30	1.3792E-04	1.6997E-04	2.3664E-01	2.3342E-01
	40	1.3792E-04	1.6997E-04	2.3664E-01	2.3342E-01
	50	1.3792E-04	1.6997E-04	2.3664E-01	2.3341E-01
	60	1.3792E-04	1.6997E-04	2.3663E-01	2.3341E-01
	70	1.3792E-04	1.6996E-04	2.3663E-01	2.3341E-01

For HEU content:

$$\begin{aligned} TSA &= TotA / m, \\ &= 7.2456 \times 10^{-1}\ (TBq) / 35{,}200\ (g), \qquad \text{[Table 6 (Appendix 4.5.1)]} \\ &= 2.0584 \times 10^{-5}\ TBq/g, \\ \rho P &= 9 \times 10^{-6}\ g/cm^3. \qquad \text{(The maximum density of powder aerosols in the fill gas)} \end{aligned}$$

For any packaging arrangement:

C_N = activity per unit volume of medium that could escape from the containment system (TBq/cm^3),
= $TSA \times \rho_P$,
= 2.0584×10^{-5} $(TBq/g) \times 9 \times 10^{-6}$ (g/cm^3),
= 1.8526×10^{-10} TBq/cm^3.

Using Curren's maximum aerosol density, $C_A = C_N$:

C_A = activity per unit volume of exiting gas (TBq/cm^3), (HAC)
= 1.8526×10^{-10} TBq/cm^3.

Section 6.1 of ANSI N14.5-1997 calculates L_N with (Eq. 3) and L_A with (Eq. 4). L_N and L_A are the maximum allowable leakage rates for the containment vessel fill gas aerosol during NCT and HAC, respectively.

L_N = maximum allowable leakage rate for the medium for NCT (TBq/cm^3),
= R_N / C_N, [ANSI N14.5-1997 (Eq. 3)]
= 4.2382×10^{-14} $(TBq/s) / 1.8526 \times 10^{-10}$ (TBq/cm^3),
= 2.2878×10^{-4} cm^3/s,

L_A = maximum allowable leakage rate for the medium for HAC (TBq/cm^3),
= R_A / C_A,
= 2.5155×10^{-10} $(TBq/s) / 1.8526 \times 10^{-10}$ (TBq/cm^3),
= 1.3578 cm^3/s.

L_N and L_A correspond to the upstream volumetric leakage rate (L_u) at the upstream pressure (P_u) in the ANSI N14.5-1997 formulas for use later in this appendix. The reference air leakage rates $L_{R,N}$ and $L_{R,A}$ for NCT and HAC, based on the L_N and L_A, are then calculated using the maximum temperatures and pressure combinations from Table 7 in Appendix 3.5.4 (NCT) and from Table 7 in Appendix 3.5.5 (HAC) as the basis. For conservatism, the latter values have been rounded up to compensate for numerical tolerance issues. Therefore, the following analyses will use a pressure of 31.25 psia at a temperature of 200°F for the NCT evaluation and a pressure of 112.50 psia at a temperature of 285.00°F for the HAC evaluation.

Determination of the Leakage Test Procedure Requirements for the HEU Content

This calculation will examine the most conservative effects of a fully loaded containment vessel with an HEU mass of 35.2 kg. The smallest allowable leakage values are shown in Tables 4.5 and 4.7. The A_2 value and the maximum content activity-to-A_2 value ratio for this mixture were calculated for several different decay times (Table 6, Appendix 4.5.1). As calculated in Appendix 4.5.1, the A_2 value and the maximum content activity-to-A_2 ratio used to qualify this package occur at ~70 years of decay and are 1.5245×10^{-4} TBq (4.1203×10^{-3} Ci) and 4,752.8 respectively. These values are used to determine the leakage test procedural requirements when packaging any convenience cans/contents arrangements in the ES-3100 package. The convenience cans/contents are sealed inside the containment vessel in an environmentally controlled area.

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 (*CRC Handbook of Chemistry and Physics*) 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).

$$L_N = 2.2878 \times 10^{-4} \text{ cm}^3/\text{s},$$
$$L_A = 1.3578 \text{ cm}^3/\text{s}.$$

Find the maximum pressure and temperature in the containment vessel:

Converting the temperature to degrees Kelvin:

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

$$T_N = 273.15 + 5 / 9\ (200.00°F - 32)\ (K), \quad (T = 200.00°F)$$
$$= 366.48 \text{ K}, \quad (NCT)$$

$$T_A = 273.15 + 5 / 9\ (285.00°F - 32)\ (K), \quad (T = 285.00°F)$$
$$= 413.71 \text{ K}. \quad (HAC)$$

Converting the pressures from psia to atmospheres:

$$P_N = P\ (psia) / 14.696\ (psia/atm), \quad (where\ P\ is\ the\ pressure\ in\ Sect.\ 3.3.2)$$
$$= 31.250\ (psia) / 14.696\ (psia/atm), \quad (rounded\ up\ for\ NCT)$$
$$= 2.1264 \text{ atm},$$

$$P_A = P\ (psia) / 14.696\ (psia/atm), \quad (where\ P\ is\ the\ pressure\ in\ Sect.\ 3.4.3)$$
$$= 112.50\ (psia) / 14.696\ (psia/atm), \quad (rounded\ up\ for\ HAC)$$
$$= 7.6551 \text{ atm}.$$

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:

$L_N = 2.2878 \times 10^{-4} \text{ cm}^3/\text{s}$, (Maximum upstream leakage)
$P_u = 2.1264$ atm, (Upstream pressure = 31.25 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)
$T = 366.48$ K, (Fill gas temperature = 200.00°F)

μ = 0.02165 cP, (Viscosity at temperature)
M = 29 g/g-mol. (Molecular weight of fill gas)

The average pressure is:

$P_a = (P_u + P_d) / 2,$
$= (2.1264 + 0.2382) / 2,$
$= 1.1823$ atm. (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:

$Q = P_u L_u,$ (Eq. B1)
$L_u = L_N,$ (NCT leakage)

$Q = (2.1264)(\text{atm})\ (2.2878 \times 10^{-4})(\text{cm}^3/\text{s}),$
$= 4.8647 \times 10^{-4}$ atm-cm^3/s, (NCT mass-like leakage rate)

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

$L_a = Q / P_a,$
$= 4.8647 \times 10^{-4}$ (atm-cm^3/s) / (1.1823) (atm),
$= 4.1147 \times 10^{-4}$ cm^3/s. (NCT 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)
$= (F_c + F_m)(2.1264 - 0.2382),$
$= (1.8882)(F_c + F_m)$ cm^3/s,

$F_c = (2.49 \times 10^6)\ D^4 / (a\ \mu)$ (cm^3/atm-s), (Eq. B3)
$= (2.49 \times 10^6)\ D^4 / [(0.3531)(0.02165)],$
$= (3.2573 \times 10^8)\ D^4$ cm^3/atm-s,

$F_m = (3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)$ (cm^3/atm-s), (Eq. B4)
$= (3.81 \times 10^3)\ D^3\ (366.48 / 29)^{.5} / [(0.3531)(1.1823)],$
$= (3.2447 \times 10^4)\ D^3$ cm^3/atm-s.

From the mass-like leakage calculation:

$L_a = 4.1147 \times 10^{-4}$ cm^3/s. (NCT average leakage rate)

Find the leakage hole diameter that sets:

$L_2 = L_a.$

Using the equations:

$L_2 = (1.8883)\ (F_c + F_m)\ cm^3/s,$
$F_c = (3.2573 \times 10^8)\ D^4\ cm^3/atm\text{-}s,$
$F_m = (3.2447 \times 10^4)\ D^3\ cm^3/atm\text{-}s.$

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 NCT:

D_2 = 0.001 cm, and solve for $L_a = 4.1147 \times 10^{-4}$ cm^3/s. (NCT average leakage rate)

Diameter	F_c	F_m	L_2	L_a / L_2
1.0000E-03	3.2573E-04	3.2447E-05	6.7635E-04	6.0837E-01
8.8229E-04	1.9738E-04	2.2285E-05	4.1479E-04	9.9199E-01
8.8050E-04	1.9579E-04	2.2150E-05	4.1153E-04	9.9986E-01
8.8047E-04	1.9576E-04	2.2147E-05	4.1147E-04	1.0000E+00
8.8047E-04	1.9576E-04	2.2147E-05	4.1147E-04	1.0000E+00

The NCT leakage hole diameter for the HEU oxide content:

D = 8.8047 × 10−4 cm. (NCT diameter)

NCT Reference Air Leakage Rate for HEU Content

The leakage hole diameter found for the maximum allowable leakage rate for NCT will be used to determine the reference air leakage rate. O-ring seal leakage testing must ensure that no leakage is greater than the leakage generated by the hole diameter D = 8.8047 × 10−4 cm. Therefore, the NCT reference leakage flow rate ($L_{R,N}$) must be calculated to determine the allowable test leakage rate.

Input data for NCT reference air leakage rate:

D = 8.8047×10^{-4} cm, (From NCT)
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-mol, (Molecular weight of air)
μ = 0.0185 cP, (Viscosity of air at reference temperature)

Calculate P_a:

$P_a = (P_u + P_d) / 2,$
$= (1.0 + 0.01) /2,$
$= 0.505$ atm, (NCT average pressure)

$$F_c = (2.49 \times 10^6)\, D^4 / (a\,\mu)\ (cm^3/atm\text{-}s), \qquad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\, (8.8047 \times 10^{-4})^4 / [(0.3531)\ (0.0185)],$$
$$= (3.8122 \times 10^8)\, (8.8047 \times 10^{-4})^4,$$
$$= 2.2911 \times 10^{-4}\ cm^3/atm\text{-}s,$$

$$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{.5} / (a\, P_a)\ (cm^3/atm\text{-}s), \qquad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\, (8.8047 \times 10^{-4})^3\, (298 / 29)^{.5} / [(0.3531)\ (0.505)],$$
$$= (6.8501 \times 10^4)\ 8.8047 \times 10^{-4})^3,$$
$$= 4.6756 \times 10^{-5}\ cm^3/atm\text{-}s,$$

$$L_u = (F_c + F_m)\, (P_u - P_d)\, (P_a / P_u)\ (cm^3/s), \qquad \text{(Eq. B5)}$$
$$= (2.2911 \times 10^{-4} + 4.6756 \times 10^{-5})(cm^3/atm\text{-}s)\ (1.0 - 0.01)(atm)\ (0.505 / 1.0),$$
$$= (2.7587 \times 10^{-4})(cm^3/atm\text{-}s)\ (0.49995)(atm),$$
$$= 1.3792 \times 10^{-4}\ cm^3/s.$$

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

$$L_{RN,Air} = 1.3792 \times 10^{-4}\ ref\text{-}cm^3/s. \qquad \text{(For HEU oxide content)}$$

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

$$M = 4\ g/g\text{-}mol, \qquad \text{(Molecular weight of helium)}$$
$$\mu = 0.0198\ cP, \qquad \text{(Viscosity of helium at temperature)}$$

$$F_c = (2.49 \times 10^6)\, D^4 / (a\,\mu)\ (cm^3/atm\text{-}s), \qquad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\, (8.8047\times 10^{-4})^4 / [(0.3531)\ (0.0198)],$$
$$= (3.5619 \times 10^8)\, (8.8047 \times 10^{-4})^4,$$
$$= 2.1407 \times 10^{-4}\ cm^3/atm\text{-}s,$$

$$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{.5} / (a\, P_a)\ (cm^3/atm\text{-}s), \qquad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\, (8.8047 \times 10^{-4})^3\, (298 / 4)^{.5} / [(0.3531)\ (0.505)],$$
$$= (1.8444 \times 10^5)\, (8.8047 \times 10^{-4})^3,$$
$$= 1.2590 \times 10^{-4}\ cm^3/atm\text{-}s,$$

$$L_u = (F_c + F_m)\, (P_u - P_d)\, (P_a / P_u)\ (cm^3/s), \qquad \text{(Eq. B5)}$$
$$= (2.1407 \times 10^{-4} + 1.2590 \times 10^{-4})(cm^3/atm\text{-}s)\ (1.0 - 0.01)(atm)\ (0.505 / 1.0),$$
$$= (3.3997 \times 10^{-4})(cm^3/atm\text{-}s)\ (0.49995)(atm),$$
$$= 1.6996\times 10^{-4}\ cm^3/s.$$

The allowable leakage rate using helium for leak testing is:

$$L_{RN,\,He} = 1.6996 \times 10^{-4}\ cm^3/s. \qquad \text{(NCT helium test value)}$$

HAC Leakage Hole Diameter for HEU Content

The calculation of a maximum allowable leakage rate hole diameter is based on the temperature and pressure of the fill gas aerosol for HAC, assuming the content is in an oxide powder form. Keeping

this calculation conservative, the maximum values for temperature and pressure were used as steady-state conditions for a week. The maximum values were generated during the 30-min burn test for HAC.

Input data for HAC:

$L_A = 1.3578\ cm^3/s$, (Maximum exit leakage)
$P_u = 7.6551$ atm, (Upstream pressure = 112.50 psia)
$P_d = 1.0$ atm, (Downstream pressure)
$T = 413.71$ K, (Fill gas temperature = 285.00°F)
$\mu = 0.02367$ cP, (Viscosity of air at temperature)
$M = 29$ g/g-mol, (Molecular weight of air)
$a = 0.3531$ cm, (Leak path length, 0.139-in. O-ring section diameter)

$P_a = (P_u + P_d) / 2,$
$= (7.6551 + 1.0) / 2,$ (HAC average pressure)
$= 4.3276$ 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)

$Q = (7.6551)(atm)\ (1.3578)(cm^3/s),$
$= 10.3944\ atm\text{-}cm^3/s,$ (HAC mass-like leakage rate)

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

$L_a = Q / P_a,$
$= 10.3944\ (atm\text{-}cm^3/s) / (4.3276)\ (atm),$
$= 2.4019\ cm^3/s.$ (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)
$= (F_c + F_m)\ (7.6551 - 1.0),$
$= 6.6551\ (F_c + F_m)\ cm^3/s,$

$F_c = (2.49 \times 10^6)\ D^4 / (a\ \mu)\ (cm^3/atm\text{-}s),$ (Eq. B3)
$= (2.49 \times 10^6)\ D^4 / [(0.3531)\ (0.02367)],$
$= (2.9796 \times 10^8)\ D^4\ cm^3/atm\text{-}s,$

$F_m = (3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)\ (cm^3/atm\text{-}s),$ (Eq. B4)
$= (3.81 \times 10^3)\ D^3\ (413.71 / 29)^{.5} / [(0.3531)\ (4.3276)],$
$= (9.4184 \times 10^3)\ D^3\ cm^3/atm\text{-}s.$

From the mass-like leakage calculation:

$L_a = 2.4019\ cm^3/s.$ (HAC average leakage rate)

Find the leakage hole diameter that sets:

$$L_2 = L_a.$$

Using the equations:

$$L_2 = 6.6551\ (F_c + F_m)\ cm^3/s,$$
$$F_c = (2.9796 \times 10^8)\ D^4\ cm^3/atm\text{-}s,$$
$$F_m = (9.4184 \times 10^3)\ D^3\ cm^3/atm\text{-}s.$$

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 = 2.4019 (cm^3/s). (HAC average leakage rate)

Diameter	F_c	F_m	L_2	L_a / L_2
1.0000E-02	2.9796E+00	9.4184E-03	1.9892E+01	1.2075E-01
5.8699E-03	3.5374E-01	1.9049E-03	2.3668E+00	1.0148E+00
5.8917E-03	3.5902E-01	1.9262E-03	2.4021E+00	9.9990E-01
5.8916E-03	3.5898E-01	1.9260E-03	2.4019E+00	1.0000E+00

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

$$D = 5.8916 \times 10^{-3}\ cm.$$ (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 $D = 5.8916 \times 10^{-3}$ 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:

$D = 5.8916 \times 10^{-3}$ 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-mol, (Molecular weight of air)
$\mu = 0.0185$ cP. (Viscosity at temperature)

Calculate P_a:

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

$$F_c = (2.49 \times 10^6)\, D^4 / (a\,\mu)\ (\text{cm}^3/\text{atm-s}), \qquad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\, (5.8916 \times 10^{-3})^4 / [(0.3531)\ (0.0185)],$$
$$= (3.8122 \times 10^8)\, (5.8916 \times 10^{-3})^4,$$
$$= 4.5930 \times 10^{-1}\ \text{cm}^3/\text{atm-s},$$

$$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{.5} / (a\, P_a)\ (\text{cm}^3/\text{atm-s}), \qquad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\, (5.8916 \times 10^{-3})^3\, (298 / 29)^{.5} / [(0.3531)\ (0.505)],$$
$$= (6.8501 \times 10^4)\, (5.8916 \times 10^{-3})^3,$$
$$= 1.4008 \times 10^{-2}\ \text{cm}^3/\text{atm-s},$$

$$L_u = (F_c + F_m)\, (P_u - P_d)\, (P_a / P_u)\ (\text{cm}^3/\text{s}), \qquad \text{(Eq. B5)}$$
$$= (4.5930 \times 10^{-1} + 1.4008 \times 10^{-2})(\text{cm}^3/\text{atm-s})\ (1.0 - 0.01)(\text{atm})\ (0.505 / 1.0),$$
$$= (4.7331 \times 10^{-1})(\text{cm}^3/\text{atm-s})\ (0.49995)(\text{atm}),$$
$$= 2.3663 \times 10^{-1}\ \text{cm}^3/\text{s}.$$

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

$$L_{RA,Air} = 2.3663 \times 10^{-1}\ \text{ref-cm}^3/\text{s}. \qquad \text{(for HEU oxide content)}$$

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

$$M = 4\ \text{g/g-mol}, \qquad \text{(Molecular weight of helium)}$$
$$\mu = 0.0198\ \text{cP}, \qquad \text{(Viscosity of helium at temperature)}$$

$$F_c = (2.49 \times 10^6)\, D^4 / (a\,\mu)\ (\text{cm}^3/\text{atm-s}), \qquad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\, (5.8916 \times 10^{-3}\ \text{cm})^4 / [(0.3531)\ (0.0198)],$$
$$= (3.5619 \times 10^8)\, (5.8916 \times 10^{-3}\ \text{cm})^4,$$
$$= 4.2915 \times 10^{-1}\ \text{cm}^3/\text{atm-s},$$

$$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{0.5} / (a\, P_a)\ (\text{cm}^3/\text{atm-s}), \qquad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\, (5.8916 \times 10^{-3}\ \text{cm})^3\, (298 / 4)^{.5} / [(0.3531)\ (0.505)],$$
$$= (1.8444 \times 10^5)\, (5.8916 \times 10^{-3}\ \text{cm})^3,$$
$$= 3.7718 \times 10^{-2}\ \text{cm}^3/\text{atm-s},$$

$$L_u = (F_c + F_m)\, (P_u - P_d)\, (P_a / P_u)\ (\text{cm}^3/\text{s}), \qquad \text{(Eq. B5)}$$
$$= (4.2915 \times 10^{-1} + 3.7718 \times 10^{-2})(\text{cm}^3/\text{atm-s})\ (1.0 - 0.01)(\text{atm})\ (0.505 / 1.0),$$
$$= (4.6686 \times 10^{-1})(\text{cm}^3/\text{atm-s})\ (0.49995)(\text{atm}),$$
$$= 2.3341 \times 10^{-1}\ \text{cm}^3/\text{s}.$$

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

$$L_{RA,He} = 2.3341 \times 10^{-1}\ \text{cm}^3/\text{s}. \qquad \text{(HAC helium test value)}$$

Determination of the Leakage Test Procedure Requirements for the HEU Content Transported by Air

The International Atomic Energy Agency (IAEA) TS-R-1, Paragraph 619, states: "Packages containing radioactive material, to be transported by air, shall be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than the maximum normal operating pressure plus 95 kPa." As shown in Table 2.20, the maximum normal operating pressure (MNOP) was predicted to be 31.25 psia. As shown in Appendix 3.5.1, Table 9, the MNOP determined for air transport is 28.778 psia and is bounded by the value determined for ground transportation. Therefore, the MNOP of 31.25 psia is used in the following analysis. To provide the necessary pressure differential, the following calculations will use an upstream pressure of 45.03 psia and a downstream pressure of 0 psia. Also, the following calculations will examine the most conservative effects of a fully loaded containment vessel with an HEU mass of 35.2 kg. The smallest allowable leakage values are shown in Tables 4.5 and 4.7. The A_2 value and the maximum content activity-to-A_2 value ratio for this mixture were calculated for several different decay times (Table 6, Appendix 4.5.1). As calculated in Appendix 4.5.1, the A_2 value and the maximum content activity-to-A_2 ratio used to qualify this package occur at ~70 years of decay and are 1.5245×10^{-4} TBq (4.1203×10^{-3} Ci) and 4,752.8, respectively. These values are used to determine the leakage test procedural requirements when packaging any convenience cans/contents arrangements in the ES-3100 package. The convenience cans/contents are sealed inside the containment vessel in an environmentally controlled area.

The following analysis determines the maximum allowable O-ring seal air reference leakage rate for NCT during air transport. 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 (*CRC Handbook of Chemistry and Physics*) and helium (NBS Technical Note 631). To also comply with 49 CFR 173.410(i)(2), the range of temperature evaluated will be from −40 to 55°C (ambient temperature). According to TS-G-1.1, Paragraph 619.3, the evaluation at an ambient temperature of 55°C does not consider insolation; however, self-heating of the package is taken into account. An analysis has been conducted, and results for these conditions are shown in Table 3.14. The maximum temperature predicted for the containment vessel was 63.39°C (146.11°F). This temperature will be used in the following analysis as the maximum gas temperature (T_{NL}).

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

$$L_N = 2.2878 \times 10^{-4} \text{ cm}^3/\text{s},$$
$$L_A = 1.3578 \text{ cm}^3/\text{s}.$$

Find the maximum pressure and a temperature in the containment vessel from -40 to 55°C:

Converting the temperature to Kelvin:

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

T_{NL} = 273.15 + 5 / 9 (−40°F − 32) (K), [T = −40°F (−40°C)]
= 233.15 K, (NCT low limit)

T_{NH} = 273.15 + 5 / 9 (146.11°F − 32) (K), [T = 146.11°F (63.39°C)]
= 336.54 K, (NCT high limit)

Converting the pressures from psia to atmospheres:

P_N = P (psia) / 14.696 (psia/atm), [where P is the pressure in Sect. 3.3.2 plus 13.78 psia (95 kPa)]
= 45.03 (psia) / 14.696 (psia/atm), (rounded up for NCT)
= 3.0641 atm,

NCT Leakage Hole Diameter for the HEU Content during Air Transport at the Lower Temperature Limit of TS-G-1.1

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 as dictated for air transport.

Input data for NCT at the lower temperature limit with air fill gas:

L_N = 2.2878×10^{-4} cm^3/s, (Maximum upstream leakage)
P_u = 3.0641 atm, (Upstream pressure = 45.03 psia)
P_d = 0 atm, [Downstream pressure = 0 psia, per 10 CFR 71.71(3)]
a = 0.3531 cm, (Leak path length, 0.139-in. O-ring section diameter)
T = 233.15 K, (Fill gas temperature = −40°F)
μ = 0.01518 cP, (Viscosity at temperature)
M = 29 g/g-mol. (Molecular weight of fill gas)

The average pressure is:

P_a = $(P_u + P_d) / 2$,
= $(3.0641 + 0) / 2$,
= 1.5320 atm. (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 = $P_u L_u$, (Eq. B1)
L_u = L_N, (NCT leakage)

Q = $(3.0641)(atm)\ (2.2878 \times 10^{-4})(cm^3/s)$,
= 7.0100×10^{-4} $atm\text{-}cm^3/s$, (NCT mass-like leakage rate)

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

$L_a = Q / P_a$,
$= 7.0099 \times 10^{-4}$ (atm-cm^3/s) / (1.5320) (atm),
$= 4.5755 \times 10^{-4}$ cm^3/s. (NCT 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)
$= (F_c + F_m) (3.0641 - 0.0000)$,
$= (3.0641) (F_c + F_m)$ cm^3/s,

$F_c = (2.49 \times 10^6) D^4 / (a \mu)$ (cm^3/atm-s), (Eq. B3)
$= (2.49 \times 10^6) D^4 / [(0.3531) (0.01518)]$,
$= (4.6459 \times 10^8) D^4$ cm^3/atm-s,

$F_m = (3.81 \times 10^3) D^3 (T / M)^{.5} / (a P_a)$ (cm^3/atm-s), (Eq. B4)
$= (3.81 \times 10^3) D^3 (233.15 / 29)^{.5} / [(0.3531) (1.5320)]$,
$= (1.9972 \times 10^4) D^3$ cm^3/atm-s.

From the mass-like leakage calculation:

$L_a = 4.5755 \times 10^{-4}$ cm^3/s. (NCT average leakage rate)

Find the leakage hole diameter that sets:

$L_2 = L_a$.

Using the equations:

$L_2 = (3.0641) (F_c + F_m)$ cm^3/s,
$F_c = (4.6469 \times 10^8) D^4$ cm^3/atm-s,
$F_m = (1.9972 \times 10^4) D^3$ cm^3/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 NCT:

D_2 = 0.001 cm, and solve for $L_a = 4.5755 \times 10^{-4}$ cm^3/s. (NCT average leakage rate)

Diameter	**F_c**	**F_m**	**L_2**	**L_a / L_2**
1.0000E-03	4.6459E-04	1.9972E-05	1.4847E-03	3.0817E-01
7.4332E-04	1.4183E-04	8.2025E-06	4.5971E-04	9.9530E-01
7.4243E-04	1.4116E-04	8.1733E-06	4.5756E-04	9.9997E-01
7.4243E-04	1.4115E-04	8.1731E-06	4.5755E-04	1.0000E+00

The NCT leakage hole diameter for the HEU oxide content:

$D = 7.4243 \times 10^{-4}$ cm. (NCT diameter)

NCT Reference Air Leakage Rate for HEU Content Transported by Air

The leakage hole diameter found for the maximum allowable leakage rate for NCT will be used to determine the reference air leakage rate. O-ring seal leakage testing must ensure that no leakage is greater than the leakage generated by the hole diameter $D = 7.4243 \times 10^{-4}$ cm. Therefore, the NCT reference leakage flow rate ($L_{R,N}$) must be calculated to determine the allowable test leakage rate.

Input data for NCT reference air leakage rate:

$D = 7.4243 \times 10^{-4}$ cm, (From NCT)
$a = 0.3531$ 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-mol, (Molecular weight of air)
$\mu = 0.0185$ cP, (Viscosity of air at reference temperature)

Calculate P_a:

$P_a = (P_u + P_d) / 2,$
$= (1.0 + 0.01) /2,$
$= 0.505$ atm, (NCT average pressure)

$F_c = (2.49 \times 10^6) D^4 / (a \mu)$ (cm^3/atm-s), (Eq. B3)
$= (2.49 \times 10^6) (7.4243 \times 10^{-4})^4 / [(0.3531) (0.0185)],$
$= (3.8122 \times 10^8) (7.4243 \times 10^{-4})^4,$
$= 1.1583 \times 10^{-4}$ cm^3/atm-s,

$F_m = (3.81 \times 10^3) D^3 (T / M)^{.5} / (a P_a)$ (cm^3/atm-s), (Eq. B4)
$= (3.81 \times 10^3) (7.4243 \times 10^{-4})^3 (298 / 29)^{.5} / [(0.3531) (0.505)],$
$= (6.8501 \times 10^4) (7.4243 \times 10^{-4})^3,$
$= 2.8033 \times 10^{-5}$ cm^3/atm-s,

$L_u = (F_c + F_m) (P_u - P_d) (P_a / P_u)$ (cm^3/s), (Eq. B5)
$= (1.1583 \times 10^{-4} + 2.8033 \times 10^{-5})$ (cm^3/atm-s) $(1.0 - 0.01)$ (atm) $(0.505 / 1.0),$
$= (1.4386 \times 10^{-4})$ (cm^3/atm-s) (0.49995) (atm),
$= 7.1922 \times 10^{-5}$ cm^3/s.

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

$L_{RN,Air} = 7.1922 \times 10^{-5}$ ref-cm^3/s. (For HEU oxide content)

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

$M = 4$ g/g-mol, (Molecular weight of helium)
$\mu = 0.0198$ cP, (Viscosity of helium at temperature)

$F_c = (2.49 \times 10^6)\, D^4 / (a\, \mu)$ (cm^3/atm-s), (Eq. B3)
$= (2.49 \times 10^6)\, (7.4243 \times 10^{-4})^4 / [(0.3531)\, (0.0198)]$,
$= (3.5619 \times 10^8)\, (7.4243 \times 10^{-4})^4$,
$= 1.0822 \times 10^{-4}$ cm^3/atm-s,

$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{.5} / (a\, P_a)$ (cm^3/atm-s), (Eq. B4)
$= (3.81 \times 10^3)\, (7.4243 \times 10^{-4})^3\, (298 / 4)^{.5} / [(0.3531)\, (0.505)]$,
$= (1.8444 \times 10^5)\, (7.4243 \times 10^{-4})^3$,
$= 7.5480 \times 10^{-5}$ cm^3/atm-s,

$L_u = (F_c + F_m)\, (P_u - P_d)\, (P_a / P_u)$ (cm^3/s), (Eq. B5)
$= (1.0822 \times 10^{-4} + 7.5480 \times 10^{-5})$ (cm^3/atm-s) $(1.0 - 0.01)$ (atm) $(0.505 / 1.0)$,
$= (1.8379 \times 10^{-4})$ (cm^3/atm-s) (0.49995) (atm),
$= 9.1841 \times 10^{-5}$ cm^3/s.

The allowable leakage rate using helium for leak testing is:

$L_{RN,\,He} = 9.1841 \times 10^{-5}$ cm^3/s.

NCT Leakage Hole Diameter for the HEU Content during Air Transport at the Upper Temperature Limit [146.11°F (63.39°C)] per TS-G-1.1

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 at the upper temperature limit with air fill gas:

$L_N = 2.2878 \times 10^{-4}$ cm^3/s, (Maximum upstream leakage)
$P_u = 3.0641$ atm, (Upstream pressure = 45.03 psia)
$P_d = 0$ atm, [Downstream pressure = 0 psia, per 10 CFR 71.71(3)]
$a = 0.3531$ cm, (Leak path length, 0.139-in. O-ring section diameter)
$T = 336.54$ K, [Fill gas temperature = 146.11°F (63.39°C)]
$\mu = 0.02031$ cP, (Viscosity at temperature)
$M = 29$ g/g-mol. (Molecular weight of fill gas)

The average pressure is:

$P_a = (P_u + P_d) / 2$,
$= (3.0641 + 0.0000) / 2$,
$= 1.5320$ atm. (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:

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

$$Q = (3.0641)\ (\text{atm})\ (2.2878 \times 10^{-4})\ (\text{cm}^3/\text{s}),$$
$$= 7.0099 \times 10^{-4}\ \text{atm-cm}^3/\text{s}, \quad \text{(NCT mass-like leakage rate)}$$

$$Q = P_a L_a, \quad \text{(Eq. B1)}$$

$$L_a = Q / P_a,$$
$$= 7.0099 \times 10^{-4}\ (\text{atm-cm}^3/\text{s}) / (1.5320)\ (\text{atm}),$$
$$= 4.5755 \times 10^{-4}\ \text{cm}^3/\text{s}. \quad \text{(NCT average leakage rate)}$$

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

$$L_a = (F_c + F_m)\ (P_u - P_d)\ \text{cm}^3/\text{s}, \quad \text{(Eq. B2)}$$
$$= (F_c + F_m)\ (3.0641 - 0),$$
$$= (3.0641)\ (F_c + F_m)\ \text{cm}^3/\text{s},$$

$$F_c = (2.49 \times 10^6)\ D^4 / (a\ \mu)\ (\text{cm}^3/\text{atm-s}), \quad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\ D^4 / [(0.3531)\ (0.02031)],$$
$$= (3.4723 \times 10^8)\ D^4\ \text{cm}^3/\text{atm-s},$$

$$F_m = (3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)\ (\text{cm}^3/\text{atm-s}), \quad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\ D^3\ (336.54 / 29)^{.5} / [(0.3531)\ (1.5320)],$$
$$= (2.3995 \times 10^4)\ D^3\ \text{cm}^3/\text{atm-s}.$$

From the mass-like leakage calculation:

$$L_a = 4.5755 \times 10^{-4}\ \text{cm}^3/\text{s}. \quad \text{(NCT average leakage rate)}$$

Find the leakage hole diameter that sets:

$$L_2 = L_a.$$

Using the equations:

$$L_2 = (3.0641)\ (F_c + F_m)\ \text{cm}^3/\text{s},$$
$$F_c = (3.4723 \times 10^8)\ D^4\ \text{cm}^3/\text{atm-s},$$
$$F_m = (2.3995 \times 10^4)\ D^3\ \text{cm}^3/\text{atm-s}.$$

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 NCT:

D_2 = 0.001 cm, and solve for $L_a = 4.5755 \times 10^{-4}$ cm^3/s. (NCT average leakage rate)

Diameter	F_c	F_m	L_2	L_a / L_2
1.0000E-03	3.4723E-04	2.3995E-05	1.1375E-03	4.0225E-01
7.9494E-04	1.3866E-04	1.2054E-05	4.6180E-04	9.9079E-01
7.9309E-04	1.3737E-04	1.1970E-05	4.5760E-04	9.9989E-01
7.9307E-04	1.3736E-04	1.1969E-05	4.5755E-04	1.0000E+00

The NCT leakage hole diameter for the HEU oxide content:

$D = 7.9307 \times 10^{-4}$ cm. (NCT diameter)

NCT Reference Air Leakage Rate for HEU Content Transported by Air

The leakage hole diameter found for the maximum allowable leakage rate for NCT will be used to determine the reference air leakage rate. O-ring seal leakage testing must ensure that no leakage is greater than the leakage generated by the hole diameter $D = 7.9307 \times 10^{-4}$ cm. Therefore, the NCT reference leakage flow rate ($L_{R,N}$) must be calculated to determine the allowable test leakage rate.

Input data for NCT reference air leakage rate:

$D = 7.9307 \times 10^{-4}$ cm, (From NCT)
$a = 0.3531$ 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-mol, (Molecular weight of air)
$\mu = 0.0185$ cP, (Viscosity of air at reference temperature)

Calculate P_a:

$P_a = (P_u + P_d) / 2$,
$= (1.0 + 0.01) /2$,
$= 0.505$ atm, (NCT average pressure)

$F_c = (2.49 \times 10^6) D^4 / (a \mu)$ (cm^3/atm-s), (Eq. B3)
$= (2.49 \times 10^6) (7.9307 \times 10^{-4})^4 / [(0.3531) (0.0185)]$,
$= (3.8122 \times 10^8) (7.9307 \times 10^{-4})^4$,
$= 1.5080 \times 10^{-4}$ cm^3/atm-s,

$F_m = (3.81 \times 10^3) D^3 (T / M)^{.5} / (a P_a)$ (cm^3/atm-s), (Eq. B4)
$= (3.81 \times 10^3) (7.8970 \times 10^{-4})^3 (298 / 29)^{.5} / [(0.3531) (0.505)]$,
$= (6.8501 \times 10^4) (7.8970 \times 10^{-4})^3$,
$= 3.4168 \times 10^{-5}$ cm^3/atm-s,

$$L_u = (F_c + F_m)(P_u - P_d)(P_a / P_u)\ (cm^3/s), \quad \text{(Eq. B5)}$$
$$= (1.5080 \times 10^{-4} + 3.4168 \times 10^{-5})\ (cm^3/atm\text{-}s)\ (1.0 - 0.01)\ (atm)\ (0.505 / 1.0),$$
$$= (1.8497 \times 10^{-4})\ (cm^3/atm\text{-}s)\ (0.49995)\ (atm),$$
$$= 9.2475 \times 10^{-5}\ cm^3/s.$$

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

$$L_{RN,Air} = 9.2475 \times 10^{-5}\ ref\text{-}cm^3/s. \quad \text{(For HEU oxide content)}$$

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

$$M = 4\ g/g\text{-}mol, \quad \text{(Molecular weight of helium)}$$
$$\mu = 0.0198\ cP, \quad \text{(Viscosity of helium at temperature)}$$

$$F_c = (2.49 \times 10^6)\ D^4 / (a\ \mu)\ (cm^3/atm\text{-}s), \quad \text{(Eq. B3)}$$
$$= (2.49 \times 10^6)\ (7.9307 \times 10^{-4})^4 / [(0.3531)\ (0.0198)],$$
$$= (3.5619 \times 10^8)\ (7.9307 \times 10^{-4})^4,$$
$$= 1.4090 \times 10^{-4}\ cm^3/atm\text{-}s,$$

$$F_m = (3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)\ (cm^3/atm\text{-}s), \quad \text{(Eq. B4)}$$
$$= (3.81 \times 10^3)\ (7.9307 \times 10^{-4})^3\ (298 / 4)^{.5} / [(0.3531)\ (0.505)],$$
$$= (1.8444 \times 10^5)\ (7.9307 \times 10^{-4})^3,$$
$$= 9.2000 \times 10^{-5}\ cm^3/atm\text{-}s,$$

$$L_u = (F_c + F_m)(P_u - P_d)(P_a / P_u)\ (cm^3/s), \quad \text{(Eq. B5)}$$
$$= (1.4090 \times 10^{-4} + 9.2000 \times 10^{-5})\ (cm^3/atm\text{-}s)\ (1.0 - 0.01)\ (atm)\ (0.505 / 1.0),$$
$$= (2.3290 \times 10^{-4})\ (cm^3/atm\text{-}s)\ (0.49995)\ (atm),$$
$$= 1.1644 \times 10^{-4}\ cm^3/s.$$

The allowable leakage rate using helium for leak testing is:

$$L_{RN,He} = 1.1644 \times 10^{-4}\ cm^3/s.$$

The design verification tests were conducted following compliance tests in accordance with 10 CFR 71.71 and 71.73. The effectiveness of this closure system has been demonstrated by the NCT and HAC tests, which show that the complete containment system, including welds and O-ring seals, meet the leaktight criterion as defined in ANSI N14.5-1997 after the conclusion of the test series documented in ORNL/NTRC-013. This leaktight criterion is substantially below the above calculated results for air transport. Therefore, the requirements of 10 CFR Part 71.51(a)(1) are satisfied.

SECTION 4 REFERENCES

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5. SHIELDING EVALUATION

This section describes the shielding evaluation performed for the shipment of up to 36 kg of highly enriched uranium (HEU) metal or 24 kg of HEU oxide powder in the ES-3100 shipping package. The objective of this evaluation is to demonstrate—for both normal conditions of transport (NCT) and hypothetical accident conditions (HAC)—compliance of this package with the performance requirements specified in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] and U.S. Department of Transportation (DOT) regulations for packaging and shipment of hazardous materials given in Title 49 CFR.

5.1 DESCRIPTION OF SHIELDING DESIGN

5.1.1 Design Features

The ES-3100 package for NCT consists of stainless-steel convenience cans loaded with HEU material, can spacer assemblies to support and position the convenience cans, the ES-3100 containment vessel (CV), and an insulation-filled drum as shown in Appendix 1.3.1. None of the package materials are specifically designed for shielding gamma rays (photons), the primary contributor to external package dose rates for the specified source configurations. For NCT and HAC shielding calculations, the packing materials inside the CV are conservatively not modeled. It is assumed that the CV remains intact during HAC, but all the packaging materials external to the CV are removed. The geometry of the shielding analysis model is a conservative, cylindrical representation of the package.

Two sets of contents have been investigated for the shielding analysis. These are 36 kg of HEU metal and 24 kg of HEU oxide powder. The analyses of these models have been performed such that the results and conclusions cover other proposed contents in an equivalent or conservative manner. For the source calculation, the uranium is enriched at 92 wt % ^{235}U and is assumed to contain 0.6 wt % ^{233}U, 2.0 wt % ^{234}U, 1.0 wt % ^{236}U, 4.4 wt % ^{238}U, 2.5 wt % ^{237}Np, 40 parts per billion (ppb) ^{232}U, and 800 parts per million (ppm) weapons-grade plutonium to represent all other transuranic trace elements. The value of 800 ppm weapons-grade plutonium applies to ground transport only. Contents for air transport are limited to 40 ppm weapons-grade plutonium. There are two sources of the transuranic contamination in this HEU. First, much of this uranium originated from recycled material. Second, some uranium had plutonium components removed by machining or other processes, but left contamination. This contamination became mixed with the uranium as it was recast and used for other purposes.

5.1.2 Summary Table of Maximum Radiation Levels

The results of the shielding model evaluations, summarized in Tables 5.1 and 5.2, are the calculated dose rates at the locations indicated for the uranium metal and uranium oxide contents. These dose rates are based on the conservative assumption there is no packaging material except the content inside the CV. The side dose rates in Table 5.1 for the HEU metal content are maximized by assuming the content in the hemi-shell configuration. The top and bottom dose rates for the HEU metal content are maximized by assuming the content in the form of a cylinder at the top or at the bottom of the CV, respectively. For the HEU oxide content, the side drum surface photon dose rate presented in Table 5.2 is from the solid cylindrical configuration of 47.365 cm height and density of 4.0 g/cm^3. The 1 m from the side surface photon dose rates for the NCT and HAC are from the cylindrical shell configuration of 2.6275 cm inner radius, 6.35 cm outer radius, 76.2 cm height, and density of 3.0 g/cm^3. The neutron side dose rates are from the solid cylinder at the top of the CV configuration with a density of 10.96 g/cm^3. The top and bottom dose rates are from the cylinder type configuration with a density of 10.96 g/cm^3 at the top and bottom of the CV configurations, respectively. The uncertainty associated with the results is one standard deviation of the mean (i.e., one sigma uncertainty expressed as a percentage of the mean) calculated using the MCNP Monte Carlo code (LA-UR-03-1987). The shielding evaluation demonstrates the package with HEU metal or HEU oxide content meets all dose-rate limits as specified in 10 CFR 71.47(a) and 49 CFR 173.441(a) for NCT and 10 CFR 71.51(a)(2) for HAC, as shown by the dose rates in Tables 5.1 and 5.2 and the information in Sect. 5.3. The maximum radiation level at the package surface is measured when it is presented for transport. The maximum radiation level at 1 m from the external surface will also be measured to establish the transport index (TI) for the package. The calculated TI values are 6.2 and 5.1 for the HEU metal and HEU oxide contents, respectively. The measured dose rates are expected to be much lower than the calculated dose rates due to conservatism and bounding nature of the calculations. The measured radiation levels are evaluated against the allowable radiation levels prescribed in 10 CFR 71.47 and 49 CFR 173.441.

5.2 SOURCE SPECIFICATION

The principal source for the calculated dose rates is the decay of the radioactive isotopes. There is also neutron and photon production from spontaneous and neutron-induced fissions, secondary photon generation, and [alpha (α), n] reactions in trace element impurities. The isotopic content used in the shielding calculations is shown in Table 5.3. ^{237}Np and transuranic (2.58 wt % combined in Table 5.3) are conservatively added to the source term without increasing the content mass. A trace amount of ^{232}U (40 ppb), which significantly increases the dose rate, is also added to the source term. This composition was chosen to represent all proposed package contents described in Sect. 1.2.2. The uranium metal source is assumed to be the same as that for the oxides per unit HEU mass. Details of the source specifications and their use in the dose-rate calculations are provided in Appendix 5.5.1.

Table 5.1. Calculated external dose rates for the ES-3100 package with 36 kg of HEU metal contents

mSv/h (mrem/h) with ± one sigma uncertainty (%) [a, b]

	Drum surface			One meter from surface [c]		
	Side	**Top**	**Bottom**	**Side**	**Top**	**Bottom**
			NCT			
Photon	0.9580 (95.80) ± 1.47%	0.2304 (23.04) ± 0.99%	0.8000 (80.00) ± 0.64%	0.06064 (6.064) ± 0.06%	0.00672 (0.672) ± 0.15%	0.01434 (1.434) ± 0.15%
Neutron [d]	0.0158 (1.58) ± 0.32%	0.0133 (1.33) ± 0.35%	0.0204 (2.04) ± 0.36%	0.00057 (0.057) ± 0.19%	0.00038 (0.038) ± 0.19%	0.00042 (0.042) ± 0.15%
Total	0.9738 (97.38) ± 1.45%	0.2437 (24.37) ± 0.94%	0.8204 (82.04) ± 0.62%	0.06121 (6.121) ± 0.06% [e]	0.00710 (0.710) ± 0.14%	0.01476 (1.476) ± 0.15%
Limit [f]	2 (200)	2 (200)	2 (200)	0.1 (10)	0.1 (10)	0.1 (10)
			HAC			
Photon	NA [g]	NA	NA	0.12906 (12.906) ± 0.04%	0.01008 (1.008) ± 0.13%	0.02044 (2.044) ± 0.30%
Neutron [d]	NA	NA	NA	0.00036 (0.036) ± 0.19%	0.00020 (0.020) ±0.03%	0.00022 (0.022) ± 0.03%
Total	NA	NA	NA	0.12942 (12.942) ± 0.04%	0.01028 (1.028) ± 0.13%	0.02066 (2.066) ± 0.30%
Limit [h]	NA	NA	NA	10 (1000)	10 (1000)	10 (1000)

[a] Side photon and neutron dose rates are from the cylindrical hemi-shell and solid cylinder at the top configurations, respectively. The top and bottom dose rates are from the cylinder-type configurations at the top and bottom of the CV, respectively.

[b] MCNP5 Monte Carlo code results (LA-UR-03-1987). The uncertainty associated with the results is one standard deviation of the mean (i.e., one sigma uncertainty expressed as a percentage of the mean) calculated using MCNP5.

[c] One meter from the drum for NCT and one meter from the CV for HAC.

[d] Includes secondary photon dose rate (<1% of neutron dose rates).

[e] The radiation shielding transport index is 6.2.

[f] Nonexclusive use radiation dose limit in accordance with 10 CFR 71.47(a) and 49 CFR 173.441(a).

[g] Not applicable.

[h] Radiation dose limit in accordance with 10 CFR 71.51(a)(2).

Table 5.2. Calculated external dose rates for the ES-3100 package with 24 kg of HEU oxide contents

mSv/h (mrem/h) with ± one sigma uncertainty (%) [a, b]

	Drum surface			One meter from surface [c]		
	Side	**Top**	**Bottom**	**Side [c]**	**Top**	**Bottom**
			NCT			
Photon	0.7972 (79.72) ± 1.80%	0.2015 (20.15) ± 0.92%	0.7062 (70.62) ± 1.29%	0.05019 (5.019) ± 0.16%	0.00610 (0.610) ± 0.12 %	0.01319 (1.319) ± 0.09%
Neutron [d]	0.0015 (0.15) ± 0.46%	0.0011 (0.11) ± 0.91%	0.0022 (0.22) ± 0.31%	0.00005 (0.005) ± 0.04%	0.00003 (0.003) ± 0.05%	0.00005 (0.005) ± 0.04%
Total	0.7987 (79.87) ± 1.80%	0.2026 (20.26) ± 0.91%	0.7084 (70.84) ± 1.29%	0.05024 (5.024) ± 0.16% [e]	0.00613 (0.613) ± 0.12%	0.01324 (1.324) ± 0.09%
Limit [f]	2 (200)	2 (200)	2 (200)	0.1 (10)	0.1 (10)	0.1 (10)
			HAC			
Photon	NA [g]	NA	NA	0.10687 (10.687) ± 0.03%	0.00907 (0.907) ± 0.15%	0.01862 (1.862) ± 0.09%
Neutron [d]	NA	NA	NA	0.00004 (0.004) ± 0.01%	0.00003 (0.003) ± 0.02%	0.00004 (0.004) ± 0.02%
Total	NA	NA	NA	0.10691 (10.691) ± 0.03%	0.00910 (0.910) ± 0.15%	0.01866 (1.866) ± 0.09%
Limit [h]	NA	NA	NA	10 (1000)	10 (1000)	10 (1000)

[a] Side drum surface photon dose rate is from the solid cylindrical configuration (height = 47.365 cm and density = 4.0 g/cm^3 sitting at the bottom of the CV). The 1 m from the side surface photon dose rates for the NCT and HAC are from the cylindrical shell configuration (inner radius = 2.6275 cm, outer radius = 6.35 cm, height = 76.2 cm, and density 3.0 g/cm^3). The neutron side dose rates are from the solid cylinder (density = 10.96 g/cm^3) at the top of the CV configuration. The top and bottom photon and neutron dose rates are from the cylinder-type configurations (density = 10.96 g/cm^3) at the top and bottom of the CV, respectively.

[b] MCNP5 Monte Carlo code results (LA-UR-03-1987). The uncertainty associated with the results is one standard deviation of the mean (i.e., one sigma uncertainty expressed as a percentage of the mean) calculated using MCNP5.

[c] One meter from the drum for NCT and one meter from the CV for HAC.

[d] Includes secondary photon dose rate (<1% of neutron dose rates).

[e] The radiation shielding transport index is 5.1.

[f] Nonexclusive use radiation dose limit in accordance with 10 CFR 71.47(a) and 49 CFR 173.441(a).

[g] Not applicable.

[h] Radiation dose limit in accordance with 10 CFR 71.51(a)(2).

Table 5.3. Radioisotope composition for all ES-3100 package analysis source calculations with HEU content and other nuclides per HEU unit weight

Isotope	wt % [a]
^{232}U	0.000004
^{233}U	0.600000
^{234}U	2.000000
^{235}U	92.000000
^{236}U	1.000000
^{238}U	4.399996
^{237}Np	2.500000
Transuranic [b]	0.080000
Total	102.58

[a] ^{237}Np and transuranic are added to the uranium source composition without adding their weights in the source mass calculations.

[b] The transuranic contents are: 1.60×10^{-5} wt % ^{238}Pu, 7.41×10^{-2} wt % ^{239}Pu, 5.20×10^{-3} wt % ^{240}Pu, 4.48×10^{-4} wt % ^{241}Pu, 3.20×10^{-5} wt % ^{242}Pu, and 2.40×10^{-4} wt % ^{241}Am. ^{237}Np and transuranic are added to the uranium source composition without adding their weights.

5.2.1 Gamma Source

The photon source is calculated by the Standardized Computer Analysis for Licensing Evaluation (SCALE) module of ORIGEN-S (NUREG/CR-0200, Vol. II, Sect. F7) as a function of the 47 energy group photon spectrum and decay time. Additional information about ORIGEN-S methodology and input is available in Appendix 5.5.1. It is shown that the photon spectrum around 10.5 years decay time provides maximum photon dose rates, and the spectra are given in Table 5.4. Figure 5.1 shows the photon spectrum for ^{232}U and the total source composition including ^{232}U. In Table 5.4, the photon source for the 38^{th} energy group (2.6 – 2.7 MeV) is 1.062×10^4 photons/s/g. Figure 5.1 shows that this photon source comes from ^{232}U and this phenomenon is a result of the ^{232}U daughter product (i.e., ^{208}Tl) decaying to ^{208}Pb. This 38^{th} energy group photon source contributes most of the calculated photon dose rates presented in Tables 5.1 and 5.2. The photon spectrum computed by ORIGEN-S includes photons arising from X-rays, gamma-rays, internal bremsstrahlung, spontaneous fission gamma-rays, and gamma-ray accompanying (α, n) reactions.

Table 5.4. Photon source for 1 g of HEU for all contents

Group number	Energy range (MeV)	Source [a] (photons/s)
1	0.005–0.010	$8.515 \times 10^{+4}$
2	0.010–0.015	$1.700 \times 10^{+6}$
3	0.015–0.020	$7.313 \times 10^{+3}$
4	0.020–0.025	$3.595 \times 10^{+3}$
5	0.025–0.030	$1.230 \times 10^{+5}$
6	0.030–0.040	$5.112 \times 10^{+3}$
7	0.040–0.050	$6.605 \times 10^{+3}$
8	0.050–0.060	$2.147 \times 10^{+5}$
9	0.060–0.070	$1.779 \times 10^{+3}$
10	0.070–0.080	$1.941 \times 10^{+4}$
11	0.080–0.090	$1.085 \times 10^{+5}$
12	0.090–0.100	$2.244 \times 10^{+5}$
13	0.100–0.200	$1.328 \times 10^{+5}$
14	0.200–0.300	$5.245 \times 10^{+4}$
15	0.300–0.400	$2.819 \times 10^{+5}$
16	0.400–0.500	$1.556 \times 10^{+4}$
17	0.500–0.600	$1.225 \times 10^{+4}$
18	0.600–0.700	$1.485 \times 10^{+2}$
19	0.700–0.800	$2.705 \times 10^{+3}$
20	0.800–0.900	$1.802 \times 10^{+3}$
21	0.900–1.000	$4.068 \times 10^{+2}$
22	1.000–1.100	$2.527 \times 10^{+2}$
23	1.100–1.200	$2.157 \times 10^{+1}$
24	1.200–1.300	$2.105 \times 10^{+1}$
25	1.300–1.400	$2.990 \times 10^{+1}$
26	1.400–1.500	$1.300 \times 10^{+1}$
27	1.500–1.600	$1.386 \times 10^{+2}$
28	1.600–1.700	$4.719 \times 10^{+2}$
29	1.700–1.800	$5.522 \times 10^{+0}$
30	1.800–1.900	$2.999 \times 10^{+1}$
31	1.900–2.000	$4.918 \times 10^{+0}$
32	2.000–2.100	1.599×10^{-2}
33	2.100–2.200	1.308×10^{-2}
34	2.200–2.300	7.152×10^{-2}
35	2.300–2.400	5.321×10^{-4}
36	2.400–2.500	1.584×10^{-2}
37	2.500–2.600	6.552×10^{-5}
38	2.600–2.700	$1.062 \times 10^{+4}$
39	2.700–2.800	1.108×10^{-2}
40	2.800–2.900	1.917×10^{-4}
41	2.900–3.000	3.408×10^{-4}
42	3.000–3.500	6.039×10^{-1}
43	3.500–4.000	3.876×10^{-1}
44	4.000–5.000	2.959×10^{-3}
45	5.000–6.500	1.134×10^{-3}
46	6.500–8.000	2.131×10^{-4}
47	8.000–10.00	4.388×10^{-5}
Total		**$3.011 \times 10^{+6}$**

[a] ORIGEN-S code results at 10.5 years decay (NUREG/CR-0200).

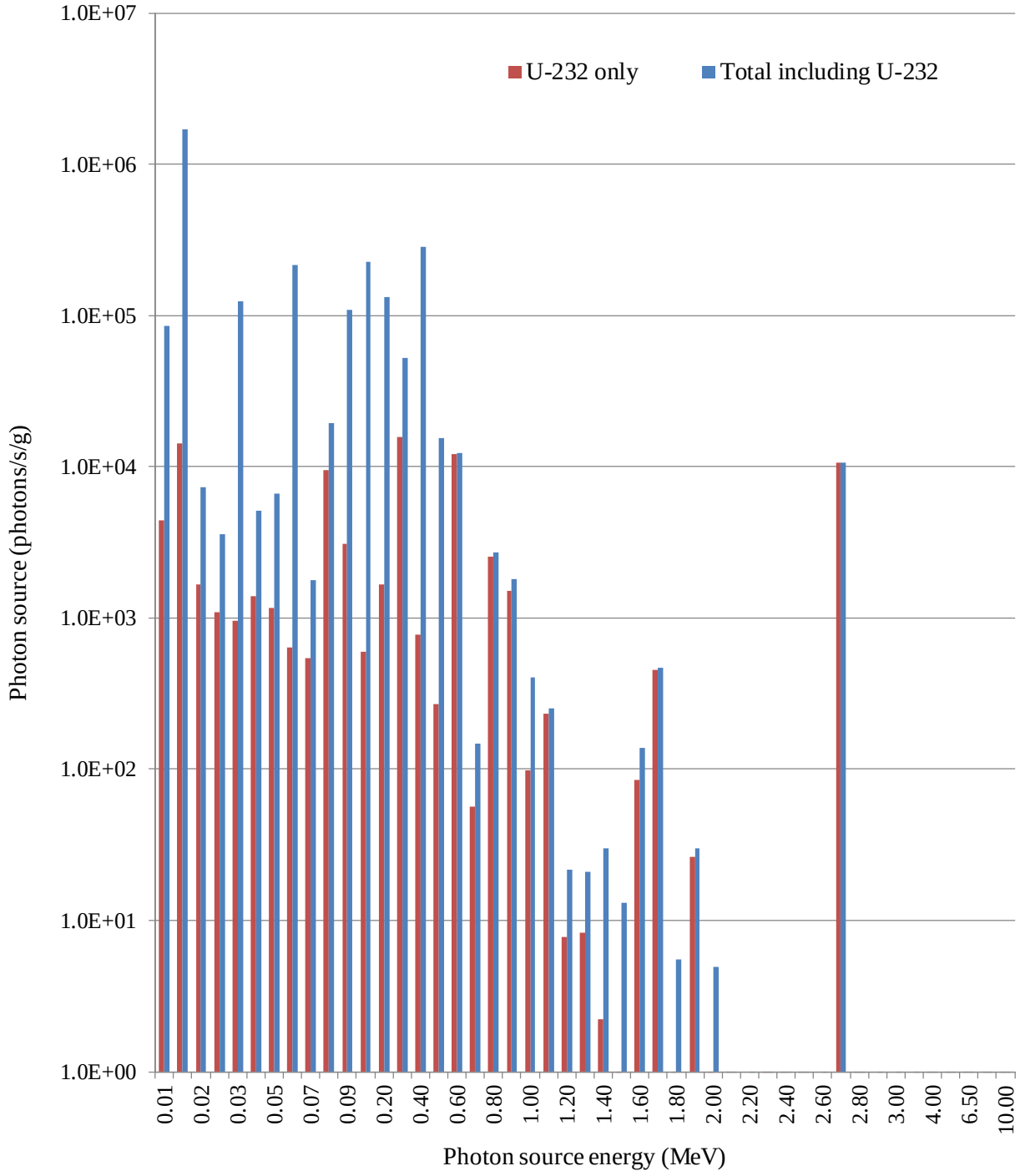


Fig. 5.1. Photon spectrum for ^{232}U only and HEU content including ^{232}U.

5.2.2 Neutron Source

The neutron source given in Table 5.5 is generated using ORIGEN-S as a function of the 27 energy group neutron spectrum and decay time. It is shown that the neutron spectrum around 50 years decay time provide maximum neutron dose rates. Figure 5.2 shows the neutron spectrum for different neutron source constituents. Figure 5.2 shows transuranic components contribute most of the neutron source spectrum, particularly at higher energy intervals. Neutron source from the spontaneous fission (α, n) and delayed neutrons are included in Table 5.5 spectrum. Induced fission neutrons and secondary photons are included in the dose rate calculations. Oxygen was not included in the uranium oxide source calculation, but the neutron source includes (α, n) neutrons from the UO_2 default option in the ORIGEN-S code (NUREG/CR-0200, Vol. II, Sect. F7). The production of neutrons from subcritical multiplication is calculated as part of the shielding evaluation by using the default option (i.e., no NONU card in the MCNP input file). If the NONU card is not used, all cells are given their regular treatment of real fission. The neutrons are captured by the fissile and fissionable materials producing neutron-induced fissions.

Table 5.5. Neutron source for 1 g of HEU for all contents

Group number	Energy range (MeV)	Source [a] (neutrons/s)
1–17	$1.00 \times 10^{-11} - 1.00 \times 10^{-4}$	0 [b]
18	$5.83 \times 10^{-4} - 3.04 \times 10^{-3}$	7.034×10^{-6}
19	$3.04 \times 10^{-3} - 1.50 \times 10^{-2}$	8.280×10^{-5}
20	$1.50 \times 10^{-2} - 1.11 \times 10^{-1}$	1.790×10^{-3}
21	$1.11 \times 10^{-1} - 4.08 \times 10^{-1}$	8.973×10^{-3}
22	$4.08 \times 10^{-1} - 9.07 \times 10^{-1}$	1.572×10^{-2}
23	$9.07 \times 10^{-1} - 1.42 \times 10^{+0}$	2.205×10^{-2}
24	$1.42 \times 10^{+0} - 1.83 \times 10^{+0}$	2.510×10^{-2}
25	$1.83 \times 10^{+0} - 3.01 \times 10^{+0}$	1.042×10^{-1}
26	$3.01 \times 10^{+0} - 6.38 \times 10^{+0}$	3.430×10^{-2}
27	$6.38 \times 10^{+0} - 2.00 \times 10^{+1}$	7.260×10^{-4}
Total		$\mathbf{2.129 \times 10^{-1}}$

[a] ORIGEN-S code results at 50 years decay (NUREG/CR-0200).
[b] Source is assumed to be zero for Groups 1–17 because of their low contributions.

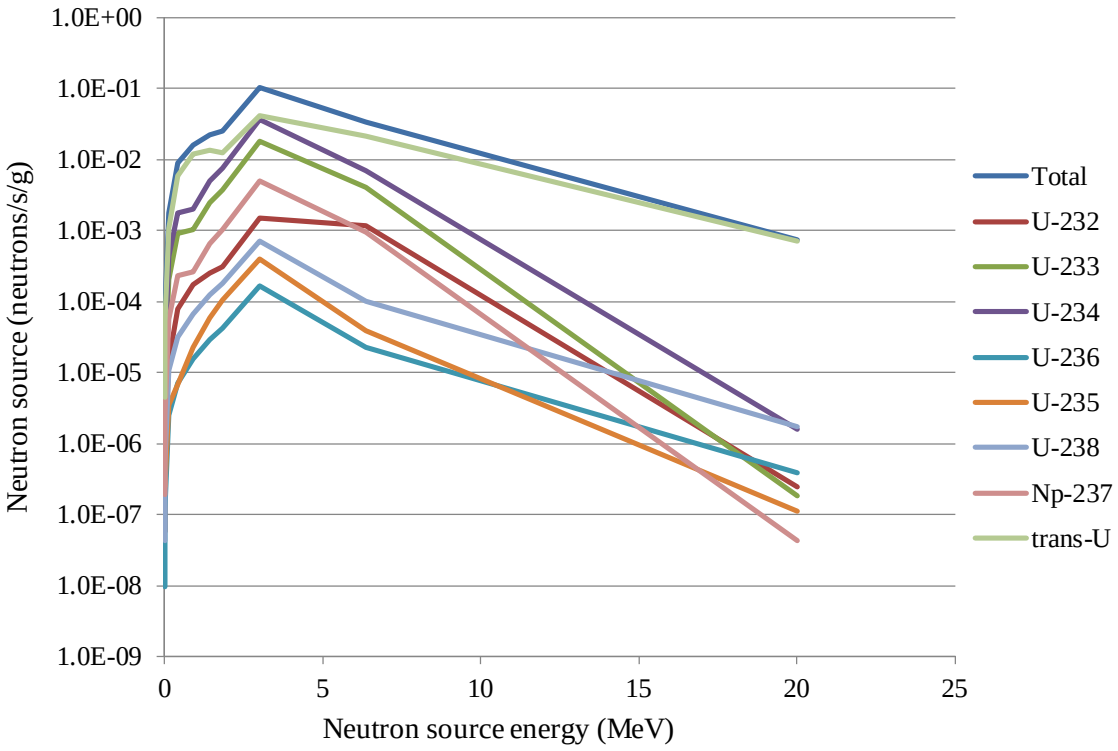


Fig. 5.2. Neutron spectrum for HEU source composition.

5.3 SHIELDING MODEL

The geometry of the shielding analysis model inside the CV is conservative because no packing materials besides the content are included in the model. The analyzed package contents are (a) 36 kg of HEU metal and (b) 24 kg of HEU oxide. The 36 kg of HEU metal analyzed are in the form of a solid cylinder, cylindrical shell, vertical plate, cylindrical hemi-shell, single solid rod, and cylindrical segment. The HEU metal in the form of a cylinder with the same radius as the CV is moved to the bottom and top of the CV for the maximum bottom and top dose rate configurations. The HEU metal in all configurations mentioned are analyzed for the maximum side dose rates. The 24 kg of HEU oxide powder analyzed are in cylindrical and cylindrical-shell forms of varying height and density. The material with maximum density in cylindrical shape and with the same radius as the CV is moved to the bottom and top of the CV for the maximum bottom and top dose rate configurations for the HEU oxide. The worst cases at the bottom, side, and top dose rates for the HEU metal and oxide are presented in Tables 5.1 and 5.2, and are assumed to bound any possible source configuration for the container.

Three-dimensional detailed geometric models are created to calculate the dose rates external to the ES-3100 shipping package when loaded with each of the configurations outlined in Sect. 5.3.1. Figure 5.3 presents the packaging without any content. The details of several sections of the packaging are shown in Figs. 5.4, 5.5, and 5.6. The shielding model of the ES-3100 package is represented in the MCNP Monte Carlo radiation transport code to perform the photon and neutron transport and dose rate calculations (LA-UR-03-1987) for these configurations. Dose rates are calculated in by converting the photon and neutron fluxes using the American National Standards Institute and American Nuclear Society conversion factors (ANSI/ANS-6.1.1).

5.3.1 Configuration of Source and Shielding

The photon and neutron sources from the radioactive contents described in the previous section and listed in Tables 5.4 and 5.5, are input to the MCNP code to calculate the ES-3100 external package dose rates given in Tables 5.1, 5.2, and 5.7.

The packaging component drawings are shown in Appendix 1.3.1. The package contents analyzed are (a) 36 kg of HEU metal and (b) 24 kg of HEU oxide. The analyses of these models have been performed in a manner covering all other proposed contents identified in Sect. 1.2.2 in an equivalent or conservative manner. Figure 5.7 shows the NCT and HAC calculation models in MCNP for cylinder type HEU metal source configuration. Figure 5.8 shows the NCT calculation model for UO_2 source configuration.

There are no radiation streaming paths from the source toward the package exterior. The models are analyzed for both photon and neutron sources, and for both NCT and HAC. Table 5.6 lists the locations of the external dose-rate detectors for the NCT and HAC models. For NCT, dose rates are calculated at detector locations that are identified by their distance from the external surface of the drum (0.1 cm and 1 m from the external surface of the drum). All components outside the CV are removed for HAC shielding models and the detector locations are modeled as if they were 1 m from the external surface of the CV. Additional information on the models is presented in Appendices. 5.5.1 and 5.5.2.

The dose rates presented in Tables 5.1 and 5.2 should bound the dose rates for all proposed content loadings in the ES-3100. In some cases, it is not possible or practical to find an exact maximum dose rate geometric configuration due to the statistical uncertainty of the calculation method, variations in model radius vs. height, variable densities, source configuration, etc. The presence of 800-ppm transuranic trace elements has no effect on the photon dose rates. Although it has significant effects on the neutron dose rates, the neutron dose rates constitute only 2.0% or less of the total dose rates.

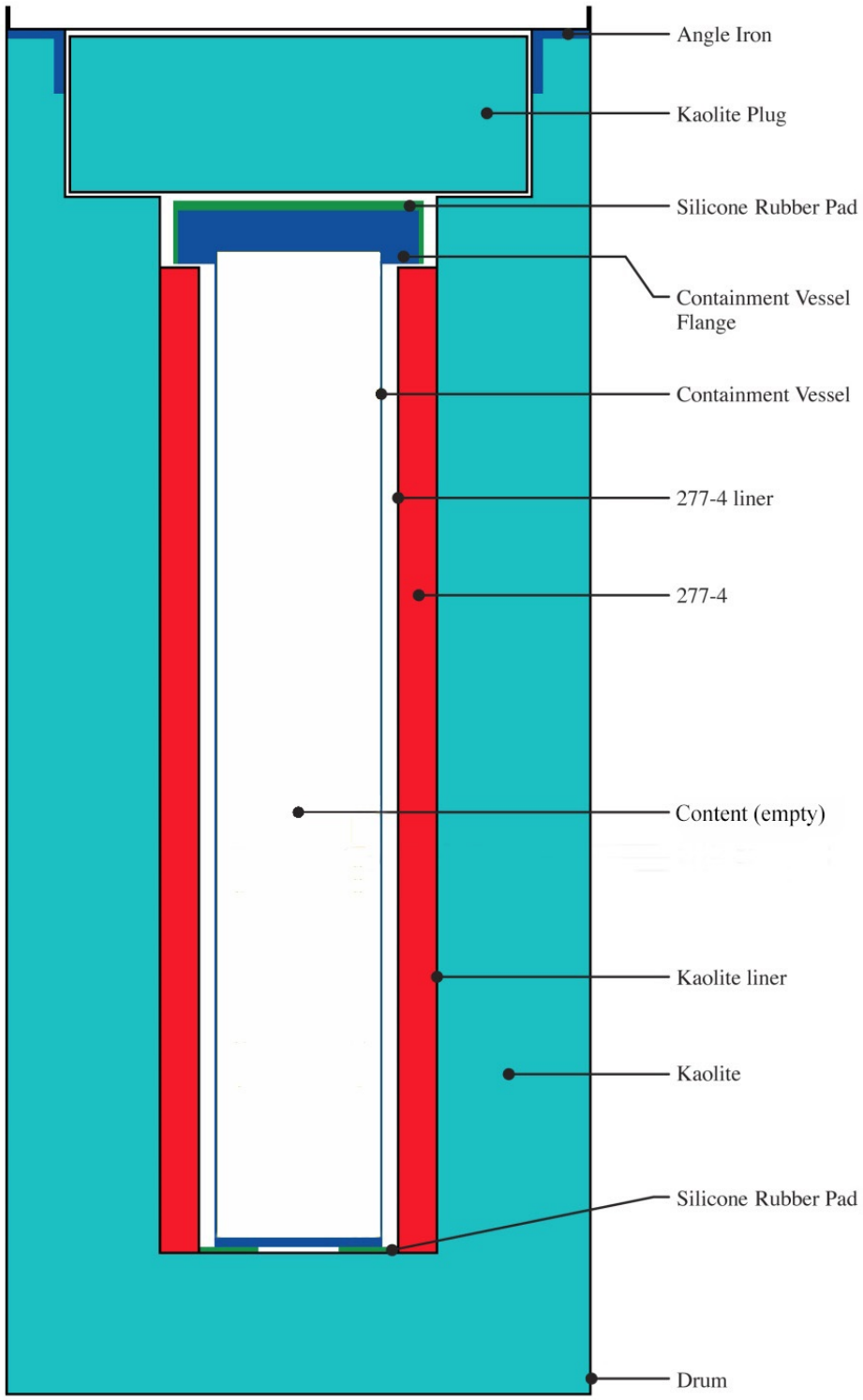
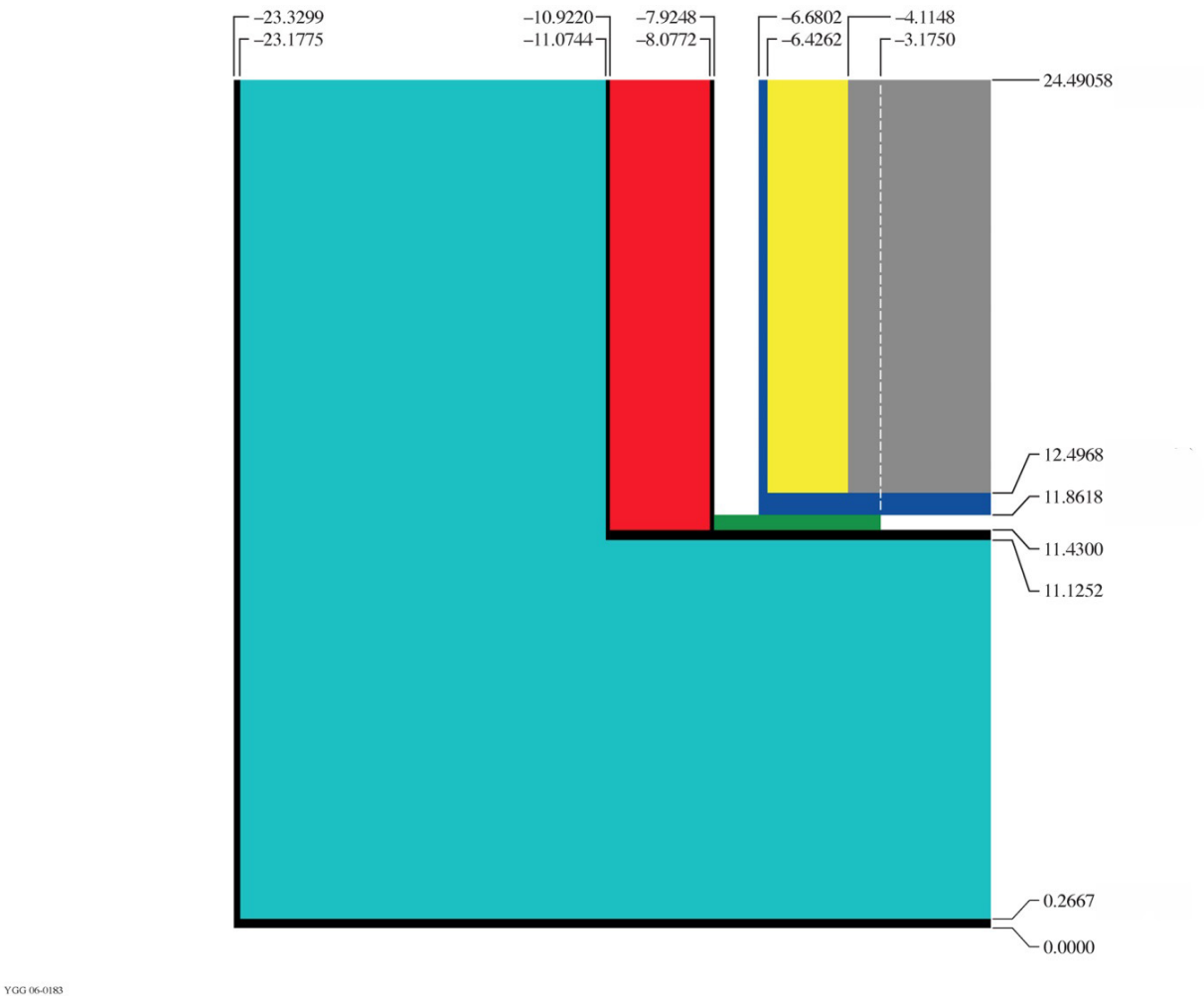
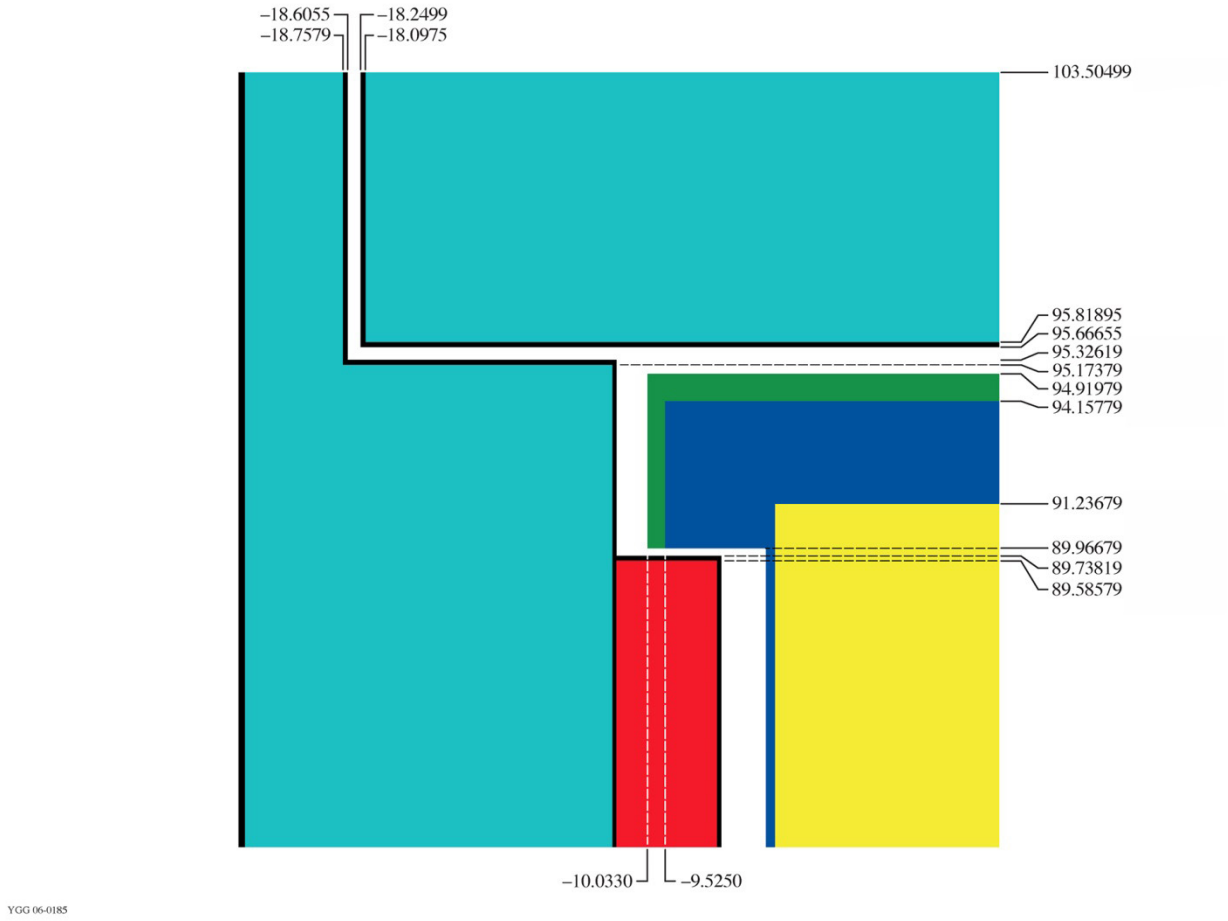


Fig. 5.3. ES-3100 packaging model.



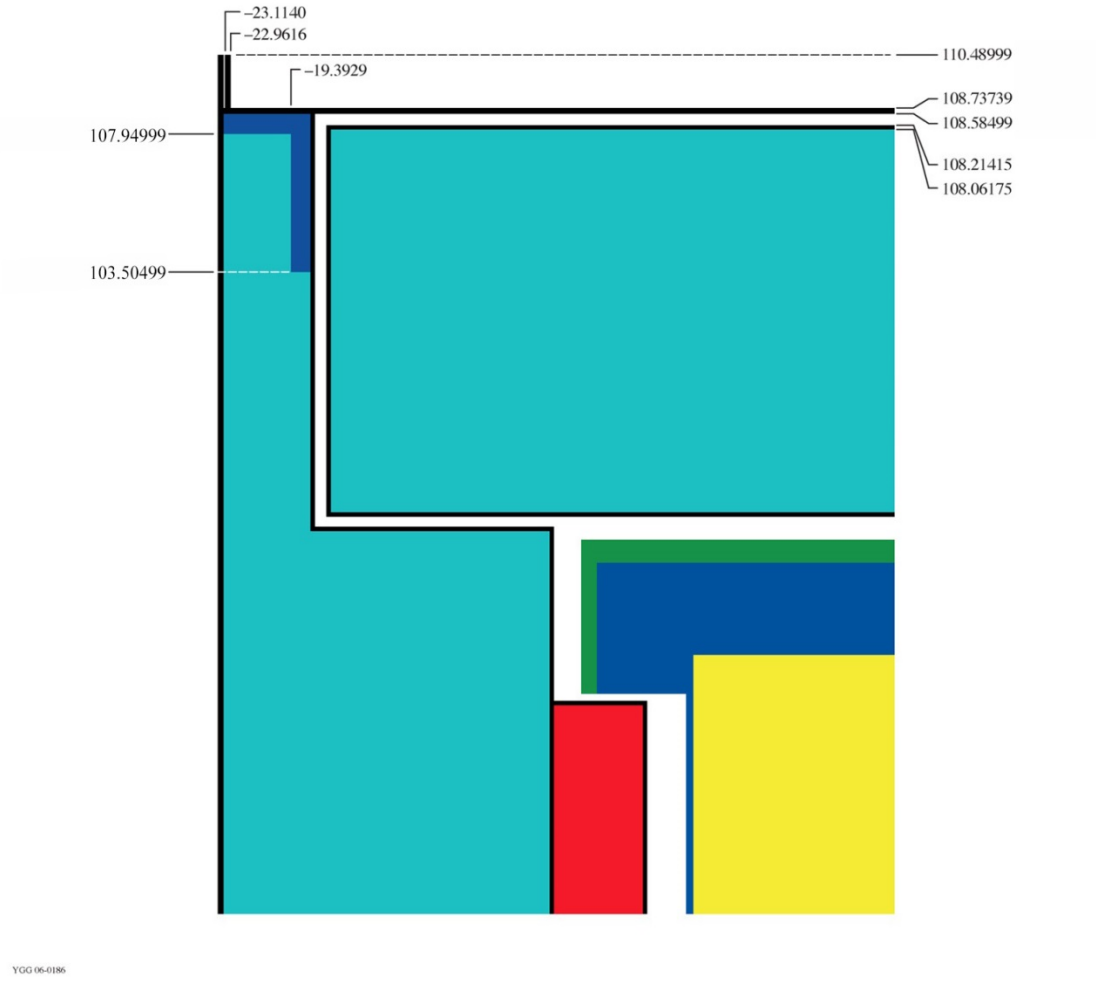
Note: Dimensions are in centimeters.

Fig. 5.4. R/Z section at the bottom of the ES-3100 package model.



Note: Dimensions are in centimeters.

Fig. 5.5. R/Z section near the top of the ES-3100 package model.



Note: Dimensions are in centimeters.

Fig. 5.6. R/Z section at the top of the ES-3100 package model.

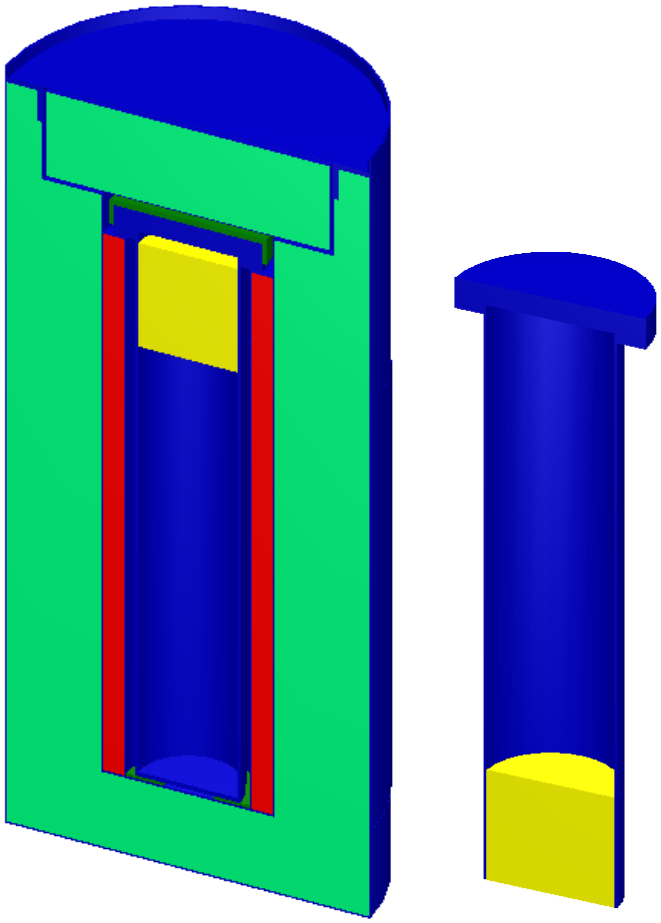


Fig. 5.7. Calculation model of the ES-3100 shipping package (x-z side section) for NCT with cylinder-type source configuration at the top of CV (left) and for HAC with cylinder type source configuration at the bottom of CV (right).

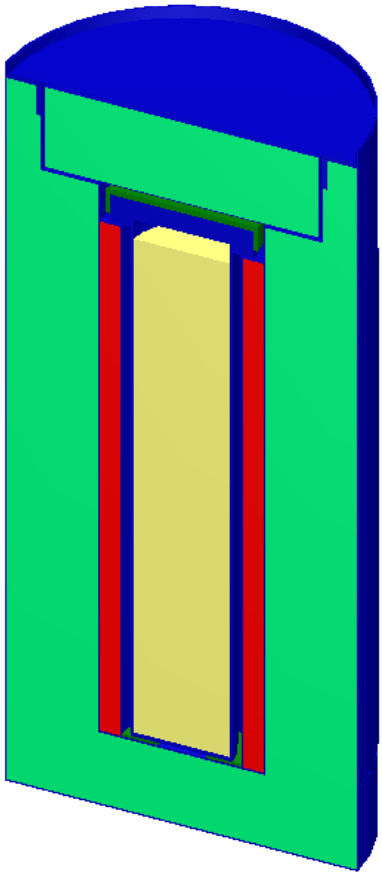


Fig. 5.8. Calculation model of the ES-3100 shipping package for NCT with UO_2 powder shown in yellow (x-z side section).

Table 5.6. Radiation detector locations

	Radius [a] (cm)	Position [b] (cm)
NCT detectors [c]		
Side surface [d]	23.4299	variable
Top surface	0.0000	108.83739
Bottom surface	0.0000	-0.1
1 m from the side [d]	123.3299	variable
1 m from the top	0.0000	208.73739
1 m from the bottom	0.0000	-100.0
HAC detectors [c]		
Side 1 m [d]	106.6802	variable
Top 1 m	0.0000	194.15779
Bottom 1 m	0.0000	-88.1382

[a] Radial distance from the centerline of the drum along x-axis. (Source is symmetrically placed on the +x-axis.)
[b] Distance from drum base for NCT detectors and from containment vessel base for HAC detectors.
[c] Locations are relative to the drum for NCT and relative to the containment vessel for HAC.
[d] Surface side location is at the axial mid-point of the content height.

5.3.1.1 Photon model for 36-kg HEU metal content

The HEU metal content in the ES-3100 may be many small, irregularly shaped pieces, each placed at some arbitrary orientation inside the convenience cans. Several conservative, regular geometry models have been devised to cover these and other proposed loadings. The convenience cans and can spacers are omitted from the models and these assumptions are conservative.

Six geometric models inside the CV are analyzed to calculate the liming dose rates for HEU metal content. The geometric configurations are solid cylinder (Fig. 5.9), cylindrical hemi-shell (Fig. 5.10), cylindrical shell (Fig. 5.11), plate (Fig. 5.12), single rod (Fig. 5.13), and cylindrical segment (Fig. 5.14). The figures show the sectional views of these configurations. The side surface, 1 m from side surface, and 1 m from CV side surface dose rates with uncertainty for these configurations are presented in Table 5.7. The cylindrical hemi-shell configuration produces the maximum NCT and HAC side photon dose rates, which are presented in Table 5.1. Brief descriptions of the six configurations are discussed below.

Solid cylinder configuration: A solid uranium metal cylinder of 6.35 cm radius and 15.1003 cm height is placed either at the top or at the bottom of the CV. The solid cylinder at the top configuration produces the maximum photon dose rates at the: (1) top surface and at 1 m from the top surface for NCT and (2) 1 m from the top CV surface for HAC. This top configuration also produces the maximum neutron dose rates at the: (1) drum top and side surface and 1 m from the top and side surface for NCT and (2) 1 m from the CV top and side surface for HAC. The solid cylinder at the bottom configuration produces the maximum photon dose rates at the: (1) bottom surface and at 1 m from the bottom surface for NCT and (2) 1 m from bottom CV surface for HAC. This bottom configuration also produces the maximum neutron dose rates at the: (1) bottom surface and 1 m from bottom surface for NCT and (2) 1 m from CV bottom surface for HAC. These maximum dose rates are presented in Table 5.1. The side and top sections of the solid cylinder configuration are shown in Fig. 5.9.

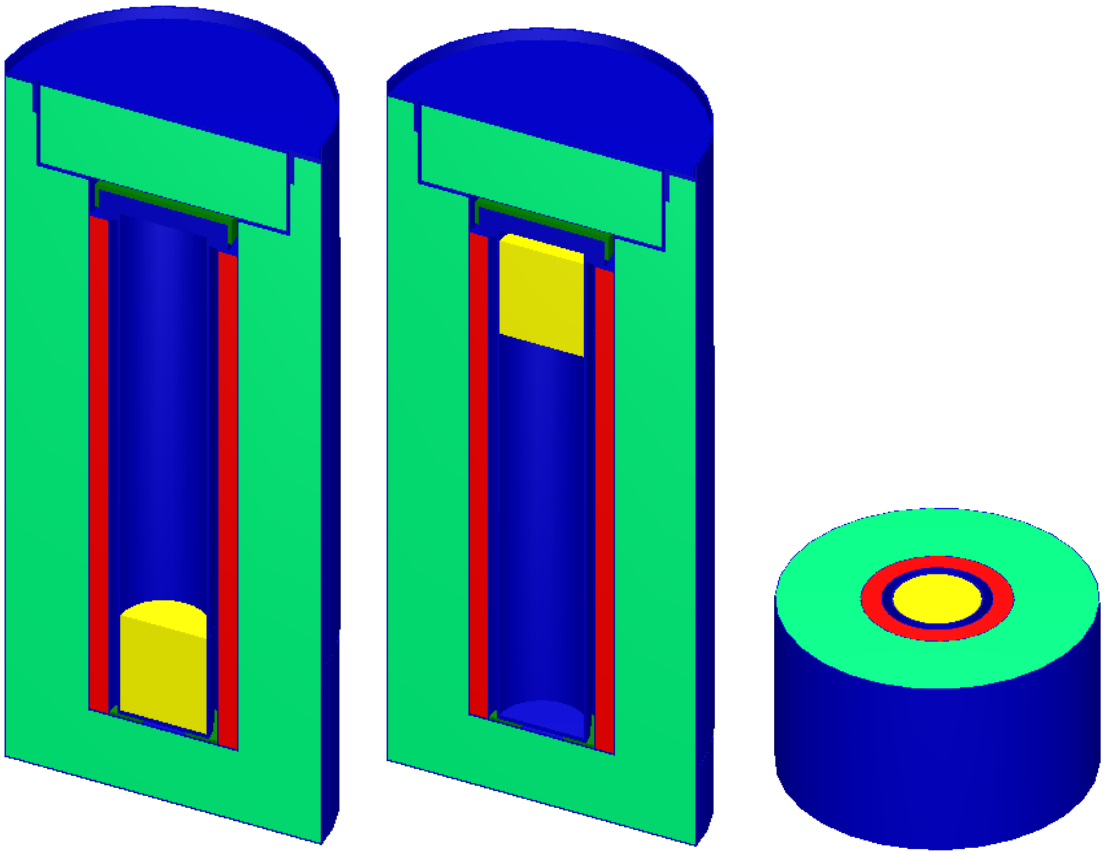


Fig. 5.9. Calculation model of the ES-3100 shipping package for NCT with cylinder type source configuration shown in yellow (x-z side and x-y top sections).

Cylindrical hemi-shell configuration: A cylindrical hemi-shell of 4.9337 cm inner radius, 6.35 cm outer radius, and 76.2 cm height with interior opening inward is placed inside the CV along +x axis. This configuration produces the maximum photon dose rates at the: (1) drum side surface for NCT, (2) 1 m from drum side for NCT, and (3) 1 m from the CV side surface for HAC. These dose rates are presented in Table 5.1. The side and top sections of the cylindrical hemi-shell calculation model are shown in Fig. 5.10.

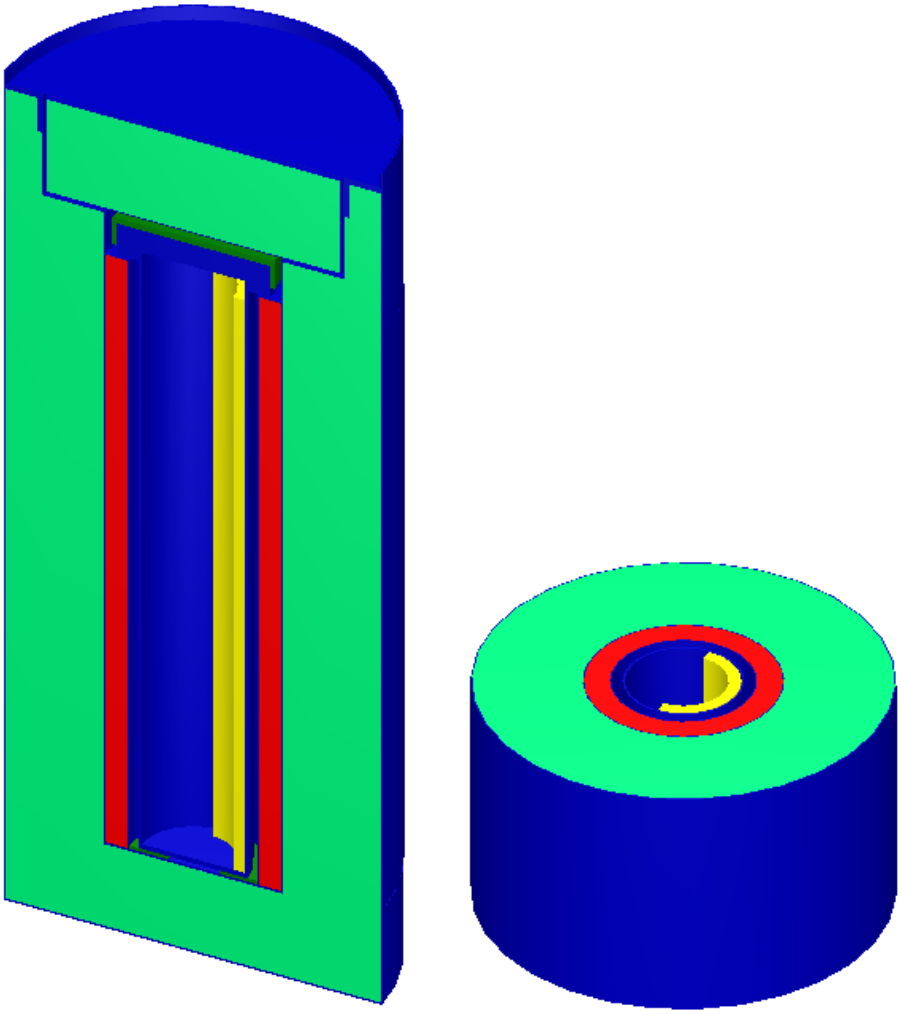


Fig. 5.10. Calculation model of the ES-3100 shipping package for NCT with cylindrical hemi-shell source configuration shown in yellow (x-z side and x-y top sections).

Cylindrical shell configuration: A cylindrical shell of variable inner radius and height with 6.35 cm outer radius is placed inside the CV for investigating side surface dose rates. The shell of 5.6861 cm inner radius and 76.2 cm height produces the maximum NCT side surface, NCT 1 m from side surface, and HAC side surface dose rates for the cylindrical configuration. The side and top sections of the cylindrical shell calculation model are shown in Fig. 5.11.

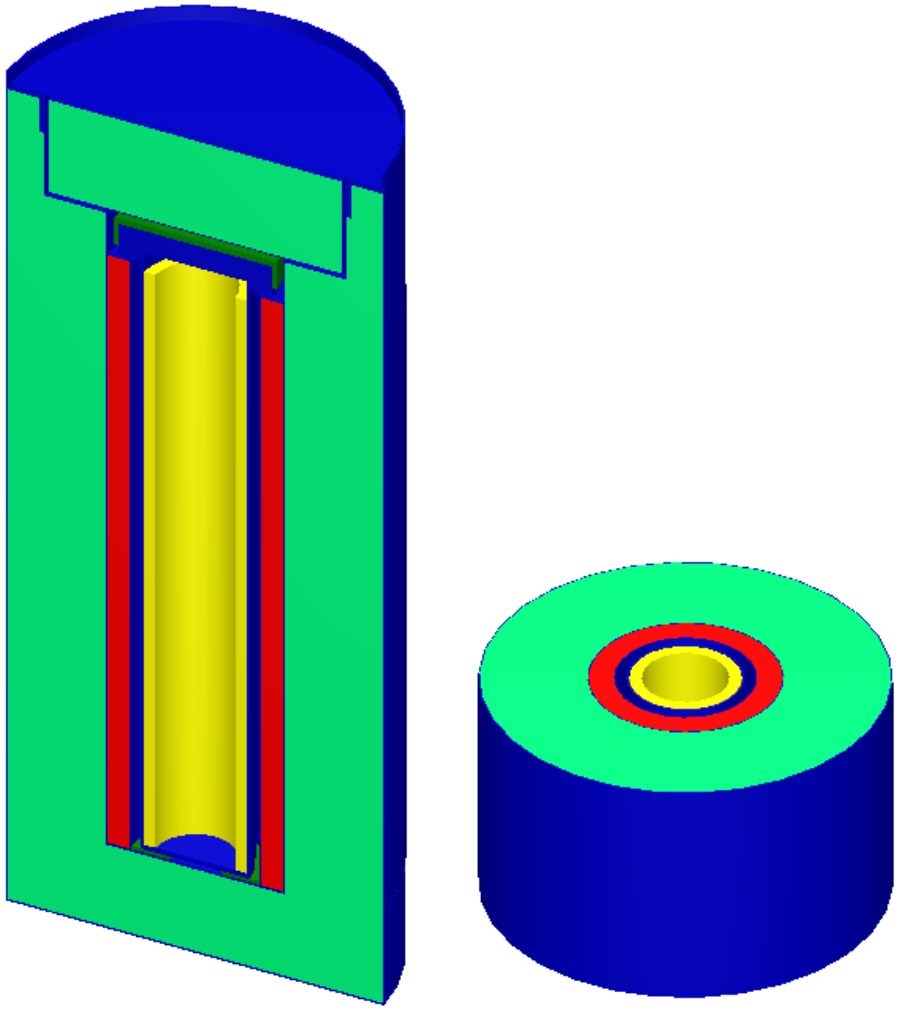


Fig. 5.11. Calculation model of the ES-3100 shipping package for NCT with cylindrical shell source configuration shown in yellow (x-z side and x-y top sections).

Rectangular plate configuration: A rectangular plate of 1.9829 cm width, 12.66 cm length, and 76.2 cm height is placed along the centerline on the y-axis. The NCT side surface, 1 m from side surface, and the HAC side surface dose rates are calculated and presented in Table 5.7. The side and top sections of the plate calculation model are shown in Fig. 5.12.

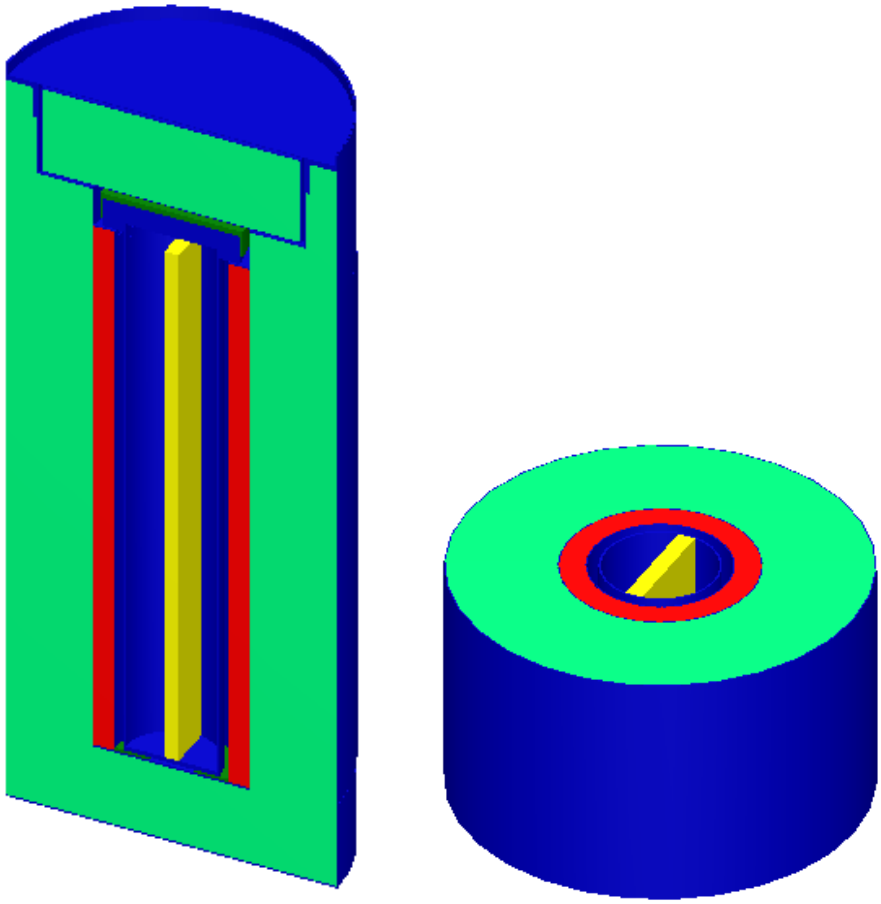


Fig. 5.12. Calculation model of the ES-3100 shipping package for NCT with plate type source configuration shown in yellow (x-z side and x-y top section).

Cylindrical rod configuration: A cylindrical rod of 2.82675 cm radius and 76.2 cm length is placed along x-axis close to the CV. The NCT side surface, 1 m from side surface, and the HAC side surface dose rates are presented in Table 5.7. The side and top sections of the cylindrical rod calculation model are shown in Fig. 5.13.

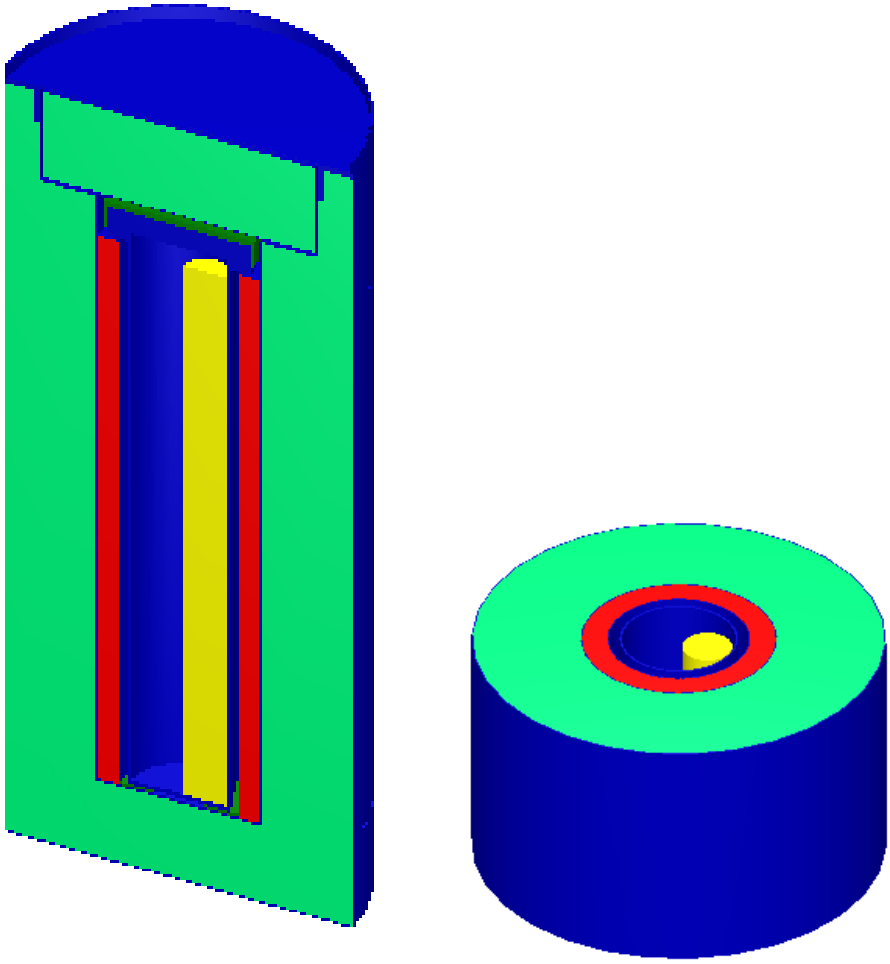


Fig. 5.13. Calculation model of the ES-3100 shipping package for NCT with single rod source configuration shown in yellow (x-z side and x-y top sections).

Cylindrical segment configuration: A cylindrical segment of 6.35 cm radius and 76.2 cm height, which is 3.1442 cm off from the center, is placed along x-axis close to the CV. The NCT side surface, 1 m from side surface, and the HAC side surface dose rates are presented in Table 5.7. The side and top sections of the cylindrical segment calculation model are shown in Fig. 5.14.

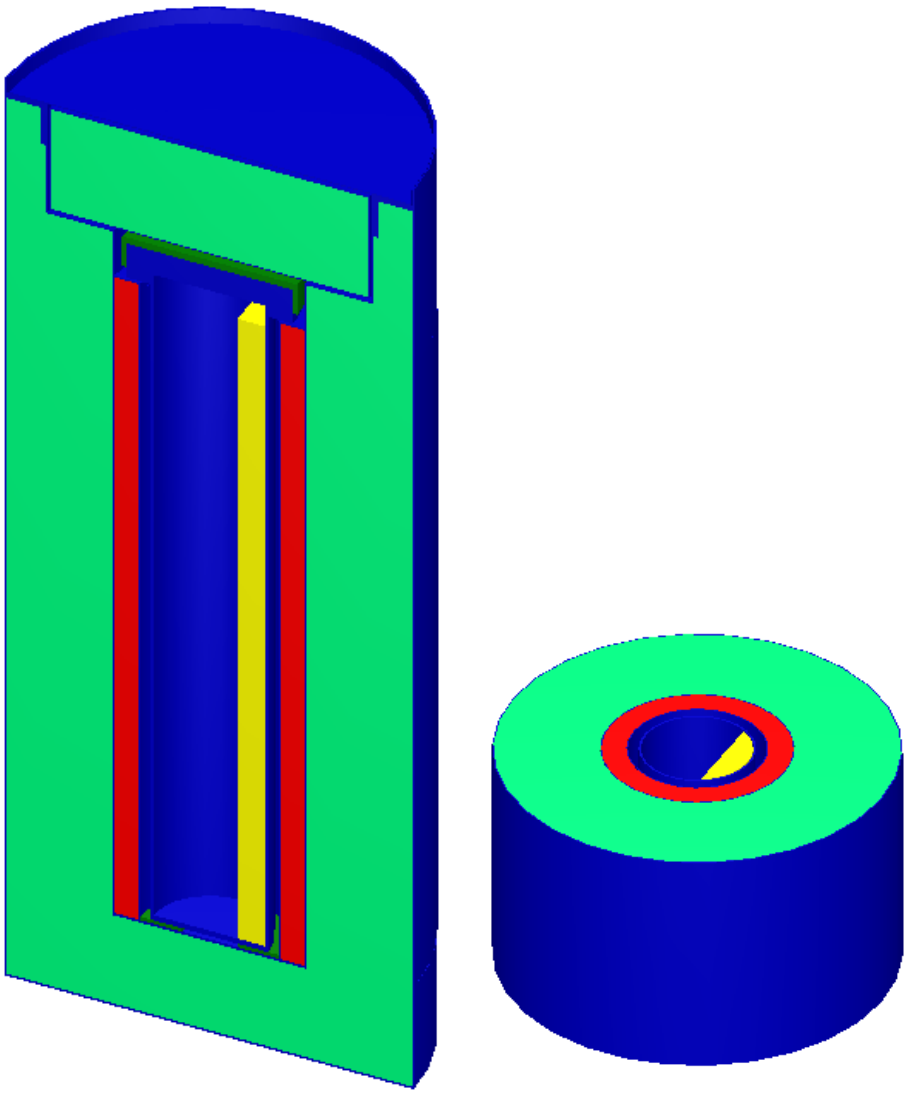


Fig. 5.14. Calculation model of the ES-3100 shipping package for NCT with cylindrical segment source configuration shown in yellow (x-z side and x-y top sections).

Table 5.7. Side dose rates for different HEU metal source configurations

Configuration	Description	Dose rates (mrem/h) with ± one sigma uncertainty (%) [a]		
Drum side surface				
NCT	**Dimension (cm) [b]**	**NCT photon**	**NCT neutron [c]**	**NCT photon and neutron**
Solid cylinder at the top of CV	Radius = 6.35 Height = 15.1003	49.6250 ± 0.66%	1.5787 ± 0.32%	51.2038 ± 0.64%
Solid cylinder at the bottom of CV	Radius = 6.35 Height = 15.1003	51.4160 ± 0.77%	1.1937 ± 0.27%	52.6097 ± 0.75%
Cylindrical hemi-shell	IR = 4.9337 OR = 6.35	95.8000 ± 1.47%	0.1335 ± 0.38%	95.9335 ± 1.47%
Cylindrical shell	IR = 5.6861 OR = 6.35	94.4591 ± 2.24%	0.1039 ± 1.07%	94.5630 ± 2.24%
Rectangular plate	Width = 1.9829 Length = 12.66	91.6170 ± 1.50%	0.1214 ± 0.58%	91.7384 ± 1.50%
Cylindrical rod	Radius = 2.82675	58.7820 ± 0.46%	0.1629 ± 0.51%	58.9449 ± 0.46%
Cylindrical segment	Depth = 3.2058	93.7360 ± 0.74%	0.1743 ± 1.00%	93.9103 ± 0.74%
1 m from drum side surface				
NCT	**Dimension (cm) [b]**	**NCT photon**	**NCT neutron [c]**	**NCT photon and neutron**
Solid cylinder at the top of CV	Radius = 6.35 Height = 15.1003	1.5469 ± 0.10%	0.0565 ± 0.19%	1.6034 ± 0.10%
Solid cylinder at the bottom of CV	Radius = 6.35 Height = 15.1003	1.6255 ± 0.10%	0.03807 ± 0.15%	2.0062 ± 0.09%
Cylindrical hemi-shell	IR = 4.9337 OR = 6.35	6.0639 ± 0.06%	0.0074 ± 0.02%	6.0713 ± 0.06%
Cylindrical shell	IR = 5.6861 OR = 6.35	6.0043 ± 0.05%	0.0060 ± 0.05%	6.0103 ± 0.05%
Rectangular plate	Width = 1.9829 Length = 12.66	5.8423 ± 0.05%	0.0072 ± 0.05%	5.8495 ± 0.05%
Cylindrical rod	Radius = 2.82675	3.5115 ± 0.07%	0.0087 ± 0.05%	3.5202 ± 0.07%
Cylindrical segment	Depth = 3.2058	5.5115 ± 0.11%	0.0089 ± 0.05%	5.5204 ± 0.11%
1 m from CV side surface				
HAC	**Dimension (cm) [b]**	**HAC photon**	**HAC neutron [c]**	**HAC photon and neutron**
Solid cylinder at the top of CV	Radius = 6.35 Height = 15.1003	3.0745 ± 0.09%	0.0362 ± 0.15%	3.1107 ± 0.09%
Solid cylinder at the bottom of CV	Radius = 6.35 Height = 15.1003	3.1979 ± 0.09%	0.0311 ± 0.15%	3.2290 ± 0.09%
Cylindrical hemi-shell	IR = 4.9337 OR = 6.35	12.9060 ± 0.04%	0.0106 ± 0.01%	12.9166 ± 0.04%
Cylindrical shell	IR = 5.6861 OR = 6.35	12.5430 ± 0.06%	0.0362 ± 0.10%	12.5792 ± 0.06%
Rectangular plate	Width = 1.9829 Length = 12.66	12.5420 ± 0.06%	0.0107 ± 0.01%	12.5527 ± 0.06%
Cylindrical rod	Radius = 2.82675	7.0261 ± 0.09%	0.0120 ± 0.01%	7.0381 ± 0.09%
Cylindrical segment	Depth = 3.2058	11.8800 ± 0.20%	0.0130 ± 0.01%	11.8930 ± 0.20%

[a] MCNP5 Monte Carlo code results (LA-UR-03-1987). The uncertainty associated with the results is one standard deviation of the mean (i.e., one sigma uncertainty expressed as a percentage of the mean) calculated using MCNP5.
[b] Height is 76.2 cm for all configurations except solid cylinders at the top or bottom of CV.
[c] Includes secondary photon.

Table 5.7 shows the cylindrical hemi-shell configuration produces the maximum NCT and HAC side dose rates. The variations in dose rates described here are due to the variations in source-detector point geometry and the self-absorption of photons in the source material. Figures 5.15, 5.16, and 5.17 show photon dose rate and the associated absolute uncertainty contours for the cylindrical hemi-shell source configuration. The photon dose contours for the cylinder source configurations at the top and bottom of the cylinder are shown in Figs. 5.18 and 5.19. The photon dose rate contours for the rectangular plate source configuration in the x-z and y-z planes are shown in Figs. 5.20 and 5.21. The calculated dose rates for 36-kg HEU metal or 24-kg HEU oxide content defined in Table 5.3 are not close to the regulatory limits.

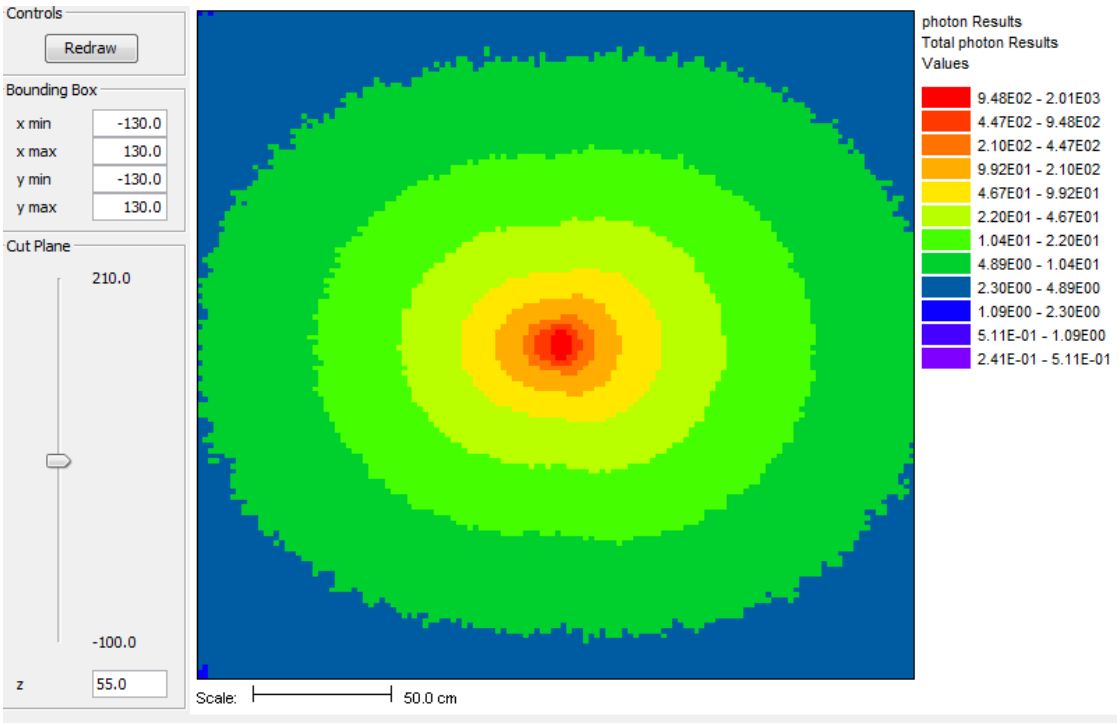


Fig. 5.15. Photon dose rate contours for the cylindrical hemi-shell configuration (x-y plane).

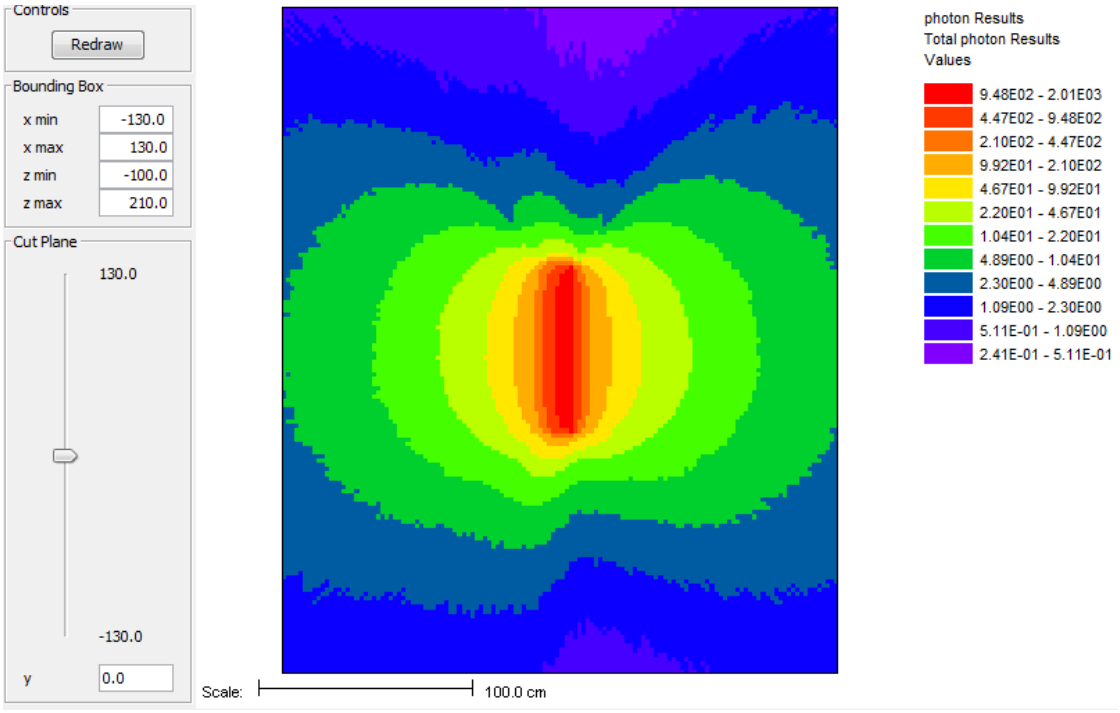


Fig. 5.16. Photon dose rate contours for the cylindrical hemi-shell configuration (x-z plane).

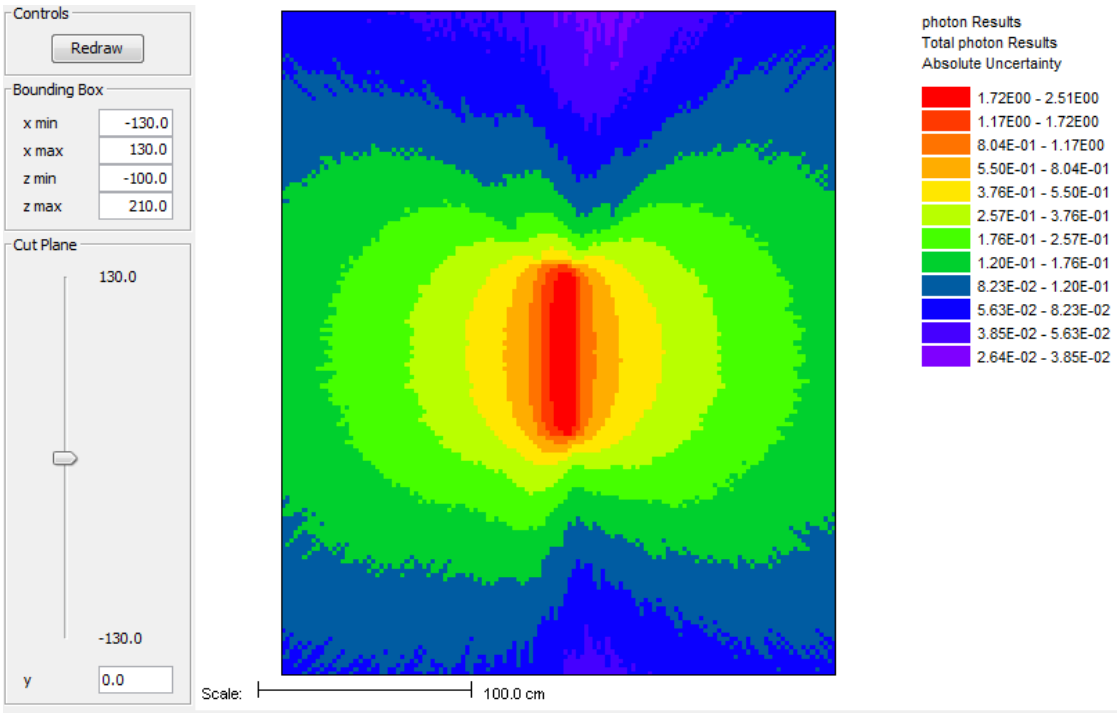


Fig. 5.17. Photon dose rate absolute uncertainty contours for the cylindrical hemi-shell configuration (x-z plane).

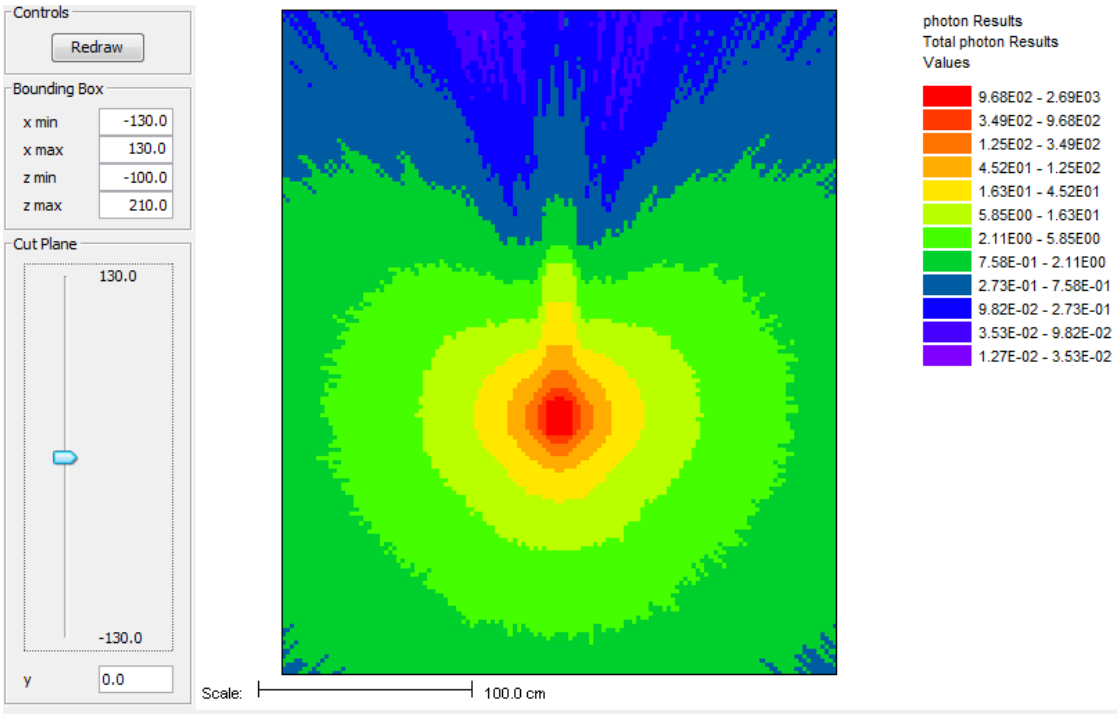


Fig. 5.18. Photon dose rate contours for the cylinder at the bottom of CV configuration (x-z plane).

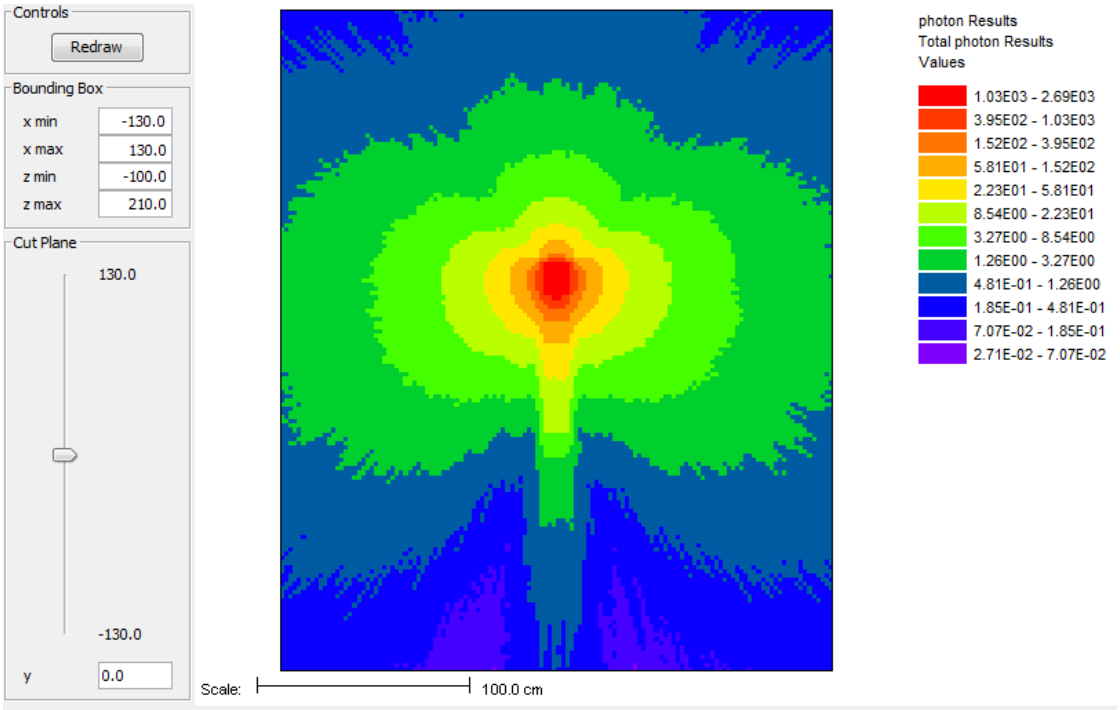


Fig. 5.19. Photon dose rate contours for the cylinder at the top of CV configuration (x-z plane).

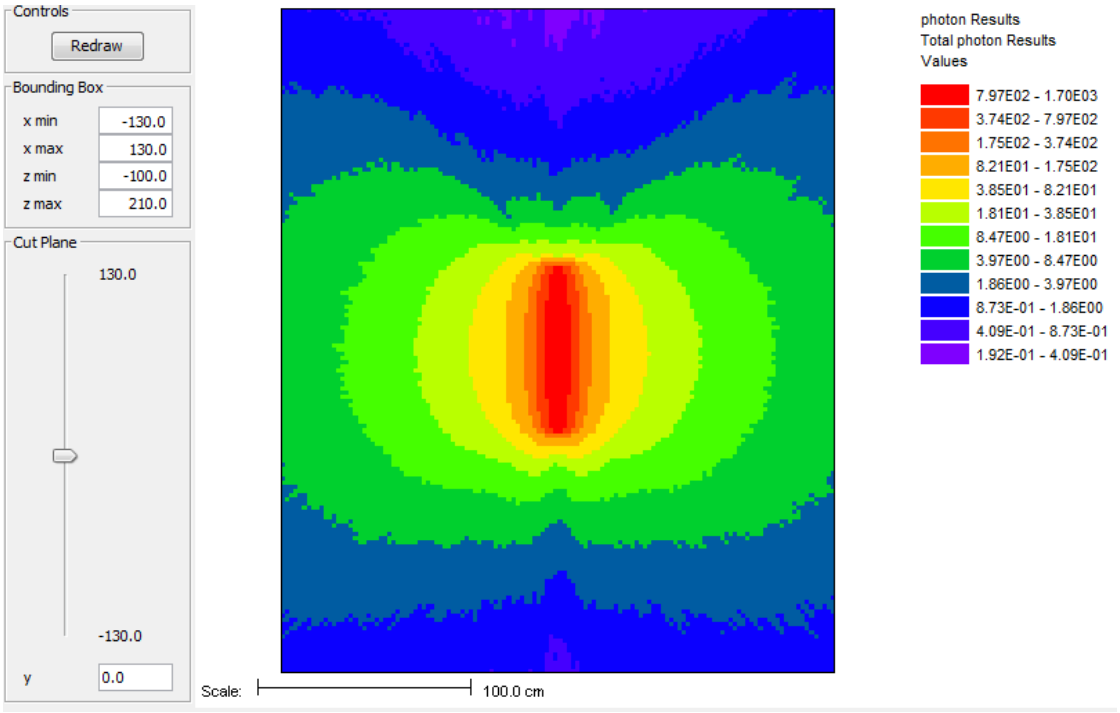


Fig. 5.20. Photon dose rate contours for the plate configuration (x-z plane).

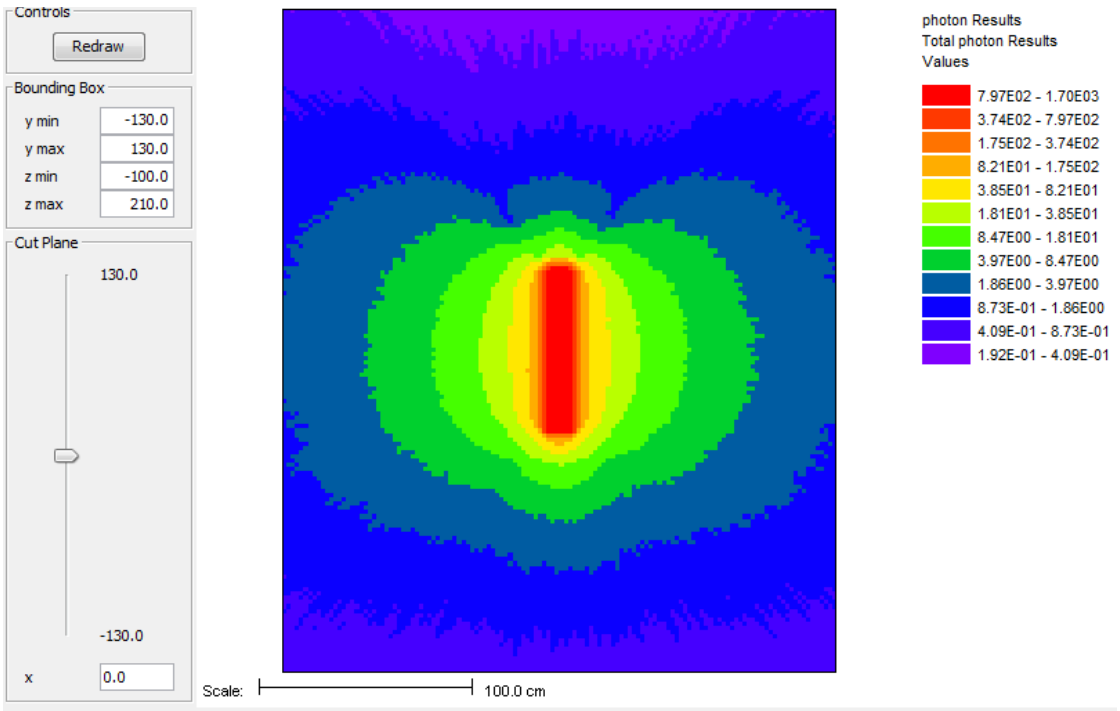


Fig. 5.21. Photon dose rate contours for the plate configuration (y-z plane).

5.3.1.2 Neutron model for 36-kg HEU metal content

For the NCT and HAC neutron top and bottom dose rate calculations for the 36-kg HEU contents, it was assumed all the uranium was a solid cylinder (i.e., radius = 6.35 cm, height = 15.1003 cm, and density = 18.82 g/cm^3) at the bottom or at the top of the CV. These configurations produce the maximum neutron top and bottom dose rates for both NCT and HAC. The results are presented in Table 5.1. The NCT and HAC neutron side dose rates are calculated for six different geometric configurations: solid cylinder (Fig. 5.9), cylindrical hemi-shell (Fig. 5.10), cylindrical shell (Fig. 5.11), plate (Fig. 5.12), single rod (Fig. 5.13), and cylindrical segment (Fig. 5.14). The side neutron dose rates for these configurations are presented in Table 5.7. The neutron dose rate and the associated absolute uncertainty contours for the cylindrical hemi-shell source configuration are shown in Figs. 5.22 and 5.23. The combined neutron and photon side dose rates for these configurations are also presented in Table 5.7. The combined side dose rates for NCT and HAC are the highest for the cylindrical hemi-shell configuration and is presented in Table 5.1.

5.3.1.3 Photon model for 24-kg HEU oxide content

The photon dose rate calculation model was developed to apply to 24 kg of HEU oxide content for all three common uranium oxides (i.e., UO_2, UO_3, and U_3O_8). The theoretical densities for these oxides are 10.96 g/cm^3, 7.29 g/cm^3, and 8.30 g/cm^3, respectively. In the package loading models, the convenience can locations are completely filled with oxide powder, and the actual densities, always less than theoretical values, will be the oxide mass divided by the model can volume. The dose rate model excludes the convenience cans, and it is represented by a solid cylinder of oxide resting on the CV interior base. The cylinder radius is 6.35 cm, and the height is variable. The density is adjusted for each calculation to preserve the 24-kg oxide mass. The HEU mass is 21.126 kg for UO_2, the largest uranium mass of the three oxides for 24 kg of HEU oxide. For side dose rate calculations, cylindrical shell with varying shell thickness and height with different UO_2 density from 2.5 to 10.96 g/cm^3 while maintaining the oxide mass of 24 kg have also been analyzed. Different configurations are analyzed to get the maximum dose rates that are presented in Table 5.2. The dose rates presented in Table 5.2 will also bound the dose rates from lower density oxides (i.e., <2.5 g/cm^3) and the oxide mass will be lower than 24 kg due to volumetric limitations inside the CV.

The photon NCT side dose rate is for a UO_2 cylinder of 47.365 cm height and 4.0 g/cm^3 density. The 1-m side NCT and side HAC photon dose rates are from the cylindrical shell configuration of 2.6275 cm inner radius, 6.35 cm outer radius, 76.2 cm height, and density of 3.0 g/cm^3. The top and bottom NCT and HAC photon dose rates are from the UO_2 solid cylinder configuration of density 10.96 g/cm^3 at the top and bottom of the CV, respectively. Figure 5.24 shows the photon dose-rate contours for the UO_2 cylinder of 75.785 cm height, 6.35 cm radius, and 2.5 g/cm^3 density.

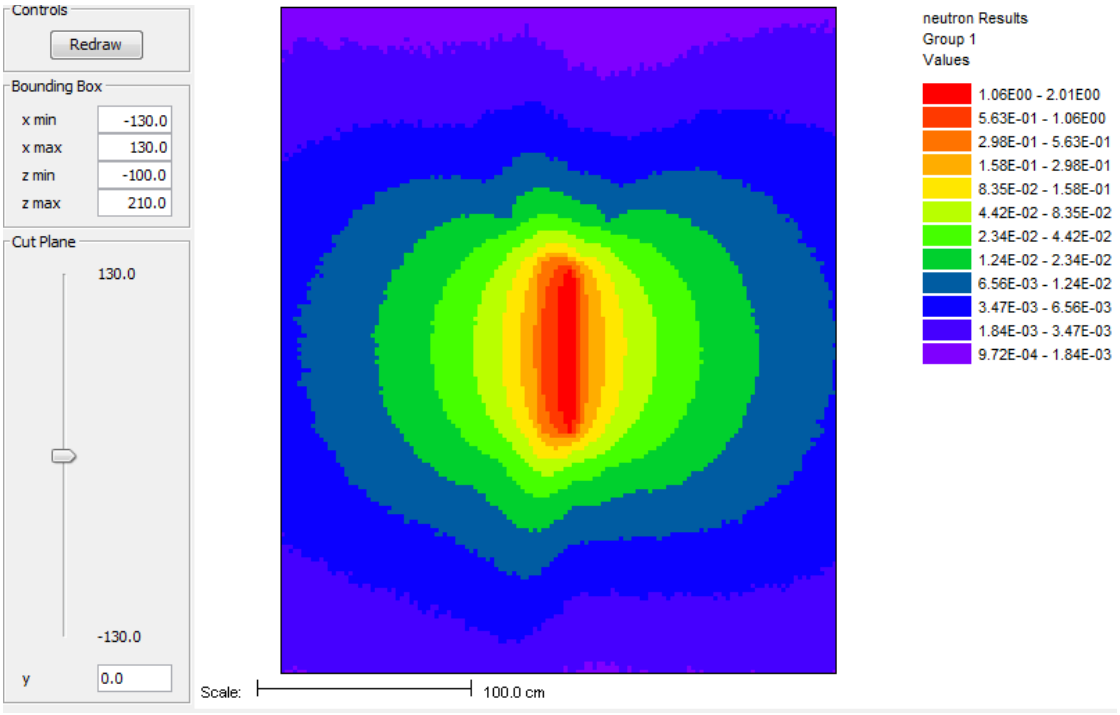


Fig. 5.22. Neutron dose rate contours for the cylindrical hemi-shell configuration (x-z plane).

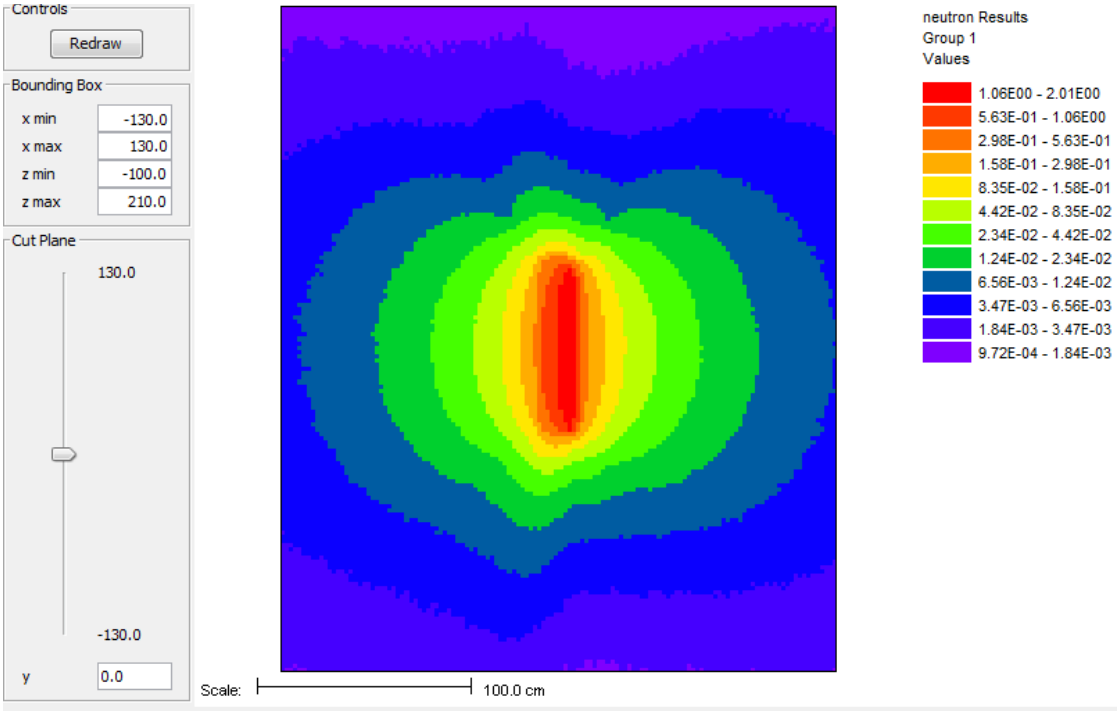


Fig. 5.23. Neutron dose rate absolute uncertainty contours for the cylindrical hemi-shell configuration (x-z plane).

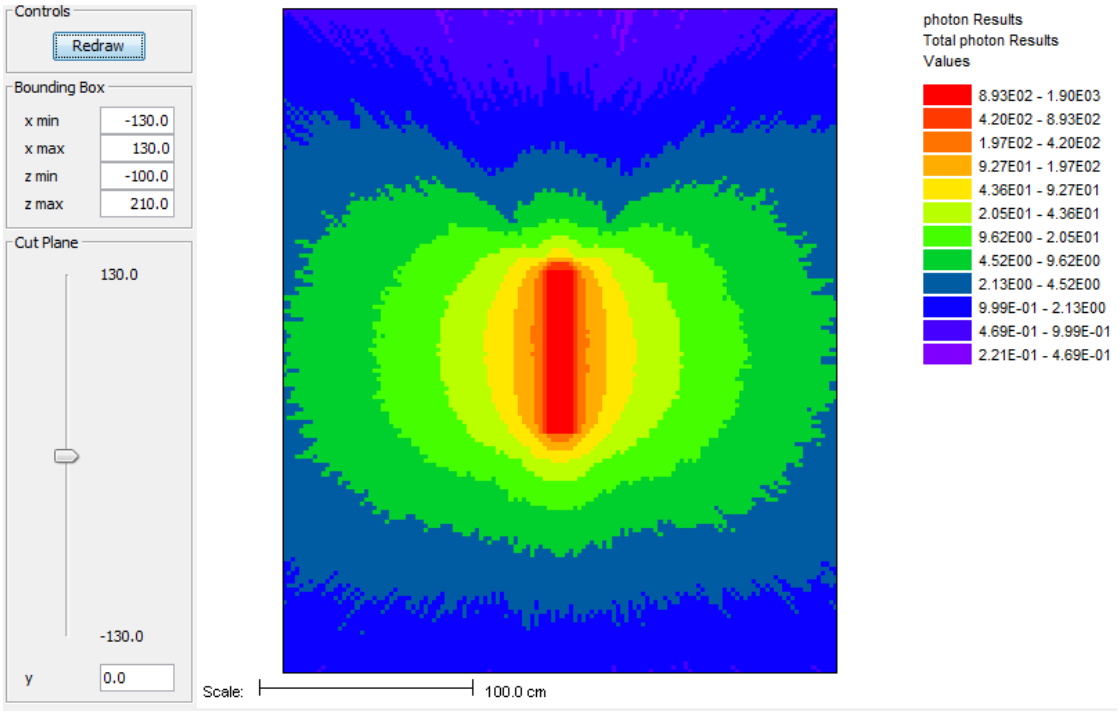


Fig. 5.24. Photon dose rate contours for the UO_2 cylindrical powder configuration of 75.785 cm height and 6.35 cm radius (x-z plane).

5.3.1.4 Neutron model for 24-kg HEU oxide content

The neutron model for the calculated dose rate is a solid cylinder of UO_2 of 6.35 cm radius either at the bottom or at the top of the CV. The density of UO_2 used in the model is 10.96 g/cm^3 and the height is 17.286 cm. The top and bottom NCT and HAC neutron dose rates are calculated by placing the UO_2 cylinder at the top and bottom of the CV, respectively. The side NCT and HAC neutron dose rates are from the UO_2 solid cylinder of density at the top of the CV. The oxide mass in a cylindrical shape is the only analyzed configuration for neutron dose rate contribution since the uranium oxides are in powder form and the contribution of neutron dose rate is <1% of the combined (photon and neutron) dose rate.

5.3.1.5 Containment vessel O-rings dose rate

The dose rate at the location of the CV O-rings is calculated for HEU metal case with cylindrical type fuel configuration at the top of the CV. Figure 5.25 shows the location of the O-rings. The radial and height locations of the point detector calculation point are 6.8 cm and 91.20 cm, respectively. The calculated photon dose rate is 483.92 mrem/h, and the neutron and secondary photon dose rate combined is 16.33 mrem/h. The calculated combined dose rate with 3σ uncertainty at the O-ring is 506.5 mrem/h. Using a 1-rad/rem conversion factor, which is applied to the photon dose rate and conservatively applied to the relatively low neutron dose rate, the maximum total calculated dose rate at the O-ring location is ~0.5 rad/h. The O-ring location dose rate for the HEU metal case bounds that for the HEU oxide case.

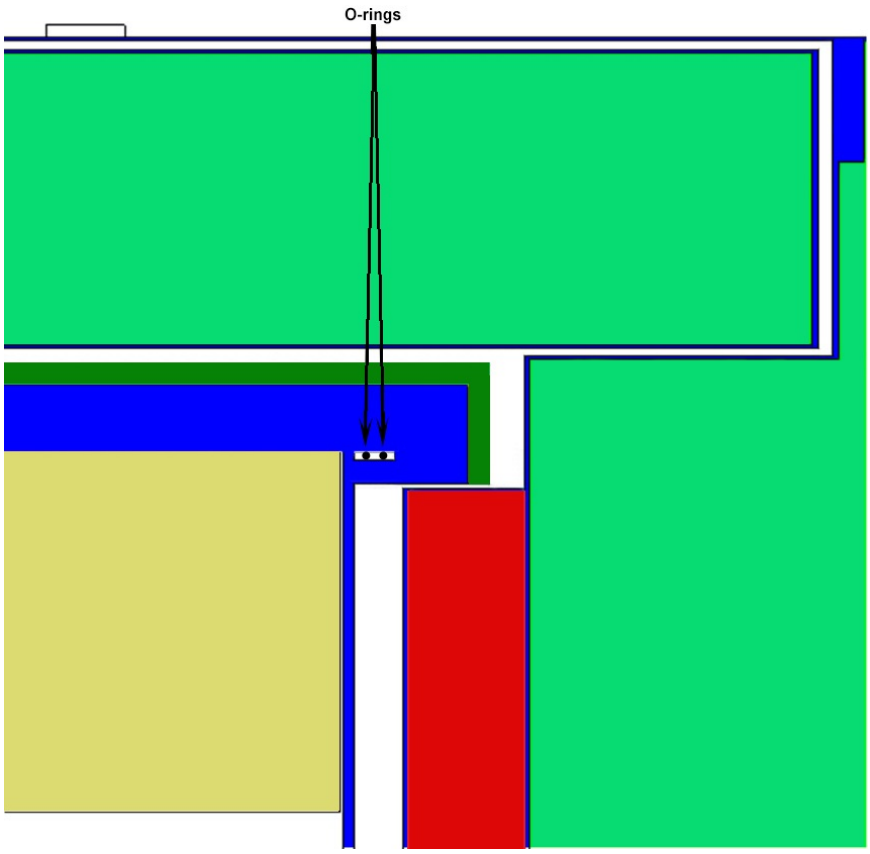


Fig. 5.25. Calculation model of the ES-3100 shipping package for NCT with cylinder type configuration at the top of CV for dose rate calculations at O-rings (x-z side section).

5.3.1.6 Effects of impurities

The content may contain radioactive and nonradioactive material as impurities. The presence of ^{232}U, ^{233}U, ^{234}U, ^{236}U, ^{237}Np, and plutonium contents is conservatively included in the source-term calculations (Table 5.3). The nonradioactive impurities, if any are present, do not affect the photon source term. The neutron dose rate is negligible in comparison to the total dose rate presented in Tables 5.1 and 5.2. Therefore, it can be concluded that the presence of nonradioactive impurities does not significantly affect the total dose rates presented in Tables 5.1 and 5.2.

5.3.1.7 Conservative features of the packaging model

Several conservative features are included in the model. All dimensions and densities of the packaging materials are modeled as equal to or less than specified or nominal values. The content is modeled conservatively to calculate the side, top, and bottom dose rates (Sect. 5.3.1). All packaging materials inside the CV are neglected. The convenience cans, can spacers, content wrappings, covers, supports, etc., are omitted. The CV model, therefore, contains HEU material content only. For HEU oxide cases, all contents are modeled as cylinders or cylindrical shells with the base resting on the lower CV surface with a maximum specified radius of 6.35 cm (the maximum allowable convenience can diameter is 5 in.) and with a height, inner radius (if any), and density adjusted for each specific model

to preserve the content mass. In this conservative manner, it is possible to cover all specified combinations of can loadings and can and spacer placements with a minimum number of calculations. The geometric configuration of some of the cases investigated represents a situation where the maximum possible mass loading for a convenience can would be exceeded if the cans had been included in the model. The calculated dose rates from the models used, however, will always exceed those from a model where the geometry is expanded so the can mass loadings are not exceeded and the internal CV hardware is included.

5.3.2 Material Properties

The material properties for the ES-3100 package shielding models are shown in Table 5.8. Kaolite is an impact-absorbing and thermal-insulating material and Cat 277-4 is a neutron-attenuating material used in the ES-3100 package. Additional information on these two materials can be found in Chapters 1, 2, and 6.

Table 5.8. Shielding model material specifications for the ES-3100 package with HEU content

Material	Density (g/cm^3)	Constituent	Weight percent
Uranium metal	18.82	^{235}U	95.0000
		^{238}U	5.0000
UO_2	10.960 [a]	O	11.9800
		^{235}U	83.6200
		^{238}U	4.4000
Stainless steel	7.92	C	0.0800
		^{28}Si	0.9187
		^{29}Si	0.0483
		^{30}Si	0.0330
		P	0.0450
		^{50}Cr	0.7930
		^{52}Cr	15.9029
		^{53}Cr	1.8380
		^{54}Cr	0.4661
		Mn	2.0000
		^{54}Fe	3.8602
		^{56}Fe	62.8377
		^{57}Fe	1.4772
		^{58}Fe	0.2000
		^{58}Ni	6.3838
		^{60}Ni	2.5437
		^{61}Ni	0.1124
		^{62}Ni	0.3643
		^{64}Ni	0.0958
Cat 277-4	1.4586	H	2.8475
		^{10}B	0.6591
		^{11}B	2.9726
		C	1.3609
		N	0.0100
		^{16}O	53.2515
		^{17}O and ^{18}O	0.1450

Table 5.8. Shielding model material specifications for the ES-3100 package with HEU content

Material	Density (g/cm^3)	Constituent	Weight percent
		Na	0.0833
		^{24}Mg	0.1867
		^{25}Mg	0.0246
		^{26}Mg	0.0282
		Al	27.6937
		^{28}Si	1.6075
		^{29}Si	0.0846
		^{30}Si	0.0577
		^{32}S	0.2071
		^{33}S	0.0017
		^{34}S	0.0098
		^{36}S	0.00002
		^{40}Ca	8.1125
		^{42}Ca	0.0569
		^{43}Ca	0.0121
		^{44}Ca	0.1920
		^{46}Ca	0.0004
		^{48}Ca	0.0188
		^{54}Fe	0.0212
		^{56}Fe	0.3453
		^{57}Fe	0.0081
		^{58}Fe	0.0011
Kaolite	0.321	^{16}O	40.9231
		^{17}O and ^{18}O	0.1114
		Na	1.4837
		^{24}Mg	6.1579
		^{25}Mg	0.8121
		^{26}Mg	0.9298
		Al	5.0808
		^{28}Si	15.7696
		^{29}Si	0.8292
		^{30}Si	0.5661
		^{40}Ca	21.2086
		^{42}Ca	0.1490
		^{43}Ca	0.0318
		^{44}Ca	0.5031
		^{46}Ca	0.0010
		^{48}Ca	0.0491
		^{54}Fe	0.2646
		^{56}Fe	4.3066
		^{57}Fe	0.1012
		^{58}Fe	0.0137
Air	0.001225	^{14}N	75.50
		^{16}O	23.20
		^{40}Ar	1.30

[a] The uranium oxide density varies with the geometric model volume to preserve the 24-kg mass.

5.4 SHIELDING EVALUATION

5.4.1 Methods

Two computer programs were used in the shielding evaluation: ORIGEN-S and MCNP5. Both are stand-alone codes. Brief descriptions of the programs are presented below.

1. ORIGEN-S (NUREG/CR-0200, Vol. II, Sect. F7) is a general depletion and decay code. Given an initial isotopic distribution, materials are decayed to provide time-dependent, energy-grouped photon and neutron sources.

2. MCNP5 (LA-UR-03-1987) is a general-purpose Monte Carlo transport code that treats multidimensional neutron, photon, and coupled problems. MCNP5 and the cross section library used for the materials in this analysis are based on Evaluated Nuclear Data Files VII cross sections for neutrons and MCPLIB04 for photons.

A Type 5 point detector tally was used for calculating the photon and neutron dose rates for NCT and HAC. These dose rates are reported in Tables 5.1, 5.2, and 5.7. Type 4 tally dose rates (segmented volume detectors) for neutrons and photons are also calculated from tally cells, each of 1 cm height, arranged around the package surface and at 1 m from the external surface of the drum for NCT and HAC side doses for symmetrical source distribution cases. Volume detectors are also used at the top and bottom surfaces and at 1m from the external top and bottom surfaces for symmetrical source distribution cases. The volume detector tallies are used only to compare the Type 5 point detector tally dose rates.

5.4.2 Input and Output Data

Sample input files are shown in Appendices 5.5.1 and 5.5.2. The limiting output dose rates are shown in Tables 5.1 and 5.2. Point detectors are used for all dose-rate calculations. A large number of particle histories were used to assemble reliable statistics. The results are judged to be acceptable from the tally fluctuation chart, and the relative error (fractional standard deviation) is lower than the criterion (0.05 for point detectors).

5.4.3 Flux-to-Dose-Rate Conversion

Dose rates were calculated at the detector locations by converting the calculated photon and neutron fluxes using the ANSI/ANS conversion factors (ANSI/ANS-6.1.1). These factors for the energy groups used in the shielding evaluation are shown in Tables 5.9 and 5.10.

5.4.4 External Radiation Levels

The calculated maximum side, top, and bottom external dose rates for the HEU metal and oxide contents are presented in Tables 5.1 and 5.2, respectively. The dose rates were calculated by the computer code MCNP. Comparison of dose rates calculated at the detector locations to the requirements of 10 CFR 71 demonstrates compliance of the package. The calculated total dose rates are well within the NCT limits of 200 mrem/h and 10 mrem/h on the drum surface and 1 m from the drum surface, respectively. Calculated HAC dose rates are well within the limit of 1000 mrem/h from the CV surface. The shielding analyses were done in a conservative manner applicable to all proposed ES-3100 package contents listed in Sect. 1.2.2.

In addition to the required external package dose rate calculations, auxiliary calculations were performed to give an upper bound estimate for the dose rate at the location of the CV O-rings. The maximum calculated combined dose rate with 3σ uncertainty at the O-ring was 506.5 mrem/h. Using a 1-rad/rem conversion factor, which was applied to the photon dose rate and conservatively applied to the relatively low neutron dose rate, the maximum total calculated dose rate at the O-ring location was ~0.5 rad/h. The O-ring location dose rate for the HEU metal case bounds that for the HEU oxide case.

Table 5.9. ANSI/ANS-1977 photon flux-to-dose-rate conversion factors

Energy (MeV)	Factor (rem/h)/(photons/s/cm^2)
0.01	3.96×10^{-6}
0.03	5.82×10^{-7}
0.05	2.90×10^{-7}
0.07	2.58×10^{-7}
0.10	2.83×10^{-7}
0.15	3.79×10^{-7}
0.20	5.01×10^{-7}
0.25	6.31×10^{-7}
0.30	7.59×10^{-7}
0.35	8.78×10^{-7}
0.40	9.85×10^{-7}
0.45	1.08×10^{-6}
0.50	1.17×10^{-6}
0.55	1.27×10^{-6}
0.60	1.36×10^{-6}
0.65	1.44×10^{-6}
0.70	1.52×10^{-6}
0.80	1.68×10^{-6}
1.00	1.98×10^{-6}
1.40	2.51×10^{-6}
1.80	2.99×10^{-6}
2.20	3.42×10^{-6}
2.60	3.82×10^{-6}
2.80	4.01×10^{-6}
3.25	4.41×10^{-6}
3.75	4.83×10^{-6}
4.25	5.23×10^{-6}
4.75	5.60×10^{-6}
5.00	5.80×10^{-6}
5.25	6.01×10^{-6}
5.75	6.37×10^{-6}
6.25	6.74×10^{-6}
6.75	7.11×10^{-6}
7.50	7.66×10^{-6}
9.00	8.77×10^{-6}
11.00	1.03×10^{-5}
13.00	1.18×10^{-5}
15.00	1.33×10^{-5}

Table 5.10. ANSI/ANS-1977 neutron flux-to-dose-rate conversion factors

Energy (MeV)	Factor (rem/h)/(neutrons/s/cm^2)
2.5×10^{-8}	3.67×10^{-6}
1.0×10^{-7}	3.67×10^{-6}
1.0×10^{-6}	4.46×10^{-6}
1.0×10^{-5}	4.54×10^{-6}
1.0×10^{-4}	4.18×10^{-6}
1.0×10^{-3}	3.76×10^{-6}
1.0×10^{-2}	3.56×10^{-6}
1.0×10^{-1}	2.17×10^{-5}
5.0×10^{-1}	9.26×10^{-5}
1.0	1.32×10^{-4}
2.5	1.25×10^{-4}
5.0	1.56×10^{-4}
7.0	1.47×10^{-4}
10.0	1.47×10^{-4}
14.0	2.08×10^{-4}
20.0	2.27×10^{-4}

5.5 APPENDIX

5.5.1 Origen-S Input Data

5.5.2 MCNP Input Files

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5.5.1 Origen-S Input Data

The ORIGEN-S (NUREG/CR-0200) input file used for the Table 5.1 and 5.2 calculated dose rates is provided. The input file in Appendix 5.5.1.1 is for the source term based on the radionuclides in Table 5.3. The concentration of each isotope is based on 1 g of highly enriched uranium (HEU). This is a conservative assumption because the uranium mass is not compensated (reduced) due to the addition of the radionuclide impurity masses of ^{237}Np and Pu. This file has generated the photon and neutron spectrum in Tables 5.4 and 5.5, respectively, which are used to calculate the HEU metal and oxide results in Tables 5.1 and 5.2.

5.5.1.1 Source generation file for radionuclides only

```
#origen
'
'  source term for ES-3100 HEU (This revision - same source term was used
'  in older version)
'  This revision used 47 group photon spectrum instead of 18 group used
'  in earlier version - this is the only difference
'  assumed 95 wt% U-235 and 5 wt% U-238 and also used
'  used U-232, U-233, U-234, U-236, Np-237, and Transuranic U in
'  1 gm basis - source term calculations
'
0$$ 6 13 a8 26 e
1$$ 1 t
master photon
'
'   used 47 energy groups for photons (a33 item) specified in 83** card
'   used 27 default neutron energy groups
'   units of concentration in gm (a16 item)
'
3$$ 21 0 1 -88 6 a16 2 a33 47
'
'   used UO2 medium composition for the alpha-n (conservative assumption
'   for Uranium metal case)
'
54$$ a11 0 e
4** a4 1-70 t
35$$ 0 t
'
'   no of nuclides or elements used as initial condition (a13)
'   time interval in years in card 60
'   input card for both title and basis
'
56$$ 0 10 a13 13 5 3 a17 2 e
'
'   time subtracted from first time period in card 60
'
57** 0 e t
input source concentration in grams
 basis 1 gm U-metal
60** 7  10  10.5  12  15  20  30  40  50  60
'
'    print options specified here from Table F7.6.1
'
65$$ a4 1 a7 1 a10 1 a13 1 a25 1 a28 1 a31 1 a34 1 a46 1 a49 1 a52 1 e
'
'    source term nuclide or element
'
```

```
73$$ 922320      922330       922340
     922350      922360       922380     932370     942380
     942390      942400       942410     942420     952410
'
'    nuclide or element concentration
'
74** 4.0000-08  6.0000-03    2.0000-02
     0.9200000  1.0000-02    0.04399996  0.0250000  1.6000-07
     7.4100-04  5.2000-05    4.4800-06   3.2000-07  2.4000-06
'
'    library kind (used 2 for actinide library)
'
75$$ 2 2 2 2 2 2 2 2 2 2 2 2
81$$ 2 0 26 1 e
82$$ 2 2 2 2 2 2 2 2 2
'
'    gamma energy group structure (user specified here)
'
83** 10.0+6 8.0+6 6.5+6 5.0+6 4.0+6 3.5+6 3.0+6 2.9+6 2.8+6 2.7+6
      2.6+6 2.5+6 2.4+6 2.3+6 2.2+6 2.1+6 2.0+6 1.9+6 1.8+6 1.7+6
      1.6+6 1.5+6 1.4+6 1.3+6 1.2+6 1.1+6 1.0+6 0.9+6 0.8+6 0.7+6
      0.6+6 0.5+6 0.4+6 0.3+6 0.2+6 0.1+6 .09+6 .08+6 .07+6 .06+6
      .05+6 .04+6 .03+6 .025+6 .020+6 .015+6 .010+6  .005+6 t
56$$ f0 t
end
```

5.5.2 MCNP Input Data

Included here are some of the input files used for the dose rate calculations that provide results listed in Tables 5.1 and 5.2. For the normal conditions of transport (NCT) cases, the detectors are set at 0.1 cm and 1 m from the drum side, top, and bottom surfaces. For the hypothetical accident conditions (HAC) cases, all cells and surfaces external to the containment vessel (CV) are eliminated, and the detectors are set at 1 m from the external surface of the CV. For photon dose-rate calculations for both NCT and HAC cases, the 47 energy group photon spectrum in Table 5.4 are used. For neutron and secondary photon dose-rate calculations for both NCT and HAC cases, the 18–27 energy group neutron spectra in Table 5.5 are used. The contribution of low energy spectra (Groups 1-17) to the neutron dose rate is neglected because the contribution to the dose rate from these groups is minimal. The secondary photon dose-rates are less than 1% of the neutron dose rates and the contribution from the secondary photon dose rates are shown as part of the neutron dose rates in Tables 5.1 and 5.2.

Representative input files used for the dose rates calculations are listed below.

Section	Description
5.5.2.1	NCT for 36-kg uranium metal photon side dose-rate calculations (cylindrical hemi-shell configuration source moved towards x-axis in CV)
5.5.2.2	NCT for 36-kg uranium metal photon top dose-rate calculations (cylinder configuration source moved to the top of CV)
5.5.2.3	NCT for 36-kg uranium metal neutron and secondary photon top and side dose-rate calculations (cylinder configuration source moved to the top of CV)
5.5.2.4	HAC for 36-kg uranium metal neutron and secondary photon side dose-rate calculations (cylindrical hemi-shell configuration source moved towards x-axis in CV)
5.5.2.5	NCT for 24-kg uranium oxide photon side dose-rate calculations (cylindrical configuration source)

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5.5.2.1 NCT for 36-kg uranium metal photon side dose-rate calculations (cylindrical hemi-shell configuration source moved towards x-axis in CV)

```
photon_hemishell.inp - ES-3100: 2015 HEU detailed model (primary photons)
c                U-metal case (76.2 cm ht cylindrical hemishell
c                density = 18.82 g/cc; IR=4.9337 cm; OR=6.35 cm)
c    configuration
c    (side dose rate calculations)
c    source in cylindrical hemishell form sitting at the bottom of CV for
c    side dose rate calculations for 2015 calculation Revision
c
c    mcnp geometry model (CV and outside) is identical to criticality model
c    (KENO Model).
c    47 energy groups are used for the photon spectrum.  In the older version,
c    18 energy groups were used.
c    surface detectors are placed 0.1 cm and 100 cm way from the surfaces
c    and detectors are placed on the side, top, and bottom.
c    point detectors are used for dose rate calculations (used for results).
c    segmented volume detectors are used for side dose rate calculations (for checking).
c    volume detectors are used to check bottom and top dose rate calculations.
c    ANSI/ANS-6.1.1-1977 Dose conversion factors are used,
c    multiplied by 1000 to convert from rem to mrem
c
c   mode p - (primary  photons)
c
c    --------------
c     Cell Cards
c    --------------
c
    1     0             -1 401      imp:n,p=1 $ inner void
    2     1   -18.82    -2 1 401    imp:n,p=1 $ source shell
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51     2   -7.92     -51      imp:n,p=1 $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61     4   -0.321    -61      imp:n,p=1 $ bottom kaolite
   62     2   -7.92     -62 61   imp:n,p=1 $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71     2   -7.92     -71      imp:n,p=1 $ bottom liner
   72     4   -0.321    -72 71   imp:n,p=1 $ bottom liner+kaolite
   73     2   -7.92     -73 72   imp:n,p=1 $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81     0             -81      imp:n,p=1 $ void
   82     3   -1.2      -82 81   imp:n,p=1 $ void+pad
   83     2   -7.92     -83 82   imp:n,p=1 $ void+pad+liner
   84     5   -1.4586   -84 83   imp:n,p=1 $ void+pad+liner+277-4
   85     2   -7.92     -85 84   imp:n,p=1 $ void+pad+liner+277-4+liner
   86     4   -0.321    -86 85   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite
   87     2   -7.92     -87 86   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91     2   -7.92     -91      imp:n,p=1 $ cv bottom
```

```
   92     0             -92 91   imp:n,p=1 $ cv bottom+void
   93     2   -7.92     -93 92   imp:n,p=1 $ cv bottom+void+liner
   94     5   -1.4586   -94 93   imp:n,p=1 $ cv bottom+void+liner+277-4
   95     2   -7.92     -95 94   imp:n,p=1 $ cv bottom+void+liner+277-4+liner
   96     4   -0.321    -96 95   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite
   97     2   -7.92     -97 96   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101     0             -101 #1 #2  imp:n,p=1 $ cv void
  102     2   -7.92     -102 101  imp:n,p=1 $ cv void+ss
  103     0             -103 102  imp:n,p=1 $ cv void+ss+void
  104     2   -7.92     -104 103  imp:n,p=1 $ cv void+ss+void+liner
  105     5   -1.4586   -105 104  imp:n,p=1 $ cv void+ss+void+liner+277-4
  106     2   -7.92     -106 105  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner
  107     4   -0.321    -107 106  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite
  108     2   -7.92     -108 107  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite+drum
  109     0             -109 108  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110     0             -110 109  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111     0             -111 110  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.5857 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
c
c 111     0             -111      imp:n,p=1 $ cv void (to be filled by content can)
  112     0             -112      imp:n,p=1 $ cv void
  113     2   -7.92     -113 112  imp:n,p=1 $ cv void+ss
  114     0             -114 113  imp:n,p=1 $ cv void+ss+void
  115     2   -7.92     -115 114  imp:n,p=1 $ cv void+ss+void+liner
  116     4   -0.321    -116 115  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  117     2   -7.92     -117 116  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 4) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122     0             -122      imp:n,p=1 $ cv void
  123     2   -7.92     -123 122  imp:n,p=1 $ cv void+ss
  124     0             -124 123  imp:n,p=1 $ cv void+ss+void
  125     2   -7.92     -125 124  imp:n,p=1 $ cv void+ss+void+liner
  126     4   -0.321    -126 125  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  127     2   -7.92     -127 126  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132     0             -132      imp:n,p=1 $ cv void
  133     2   -7.92     -133 132  imp:n,p=1 $ cv void+ss
  134     3   -1.20     -134 133  imp:n,p=1 $ cv void+ss+rubber
  135     0             -135 134  imp:n,p=1 $ cv void+ss+rubber+void
  136     2   -7.92     -136 135  imp:n,p=1 $ cv void+ss+rubber+void+liner
  137     4   -0.321    -137 136  imp:n,p=1 $ cv void+ss+rubber+void+liner+kaolite
  138     2   -7.92     -138 137  imp:n,p=1 $ cv +void+ss+rubber+void+liner+kaolite+drum
c
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (middle section of CV flange)
c
  141     2   -7.92     -141      imp:n,p=1 $ ss
  142     3   -1.20     -142 141  imp:n,p=1 $ ss+rubber
```

```
  143     0             -143 142  imp:n,p=1 $ ss+rubber+void
  144     2   -7.92     -144 143  imp:n,p=1 $ ss+rubber+void+liner
  145     4   -0.321    -145 144  imp:n,p=1 $ ss+rubber+void+liner+kaolite
  146     2   -7.92     -146 145  imp:n,p=1 $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151     3   -1.20     -151      imp:n,p=1 $ rubber
  152     0             -152 151  imp:n,p=1 $ rubber+void
  153     2   -7.92     -153 152  imp:n,p=1 $ rubber+void+liner
  154     4   -0.321    -154 153  imp:n,p=1 $ rubber+void+liner+kaolite
  155     2   -7.92     -155 154  imp:n,p=1 $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161     0             -161      imp:n,p=1 $ void
  162     2   -7.92     -162 161  imp:n,p=1 $ void+liner
  163     4   -0.321    -163 162  imp:n,p=1 $ void+liner+kaolite
  164     2   -7.92     -164 163  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171     0             -171      imp:n,p=1 $ void
  172     2   -7.92     -172 171  imp:n,p=1 $ void+liner
  173     4   -0.321    -173 172  imp:n,p=1 $ void+liner+kaolite
  174     2   -7.92     -174 173  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181     0             -181      imp:n,p=1 $ void
  182     2   -7.92     -182 181  imp:n,p=1 $ void+liner
  183     4   -0.321    -183 182  imp:n,p=1 $ void+liner+kaolite
  184     2   -7.92     -184 183  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191     2   -7.92     -191      imp:n,p=1 $ ss (liner)
  192     0             -192 191  imp:n,p=1 $ ss+void
  193     2   -7.92     -193 192  imp:n,p=1 $ ss+void+liner
  194     4   -0.321    -194 193  imp:n,p=1 $ ss+void+liner+kaolite
  195     2   -7.92     -195 194  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201     4   -0.321    -201      imp:n,p=1 $ kaolite
  202     2   -7.92     -202 201  imp:n,p=1 $ kaolite+liner
  203     0             -203 202  imp:n,p=1 $ kaolite+liner+void
  204     2   -7.92     -204 203  imp:n,p=1 $ kaolite+liner+void+liner
  205     4   -0.321    -205 204  imp:n,p=1 $ kaolite+liner+void+liner+kaolite
  206     2   -7.92     -206 205  imp:n,p=1 $ kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211     4   -0.321    -211      imp:n,p=1 $ kaolite
  212     2   -7.92     -212 211  imp:n,p=1 $ kaolite+liner
  213     0             -213 212  imp:n,p=1 $ kaolite+liner+void
  214     2   -7.92     -214 213  imp:n,p=1 $ kaolite+liner+void+liner
  215     2   -7.92     -215 214  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  216     4   -0.321    -216 215  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite
  217     2   -7.92     -217 216  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite+drum
```

```
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221     4   -0.321    -221      imp:n,p=1 $ kaolite
  222     2   -7.92     -222 221  imp:n,p=1 $ kaolite+liner
  223     0             -223 222  imp:n,p=1 $ kaolite+liner+void
  224     2   -7.92     -224 223  imp:n,p=1 $ kaolite+liner+void+liner
  225     2   -7.92     -225 224  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  226     2   -7.92     -226 225  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231     2   -7.92     -231      imp:n,p=1 $ liner
  232     0             -232 231  imp:n,p=1 $ liner+void
  233     2   -7.92     -233 232  imp:n,p=1 $ liner+void+liner
  234     2   -7.92     -234 233  imp:n,p=1 $ liner+void+liner+iron-angle
  235     2   -7.92     -235 234  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241     0             -241      imp:n,p=1 $ liner+void
  242     2   -7.92     -242 241  imp:n,p=1 $ liner+void+liner
  243     2   -7.92     -243 242  imp:n,p=1 $ liner+void+liner+iron-angle
  244     2   -7.92     -244 243  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251     2   -7.92     -251      imp:n,p=1 $ ss lid
  252     0             -252 251  imp:n,p=1 $ ss lid+void
  253     2   -7.92     -253 252  imp:n,p=1 $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261     0             -261 #502      imp:n,p=1 $ void
  262     2   -7.92     -262 261  imp:n,p=1 $ void+ss lid
  263     0             -263 262  imp:n,p=1 $ void+ss lid+void
  264     2   -7.92     -264 263  imp:n,p=1 $ void+ss lid+void+drum
c
c   Put volume source for top and bottom detectors
c
  501     0             -501      imp:n,p=1 $ bottom surface detector
  502     0             -502      imp:n,p=1 $ top surface detector
  551     0             -551      imp:n,p=1 $ 1 m from bottom surface - detector
  552     0             -552      imp:n,p=1 $ 1 m from top surface - detector
c
  998     0             -999      51 62 73 87 97 111 117 127 138 146 155
                                  164 174 184 195 206 217 226 235 244 253
                                  264 501 502 551 552
                                  imp:n,p=1 $ inside boundary
  999     0              999      imp:n,p=0 $ outside world

c    ------------------
c    Surface Cards
c    ------------------
c
    1  rcc  0.0 0.0 12.4968   0.0 0.0  76.20   4.9337  $ inner radius cylindrical hemishell
source
    2  rcc  0.0 0.0 12.4968   0.0 0.0  76.20   6.35    $ outer radius cylindrical hemishell
source
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
```

```
c
   51  rcc  0.0 0.0  0.0     0.0 0.0 0.2667   23.3299  $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.1775  $ bottom kaolite
   62  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.3299  $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  11.0744  $ bottom liner
   72  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.1775  $ bottom liner+kaolite
   73  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.3299  $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    3.1750  $ void
   82  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    7.9248  $ void+pad
   83  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    8.0772  $ void+pad+liner
   84  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   10.9220  $ void+pad+liner+277-4
   85  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   11.0744  $ void+pad+liner+277-4+liner
   86  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.1775  $ void+pad+liner+277-4+liner+kaolite
   87  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.3299  $
void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    6.6802  $ cv bottom
   92  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    7.9248  $ cv bottom+void
   93  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    8.0772  $ cv bottom+void+liner
   94  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   10.9220  $ cv bottom+void+liner+277-4
   95  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   11.0744  $ cv bottom+void+liner+277-4+liner
   96  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.1775  $ cv
bottom+void+liner+277-4+liner+kaolite
   97  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.3299  $ cv
bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.4262  $ cv void
  102  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.6802  $ cv void+ss
  103  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  7.9248  $ cv void+ss+void
  104  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  8.0772  $ cv void+ss+void+liner
  105  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 10.9220  $ cv void+ss+void+liner+277-4
  106  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 11.0744  $ cv void+ss+void+liner+277-4+liner
  107  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.1775  $ cv
void+ss+void+liner+277-4+liner+kaolite
  108  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum
  109  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 24.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 123.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 124.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.58579 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
c
  112  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.4262  $ cv void
  113  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.6802  $ cv void+ss
```

```
  114  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  7.9248  $ cv void+ss+void
  115  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 11.0744  $ cv void+ss+void+liner
  116  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.1775  $ cv void+ss+void+liner+kaolite
  117  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 5) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.4262  $ cv void
  123  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.6802  $ cv void+ss
  124  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 10.9220  $ cv void+ss+void
  125  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 11.0744  $ cv void+ss+void+liner
  126  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.1775  $ cv void+ss+void+liner+kaolite
  127  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  6.4262  $ cv void
  133  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  9.5250  $ cv void+ss
  134  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.0330  $ cv void+ss+rubber
  135  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.9220  $ cv void+ss+rubber+void
  136  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 11.0744  $ cv void+ss+rubber+void+liner
  137  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.1775  $ cv void+ss+rubber+void+liner+kaolite
  138  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.3299  $ cv
void+ss+rubber+void+liner+kaolite+drum
c
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (lower section of CV flange)
c
  141  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210  9.5250  $ ss
  142  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.0330  $ ss+rubber
  143  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.9220  $ ss+rubber+void
  144  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 11.0744  $ ss+rubber+void+liner
  145  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.1775  $ ss+rubber+void+liner+kaolite
  146  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.3299  $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.0330  $ rubber
  152  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.9220  $ rubber+void
  153  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 11.0744  $ rubber+void+liner
  154  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.1775  $ rubber+void+liner+kaolite
  155  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.3299  $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 10.9220  $ void
  162  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 11.0744  $ void+liner
  163  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.1775  $ void+liner+kaolite
  164  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 10.9220  $ void
  172  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 18.7579  $ void+liner
  173  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.1775  $ void+liner+kaolite
  174  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
```

```
c
  181  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.6055  $ void
  182  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.7579  $ void+liner
  183  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.1775  $ void+liner+kaolite
  184  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.3299  $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.2499   $ ss (liner)
  192  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.6055   $ ss+void
  193  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.7579   $ ss+void+liner
  194  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.1775   $ ss+void+liner+kaolite
  195  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.3299   $ ss+void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.0975  $ kaolite
  202  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.2499  $ kaolite +liner
  203  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.6055  $ kaolite+liner+void
  204  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.7579  $ kaolite+liner+void+liner
  205  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.1775  $ kaolite+liner+void+liner+kaolite
  206  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.3299  $
kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.0975  $ kaolite
  212  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.2499  $ kaolite +liner
  213  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.6055  $ kaolite+liner+void
  214  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.7579  $ kaolite+liner+void+liner
  215  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  19.3929  $ kaolite+liner+void+liner+iron-angle
  216  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.1775  $
kaolite+liner+void+liner+iron-angle+kaolite
  217  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.3299  $
kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.0975  $ kaolite
  222  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.2499  $ kaolite +liner
  223  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.6055  $ kaolite+liner+void
  224  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.7579  $ kaolite+liner+void+liner
  225  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.1775  $ kaolite+liner+void+liner+iron-angle
  226  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.3299  $
kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.2499  $ ss liner
  232  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.6055  $ ss liner+void
  233  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.7579  $ ss liner+void+liner
  234  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.1775  $ ss liner+void+liner+iron-angle
  235  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.3299  $ ss liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.6055  $ void
  242  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.7579  $ void+liner
  243  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.1775  $ void+liner+iron-angle
  244  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.3299  $ void+liner+iron-angle+drum
c
```

```
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1140  $ ss lid
  252  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1775  $ ss lid+void
  253  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.3299  $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  22.9616  $ void
  262  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1140  $ void+ss lid
  263  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1775  $ void+ss lid+void
  264  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.3299  $ void+ss lid+void+drum
c
c   Segmented side volume detectors
c
  301  pz 13
  302  pz 14
  303  pz 15
  304  pz 16
  305  pz 17
  306  pz 18
  307  pz 19
  308  pz 20
  309  pz 21
  310  pz 22
  311  pz 23
  312  pz 24
  313  pz 25
  314  pz 26
  315  pz 27
  316  pz 28
  317  pz 29
  318  pz 30
  319  pz 31
  320  pz 32
  321  pz 33
  322  pz 34
  323  pz 35
  324  pz 36
  325  pz 37
  326  pz 38
  327  pz 39
  328  pz 40
  329  pz 41
  330  pz 42
  331  pz 43
  332  pz 44
  333  pz 45
  334  pz 46
  335  pz 47
  336  pz 48
  337  pz 49
  338  pz 50
  339  pz 51
  340  pz 52
  341  pz 53
  342  pz 54
  343  pz 55
  344  pz 56
  345  pz 57
  346  pz 58
```

```
  347  pz 59
  348  pz 60
  349  pz 61
  350  pz 62
  351  pz 63
  352  pz 64
  353  pz 65
  354  pz 66
  355  pz 67
  356  pz 68
  357  pz 69
  358  pz 70
  359  pz 71
  360  pz 72
  361  pz 73
  362  pz 74
  363  pz 75
  364  pz 76
  365  pz 77
  366  pz 78
  367  pz 79
  368  pz 80
  369  pz 81
  370  pz 82
  371  pz 83
  372  pz 84
  373  pz 85
  374  pz 86
  375  pz 87
  376  pz 88
  377  pz 89
c
c   plane perpendicular to x-axis
c
  401  px 0
c
c   Put volume source for top and bottom detectors
c
  501  rcc 0.0 0.0 -0.5  0.0 0.0  0.5  1.0          $ bottom surface vol detector
  502  rcc 0.0 0.0 108.73739  0.0 0.0  0.5  1.0     $ top surface vol detector
  551  rcc 0.0 0.0 -100.5  0.0 0.0  0.5  1.0        $ 1 m from bottom surface - vol detector
  552  rcc 0.0 0.0 208.73739  0.0 0.0  0.5  1.0     $ 1 m from top surface - vol detector
c
  999  sph  0.0 0.0  0.000  999.0                          $ boundary
c

c    ----------------------
c    Data Cards
c    ----------------------
mode  p
c
c      uranium metal (18.82 g/cc)
c
m1    92235.70c  -0.9500    $ U-235           95.0000  wt%
      92238.70c  -0.0500    $ U-238            5.0000  wt%
c
c      ss 304 (7.92 g/cc)
c
m2     6000.70c  -0.00080    $ Carbon(C)        0.0800  wt%
      14028.70c  -0.00919    $ Silicon(Si-28)   0.9187  wt%
      14029.70c  -0.00048    $ Si-29            0.0483  wt%
```

```
      14030.70c  -0.00033    $ Si-30            0.0330  wt%
      15031.70c  -0.00045    $ Phosphorus(P)    0.0450  wt%
      24050.70c  -0.00793    $ Cromium (Cr-50)  0.7930  wt%
      24052.70c  -0.15903    $ Cr-52           15.9029  wt%
      24053.70c  -0.01838    $ Cr-53            1.8380  wt%
      24054.70c  -0.00466    $ Cr-54            0.4661  wt%
      25055.70c  -0.02000    $ Manganese (Mn)   2.0000  wt%
      26054.70c  -0.03860    $ Iron (Fe-54)     3.8602  wt%
      26056.70c  -0.62838    $ Fe-56           62.8377  wt%
      26057.70c  -0.01477    $ Fe-57            1.4772  wt%
      26058.70c  -0.00200    $ Fe-58            0.2000  wt%
      28058.70c  -0.06384    $ Nickel (Ni-58)   6.3838  wt%
      28060.70c  -0.02544    $ Ni-60            2.5437  wt%
      28061.70c  -0.00112    $ Ni-61            0.1124  wt%
      28062.70c  -0.00364    $ Ni-62            0.3643  wt%
      28064.70c  -0.00096    $ Ni-64            0.0958  wt%
c
c      rubber foam (1.20 g/cc)
c
m3     1001.70c  -0.08157    $ Hydrogen (H)     8.1573 wt%
       6000.70c  -0.32377    $ Carbon (C)      32.3767 wt%
       8016.70c  -0.21520    $ Oxygen (O-16)   21.5196 wt%
       8017.70c  -0.00059    $ O-17 & O-18      0.0586 wt%
      14028.70c  -0.34806    $ Silicon(Si-28)  34.8061 wt%
      14029.70c  -0.01831    $ Si-29            1.8314 wt%
      14030.70c  -0.01250    $ Si-30            1.2503 wt%
c
c      kaolite (0.321 g/cc)
c
m4     8016.70c -0.4092    $ Oxygen (O-16)   40.9231 wt%
       8017.70c -0.0011    $ Oxygen (17&18)   0.1114 wt%
      11023.70c -0.0148    $ Sodium (Na)      1.4837 wt%
      12024.70c -0.0786    $ Magnesium (Mg-24)6.1579 wt%
      12025.70c -0.0081    $ Mg-25            0.8121 wt%
      12026.70c -0.0093    $ Mg-26            0.9298 wt%
      13027.70c -0.0508    $ Al               5.0808 wt%
      14028.70c -0.1576    $ Silicon (Si-28) 15.7596 wt%
      14029.70c -0.0083    $ Si-29            0.8292 wt%
      14030.70c -0.0057    $ Si-30            0.5661 wt%
      20040.70c -0.2121    $ Calcium (Ca-40  21.2086 wt%
      20042.70c -0.0015    $ Ca-42            0.1490 wt%
      20043.70c -0.0003    $ Ca-43            0.0318 wt%
      20044.70c -0.0050    $ Ca-44            0.5031 wt%
      20046.70c -0.00001   $ Ca-46            0.0010 wt%
      20048.70c -0.0005    $ Ca-48            0.0491 wt%
      22046.70c -0.0006    $ Titanium (Ti-46) 0.0570 wt%
      22047.70c -0.0005    $ Ti-47            0.0525 wt%
      22048.70c -0.0053    $ Ti-48            0.5311 wt%
      22049.70c -0.0004    $ Ti-49            0.0398 wt%
      22050.70c -0.0004    $ Ti-50            0.0407 wt%
      26054.70c -0.0026    $ Iron (Fe-54)     0.2646 wt%
      26056.70c -0.0431    $ Fe-56            4.3066 wt%
      26057.70c -0.0010    $ Fe-57            0.1012 wt%
      26058.70c -0.0001    $ Fe-58            0.0137 wt%
c
c      Cat 277-4 (1.4586 g/cc)
c
m5     1001.70c -0.0285    $ Hydrogen         2.8475 wt%
       5010.70c -0.0066    $ Boron (B-10)     0.6591 wt%
       5011.70c -0.0297    $ Boron (B-11)     2.9726 wt%
       6000.70c -0.0136    $ Carbon (C)       1.3609 wt%
```

```
       7014.70c -0.0001    $ Nitrogen (N)     0.0100 wt%
       8016.70c -0.5325    $ Oxygen (O-16)   53.2515 wt%
       8017.70c -0.0015    $ Oxygen (17&18)   0.1450 wt%
      11023.70c -0.0008    $ Sodium (Na)      0.0833 wt%
      12024.70c -0.0019    $ Magnesium (Mg-24)0.1867 wt%
      12025.70c -0.0002    $ Mg-25            0.0246 wt%
      12026.70c -0.0003    $ Mg-26            0.0282 wt%
      13027.70c -0.2769    $ Al              27.6937 wt%
      14028.70c -0.0161    $ Silicon (Si-28)  1.6075 wt%
      14029.70c -0.0008    $ Si-29            0.0846 wt%
      14030.70c -0.0006    $ Si-30            0.0577 wt%
      16032.70c -0.0021    $ Sulfur (S-32)    0.2071 wt%
      16033.70c -0.00002   $ S-33             0.0017 wt%
      16034.70c -0.0001    $ S-34             0.0098 wt%
      16036.70c -0.0000002 $ S-36             0.00002 wt%
      20040.70c -0.0811    $ Calcium (Ca-40)  8.1125 wt%
      20042.70c -0.0006    $ Ca-42            0.0569 wt%
      20043.70c -0.0001    $ Ca-43            0.0121 wt%
      20044.70c -0.0019    $ Ca-44            0.1920 wt%
      20046.70c -0.000004  $ Ca-46            0.0004 wt%
      20048.70c -0.0002    $ Ca-48            0.0188 wt%
      26054.70c -0.0002    $ Iron (Fe-54)     0.0212 wt%
      26056.70c -0.0035    $ Fe-56            0.3453 wt%
      26057.70c -0.00008   $ Fe-57            0.0081 wt%
      26058.70c -0.00001   $ Fe-58            0.0011 wt%
c
c       air (1.225e-3 g/cc)
c
m6      7014.70c  -0.755   $ Nitrogen (N-14) 75.5000 wt%
        8016.70c  -0.232   $ Oxygen (O-16)   23.2000 wt%
       18000.70c  -0.013   $ Argon (Ar-40)    1.3000 wt%
c
c      uranium metal (10.960 g/cc - variable)
c
m7     8016.70c  -0.1198    $ O               11.9800  wt%
      92235.70c  -0.8362    $ U-235           83.6200  wt%
      92238.70c  -0.0440    $ U-238            4.4000  wt%
c
c    source in ES-3100 - cylindrical hemishell at the bottom of CV
c                        (H = 76.2 cm; IR = 4.9337 cm; OR = 6.35 cm)
c
c   photon source - 3.011e+06 photons/sec/gm basis
c   material used - 36 kg U-mass
c   dose conversion factor (mrem/hr)/(photons/cm2-s) used
c   source term, wgt = 3.011e+06 * 36.0e+03  = 1.08396e+11
c
sdef cell=2 pos=0 0 12.4968 rad=d1 ext=d2  erg=d3 axs=0 0 1 wgt=1.08396e+11
c
c  source position
c
si1    4.9337   6.35         $ radial
sp1    -21       1
si2    0.0     76.20         $ axial
sp2     0        1
c
c  ORIGEN photon spectrum
c
si3     5.00e-03     1.00e-02    1.50e-02     2.00e-02    2.50e-02     3.00e-02
        4.00e-02     5.00e-02    6.00e-02     7.00e-02    8.00e-02     9.00e-02
        1.00e-01     2.00e-01    3.00e-01     4.00e-01    5.00e-01     6.00e-01
        7.00e-01     8.00e-01    9.00e-01     1.00e+00    1.10e+00     1.20e+00
```

```
        1.30e+00     1.40e+00    1.50e+00     1.60e+00    1.70e+00     1.80e+00
        1.90e+00     2.00e+00    2.10e+00     2.20e+00    2.30e+00     2.40e+00
        2.50e+00     2.60e+00    2.70e+00     2.80e+00    2.90e+00     3.00e+00
        3.50e+00     4.00e+00    5.00e+00     6.50e+00    8.00e+00    10.00e+00
sp3     0.0          8.515e+04   1.700e+06    7.313e+03   3.595e+03    1.230e+05
        5.112e+03    6.605e+03   2.147e+05    1.779e+03   1.941e+04    1.085e+05
        2.244e+05    1.328e+05   5.245e+04    2.819e+05   1.556e+04    1.225e+04
        1.485e+02    2.705e+03   1.802e+03    4.068e+02   2.527e+02    2.157e+01
        2.105e+01    2.990e+01   1.300e+01    1.386e+02   4.719e+02    5.522e+00
        2.999e+01    4.918e+00   1.599e-02    1.308e-02   7.152e-02    5.321e-04
        1.584e-02    6.552e-05   1.062e+04    1.108e-02   1.917e-04    3.408e-04
        6.039e-01    3.876e-01   2.959e-03    1.134e-03   2.131e-04    4.388e-05
c
fq0 f s d
c
c  point detectors for primary photons
c
f5:p    23.4299  0.0     50.5968   0.0     $ side surface - detector
f15:p    0.0     0.0    108.83739  0.0     $ top surface - detector
f25:p    0.0     0.0     -0.1      0.0     $ bottom surface - detector
f35:p  123.3299  0.0     50.5968   0.0     $ 1m from side surface - detector
f45:p    0.0     0.0    208.73739  0.0     $ 1m from top surface - detector
f55:p    0.0     0.0   -100.0      0.0     $ 1m from bottom surface - detector
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                  (mrem/hr)/(photons/cm2-s)
c
de0         0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df0      3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
         6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
         1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
         3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
         5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
         1.03e-2   1.18e-2   1.33e-2
c
prdmp  j  50000000 0 10
ctme 3000
```

5.5.2.2 NCT for 36-kg uranium metal photon top dose-rate calculations (cylinder configuration source moved to the top of CV)

```
photon_top.inp - ES-3100: 2015 HEU detailed mmodel (primary photons)
c
c    NCT configuration
c    (top dose rate calculations)
c    source in cylindrical form sitting at the top of CV for
c    top dose rate calculations for 2015 Revision
c
c    mcnp geometry model (CV and outside) is identical to criticality model
c    (KENO Model).
c    47 energy groups are used for the photon spectrum.  In the older version,
c    18 energy groups were used.
c    surface detectors are placed 0.1 cm and 100 cm way from the surfaces
c    and detectors are placed on the side, top, and bottom.
```

```
c    point detectors are used for dose rate calculations (used for results).
c    segmented volume detectors are used for side dose rate calculations (for checking).
c    volume detectors are used to check bottom and top dose rate calculations.
c    ANSI/ANS-6.1.1-1977 Dose conversion factors are used,
c    multiplied by 1000 to convert from rem to mrem
c
c   mode p - (primary  photons)
c
c    --------------
c     Cell Cards
c    --------------
c
    1     1   -18.82    -1       imp:n,p=1 $ source cylinder
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51     2   -7.92     -51      imp:n,p=1 $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61     4   -0.321    -61      imp:n,p=1 $ bottom kaolite
   62     2   -7.92     -62 61   imp:n,p=1 $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71     2   -7.92     -71      imp:n,p=1 $ bottom liner
   72     4   -0.321    -72 71   imp:n,p=1 $ bottom liner+kaolite
   73     2   -7.92     -73 72   imp:n,p=1 $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81     0             -81      imp:n,p=1 $ void
   82     3   -1.2      -82 81   imp:n,p=1 $ void+pad
   83     2   -7.92     -83 82   imp:n,p=1 $ void+pad+liner
   84     5   -1.4586   -84 83   imp:n,p=1 $ void+pad+liner+277-4
   85     2   -7.92     -85 84   imp:n,p=1 $ void+pad+liner+277-4+liner
   86     4   -0.321    -86 85   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite
   87     2   -7.92     -87 86   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91     2   -7.92     -91      imp:n,p=1 $ cv bottom
   92     0             -92 91   imp:n,p=1 $ cv bottom+void
   93     2   -7.92     -93 92   imp:n,p=1 $ cv bottom+void+liner
   94     5   -1.4586   -94 93   imp:n,p=1 $ cv bottom+void+liner+277-4
   95     2   -7.92     -95 94   imp:n,p=1 $ cv bottom+void+liner+277-4+liner
   96     4   -0.321    -96 95   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite
   97     2   -7.92     -97 96   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101     0             -101 #1   imp:n,p=1 $ cv void
  102     2   -7.92     -102 101  imp:n,p=1 $ cv void+ss
  103     0             -103 102  imp:n,p=1 $ cv void+ss+void
  104     2   -7.92     -104 103  imp:n,p=1 $ cv void+ss+void+liner
  105     5   -1.4586   -105 104  imp:n,p=1 $ cv void+ss+void+liner+277-4
  106     2   -7.92     -106 105  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner
  107     4   -0.321    -107 106  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite
  108     2   -7.92     -108 107  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite+drum
  109     0             -109 108  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
```

```
  110     0             -110 109  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111     0             -111 110  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.5857 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
c
  112     0             -112 #1   imp:n,p=1 $ cv void
  113     2   -7.92     -113 112  imp:n,p=1 $ cv void+ss
  114     0             -114 113  imp:n,p=1 $ cv void+ss+void
  115     2   -7.92     -115 114  imp:n,p=1 $ cv void+ss+void+liner
  116     4   -0.321    -116 115  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  117     2   -7.92     -117 116  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 4) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122     0             -122 #1   imp:n,p=1 $ cv void
  123     2   -7.92     -123 122  imp:n,p=1 $ cv void+ss
  124     0             -124 123  imp:n,p=1 $ cv void+ss+void
  125     2   -7.92     -125 124  imp:n,p=1 $ cv void+ss+void+liner
  126     4   -0.321    -126 125  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  127     2   -7.92     -127 126  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132     0             -132 #1   imp:n,p=1 $ cv void
  133     2   -7.92     -133 132  imp:n,p=1 $ cv void+ss
  134     3   -1.20     -134 133  imp:n,p=1 $ cv void+ss+rubber
  135     0             -135 134  imp:n,p=1 $ cv void+ss+rubber+void
  136     2   -7.92     -136 135  imp:n,p=1 $ cv void+ss+rubber+void+liner
  137     4   -0.321    -137 136  imp:n,p=1 $ cv void+ss+rubber+void+liner+kaolite
  138     2   -7.92     -138 137  imp:n,p=1 $ cv +void+ss+rubber+void+liner+kaolite+drum
c
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (middle section of CV flange)
c
  141     2   -7.92     -141 #1   imp:n,p=1 $ ss
  142     3   -1.20     -142 141  imp:n,p=1 $ ss+rubber
  143     0             -143 142  imp:n,p=1 $ ss+rubber+void
  144     2   -7.92     -144 143  imp:n,p=1 $ ss+rubber+void+liner
  145     4   -0.321    -145 144  imp:n,p=1 $ ss+rubber+void+liner+kaolite
  146     2   -7.92     -146 145  imp:n,p=1 $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151     3   -1.20     -151      imp:n,p=1 $ rubber
  152     0             -152 151  imp:n,p=1 $ rubber+void
  153     2   -7.92     -153 152  imp:n,p=1 $ rubber+void+liner
  154     4   -0.321    -154 153  imp:n,p=1 $ rubber+void+liner+kaolite
  155     2   -7.92     -155 154  imp:n,p=1 $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161     0             -161      imp:n,p=1 $ void
  162     2   -7.92     -162 161  imp:n,p=1 $ void+liner
  163     4   -0.321    -163 162  imp:n,p=1 $ void+liner+kaolite
  164     2   -7.92     -164 163  imp:n,p=1 $ void+liner+kaolite+drum
```

```
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171     0             -171      imp:n,p=1 $ void
  172     2   -7.92     -172 171  imp:n,p=1 $ void+liner
  173     4   -0.321    -173 172  imp:n,p=1 $ void+liner+kaolite
  174     2   -7.92     -174 173  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181     0             -181      imp:n,p=1 $ void
  182     2   -7.92     -182 181  imp:n,p=1 $ void+liner
  183     4   -0.321    -183 182  imp:n,p=1 $ void+liner+kaolite
  184     2   -7.92     -184 183  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191     2   -7.92     -191      imp:n,p=1 $ ss (liner)
  192     0             -192 191  imp:n,p=1 $ ss+void
  193     2   -7.92     -193 192  imp:n,p=1 $ ss+void+liner
  194     4   -0.321    -194 193  imp:n,p=1 $ ss+void+liner+kaolite
  195     2   -7.92     -195 194  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201     4   -0.321    -201      imp:n,p=1 $ kaolite
  202     2   -7.92     -202 201  imp:n,p=1 $ kaolite+liner
  203     0             -203 202  imp:n,p=1 $ kaolite+liner+void
  204     2   -7.92     -204 203  imp:n,p=1 $ kaolite+liner+void+liner
  205     4   -0.321    -205 204  imp:n,p=1 $ kaolite+liner+void+liner+kaolite
  206     2   -7.92     -206 205  imp:n,p=1 $ kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211     4   -0.321    -211      imp:n,p=1 $ kaolite
  212     2   -7.92     -212 211  imp:n,p=1 $ kaolite+liner
  213     0             -213 212  imp:n,p=1 $ kaolite+liner+void
  214     2   -7.92     -214 213  imp:n,p=1 $ kaolite+liner+void+liner
  215     2   -7.92     -215 214  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  216     4   -0.321    -216 215  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite
  217     2   -7.92     -217 216  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221     4   -0.321    -221      imp:n,p=1 $ kaolite
  222     2   -7.92     -222 221  imp:n,p=1 $ kaolite+liner
  223     0             -223 222  imp:n,p=1 $ kaolite+liner+void
  224     2   -7.92     -224 223  imp:n,p=1 $ kaolite+liner+void+liner
  225     2   -7.92     -225 224  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  226     2   -7.92     -226 225  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231     2   -7.92     -231      imp:n,p=1 $ liner
  232     0             -232 231  imp:n,p=1 $ liner+void
  233     2   -7.92     -233 232  imp:n,p=1 $ liner+void+liner
  234     2   -7.92     -234 233  imp:n,p=1 $ liner+void+liner+iron-angle
  235     2   -7.92     -235 234  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
```

```
  241     0             -241      imp:n,p=1 $ liner+void
  242     2   -7.92     -242 241  imp:n,p=1 $ liner+void+liner
  243     2   -7.92     -243 242  imp:n,p=1 $ liner+void+liner+iron-angle
  244     2   -7.92     -244 243  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251     2   -7.92     -251      imp:n,p=1 $ ss lid
  252     0             -252 251  imp:n,p=1 $ ss lid+void
  253     2   -7.92     -253 252  imp:n,p=1 $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261     0             -261 #502      imp:n,p=1 $ void
  262     2   -7.92     -262 261  imp:n,p=1 $ void+ss lid
  263     0             -263 262  imp:n,p=1 $ void+ss lid+void
  264     2   -7.92     -264 263  imp:n,p=1 $ void+ss lid+void+drum
c
c   Put volume source for top and bottom detectors
c
  501     0             -501      imp:n,p=1 $ bottom surface detector
  502     0             -502      imp:n,p=1 $ top surface detector
  551     0             -551      imp:n,p=1 $ 1 m from bottom surface - detector
  552     0             -552      imp:n,p=1 $ 1 m from top surface - detector
c
  998     0             -999      51 62 73 87 97 111 117 127 138 146 155
                                  164 174 184 195 206 217 226 235 244 253
                                  264 501 502 551 552
                                  imp:n,p=1 $ inside boundary
  999     0              999      imp:n,p=0 $ outside world

c    ------------------
c    Surface Cards
c    ------------------
c
    1  rcc  0.0 0.0 76.13649   0.0 0.0  15.1003  6.35 $ cylinder source at top of cv
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51  rcc  0.0 0.0  0.0     0.0 0.0 0.2667   23.3299  $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.1775  $ bottom kaolite
   62  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.3299  $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  11.0744  $ bottom liner
   72  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.1775  $ bottom liner+kaolite
   73  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.3299  $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    3.1750  $ void
   82  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    7.9248  $ void+pad
   83  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    8.0772  $ void+pad+liner
   84  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   10.9220  $ void+pad+liner+277-4
   85  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   11.0744  $ void+pad+liner+277-4+liner
   86  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.1775  $ void+pad+liner+277-4+liner+kaolite
```

```
   87  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.3299  $
void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    6.6802  $ cv bottom
   92  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    7.9248  $ cv bottom+void
   93  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    8.0772  $ cv bottom+void+liner
   94  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   10.9220  $ cv bottom+void+liner+277-4
   95  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   11.0744  $ cv bottom+void+liner+277-4+liner
   96  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.1775  $ cv
bottom+void+liner+277-4+liner+kaolite
   97  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.3299  $ cv
bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.4262  $ cv void
  102  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.6802  $ cv void+ss
  103  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  7.9248  $ cv void+ss+void
  104  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  8.0772  $ cv void+ss+void+liner
  105  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 10.9220  $ cv void+ss+void+liner+277-4
  106  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 11.0744  $ cv void+ss+void+liner+277-4+liner
  107  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.1775  $ cv
void+ss+void+liner+277-4+liner+kaolite
  108  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum
  109  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 24.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 123.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 124.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.58579 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
c
  112  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.4262  $ cv void
  113  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.6802  $ cv void+ss
  114  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  7.9248  $ cv void+ss+void
  115  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 11.0744  $ cv void+ss+void+liner
  116  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.1775  $ cv void+ss+void+liner+kaolite
  117  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 5) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.4262  $ cv void
  123  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.6802  $ cv void+ss
  124  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 10.9220  $ cv void+ss+void
  125  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 11.0744  $ cv void+ss+void+liner
  126  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.1775  $ cv void+ss+void+liner+kaolite
  127  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  6.4262  $ cv void
  133  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  9.5250  $ cv void+ss
  134  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.0330  $ cv void+ss+rubber
  135  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.9220  $ cv void+ss+rubber+void
```

```
  136  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 11.0744  $ cv void+ss+rubber+void+liner
  137  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.1775  $ cv void+ss+rubber+void+liner+kaolite
  138  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.3299  $ cv
void+ss+rubber+void+liner+kaolite+drum
c
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (lower section of CV flange)
c
  141  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210  9.5250  $ ss
  142  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.0330  $ ss+rubber
  143  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.9220  $ ss+rubber+void
  144  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 11.0744  $ ss+rubber+void+liner
  145  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.1775  $ ss+rubber+void+liner+kaolite
  146  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.3299  $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.0330  $ rubber
  152  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.9220  $ rubber+void
  153  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 11.0744  $ rubber+void+liner
  154  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.1775  $ rubber+void+liner+kaolite
  155  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.3299  $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 10.9220  $ void
  162  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 11.0744  $ void+liner
  163  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.1775  $ void+liner+kaolite
  164  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 10.9220  $ void
  172  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 18.7579  $ void+liner
  173  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.1775  $ void+liner+kaolite
  174  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.6055  $ void
  182  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.7579  $ void+liner
  183  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.1775  $ void+liner+kaolite
  184  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.3299  $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.2499   $ ss (liner)
  192  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.6055   $ ss+void
  193  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.7579   $ ss+void+liner
  194  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.1775   $ ss+void+liner+kaolite
  195  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.3299   $ ss+void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.0975  $ kaolite
  202  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.2499  $ kaolite +liner
  203  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.6055  $ kaolite+liner+void
  204  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.7579  $ kaolite+liner+void+liner
  205  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.1775  $ kaolite+liner+void+liner+kaolite
```

```
  206  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.3299  $
kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.0975  $ kaolite
  212  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.2499  $ kaolite +liner
  213  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.6055  $ kaolite+liner+void
  214  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.7579  $ kaolite+liner+void+liner
  215  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  19.3929  $ kaolite+liner+void+liner+iron-angle
  216  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.1775  $
kaolite+liner+void+liner+iron-angle+kaolite
  217  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.3299  $
kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.0975  $ kaolite
  222  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.2499  $ kaolite +liner
  223  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.6055  $ kaolite+liner+void
  224  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.7579  $ kaolite+liner+void+liner
  225  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.1775  $ kaolite+liner+void+liner+iron-angle
  226  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.3299  $
kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.2499  $ ss liner
  232  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.6055  $ ss liner+void
  233  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.7579  $ ss liner+void+liner
  234  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.1775  $ ss liner+void+liner+iron-angle
  235  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.3299  $ ss liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.6055  $ void
  242  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.7579  $ void+liner
  243  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.1775  $ void+liner+iron-angle
  244  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.3299  $ void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1140  $ ss lid
  252  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1775  $ ss lid+void
  253  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.3299  $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  22.9616  $ void
  262  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1140  $ void+ss lid
  263  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1775  $ void+ss lid+void
  264  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.3299  $ void+ss lid+void+drum
c
c   Segmented side volume detectors
c
  301  pz 13
  302  pz 14
  303  pz 15
  304  pz 16
  305  pz 17
  306  pz 18
```

```
307  pz 19
308  pz 20
309  pz 21
310  pz 22
311  pz 23
312  pz 24
313  pz 25
314  pz 26
315  pz 27
316  pz 28
317  pz 29
318  pz 30
319  pz 31
320  pz 32
321  pz 33
322  pz 34
323  pz 35
324  pz 36
325  pz 37
326  pz 38
327  pz 39
328  pz 40
329  pz 41
330  pz 42
331  pz 43
332  pz 44
333  pz 45
334  pz 46
335  pz 47
336  pz 48
337  pz 49
338  pz 50
339  pz 51
340  pz 52
341  pz 53
342  pz 54
343  pz 55
344  pz 56
345  pz 57
346  pz 58
347  pz 59
348  pz 60
349  pz 61
350  pz 62
351  pz 63
352  pz 64
353  pz 65
354  pz 66
355  pz 67
356  pz 68
357  pz 69
358  pz 70
359  pz 71
360  pz 72
361  pz 73
362  pz 74
363  pz 75
364  pz 76
365  pz 77
366  pz 78
367  pz 79
```

```
  368  pz 80
  369  pz 81
  370  pz 82
  371  pz 83
  372  pz 84
  373  pz 85
  374  pz 86
  375  pz 87
  376  pz 88
  377  pz 89
c
c   Put volume source for top and bottom detectors
c
  501  rcc 0.0 0.0 -0.5  0.0 0.0  0.5  1.0          $ bottom surface vol detector
  502  rcc 0.0 0.0 108.73739  0.0 0.0  0.5  1.0     $ top surface vol detector
  551  rcc 0.0 0.0 -100.5  0.0 0.0  0.5  1.0        $ 1 m from bottom surface - vol detector
  552  rcc 0.0 0.0 208.73739  0.0 0.0  0.5  1.0     $ 1 m from top surface - vol detector
c
  999  sph  0.0 0.0  0.000  999.0                         $ boundary
c

c    ----------------------
c    Data Cards
c    ----------------------
mode  p
c
c      uranium metal (18.82 g/cc)
c
m1    92235.70c  -0.9500    $ U-235           95.0000  wt%
      92238.70c  -0.0500    $ U-238            5.0000  wt%
c
c      ss 304 (7.92 g/cc)
c
m2     6000.70c  -0.00080    $ Carbon(C)        0.0800  wt%
      14028.70c  -0.00919    $ Silicon(Si-28)   0.9187  wt%
      14029.70c  -0.00048    $ Si-29            0.0483  wt%
      14030.70c  -0.00033    $ Si-30            0.0330  wt%
      15031.70c  -0.00045    $ Phosphorus(P)    0.0450  wt%
      24050.70c  -0.00793    $ Cromium (Cr-50)  0.7930  wt%
      24052.70c  -0.15903    $ Cr-52           15.9029  wt%
      24053.70c  -0.01838    $ Cr-53            1.8380  wt%
      24054.70c  -0.00466    $ Cr-54            0.4661  wt%
      25055.70c  -0.02000    $ Manganese (Mn)   2.0000  wt%
      26054.70c  -0.03860    $ Iron (Fe-54)     3.8602  wt%
      26056.70c  -0.62838    $ Fe-56           62.8377  wt%
      26057.70c  -0.01477    $ Fe-57            1.4772  wt%
      26058.70c  -0.00200    $ Fe-58            0.2000  wt%
      28058.70c  -0.06384    $ Nickel (Ni-58)   6.3838  wt%
      28060.70c  -0.02544    $ Ni-60            2.5437  wt%
      28061.70c  -0.00112    $ Ni-61            0.1124  wt%
      28062.70c  -0.00364    $ Ni-62            0.3643  wt%
      28064.70c  -0.00096    $ Ni-64            0.0958  wt%
c
c      rubber foam (1.20 g/cc)
c
m3     1001.70c  -0.08157    $ Hydrogen (H)     8.1573 wt%
       6000.70c  -0.32377    $ Carbon (C)      32.3767 wt%
       8016.70c  -0.21520    $ Oxygen (O-16)   21.5196 wt%
       8017.70c  -0.00059    $ O-17 & O-18      0.0586 wt%
      14028.70c  -0.34806    $ Silicon(Si-28)  34.8061 wt%
      14029.70c  -0.01831    $ Si-29            1.8314 wt%
```

```
      14030.70c  -0.01250    $ Si-30            1.2503 wt%
c
c      kaolite (0.321 g/cc)
c
m4     8016.70c -0.4092    $ Oxygen (O-16)   40.9231 wt%
       8017.70c -0.0011    $ Oxygen (17&18)   0.1114 wt%
      11023.70c -0.0148    $ Sodium (Na)      1.4837 wt%
      12024.70c -0.0616    $ Magnesium (Mg-24)6.1579 wt%
      12025.70c -0.0081    $ Mg-25            0.8121 wt%
      12026.70c -0.0093    $ Mg-26            0.9298 wt%
      13027.70c -0.0508    $ Al               5.0808 wt%
      14028.70c -0.1576    $ Silicon (Si-28) 15.7596 wt%
      14029.70c -0.0083    $ Si-29            0.8292 wt%
      14030.70c -0.0057    $ Si-30            0.5661 wt%
      20040.70c -0.2121    $ Calcium (Ca-40) 21.2086 wt%
      20042.70c -0.0015    $ Ca-42            0.1490 wt%
      20043.70c -0.0003    $ Ca-43            0.0318 wt%
      20044.70c -0.0050    $ Ca-44            0.5031 wt%
      20046.70c -0.00001   $ Ca-46            0.0010 wt%
      20048.70c -0.0005    $ Ca-48            0.0491 wt%
      22046.70c -0.0006    $ Titanium (Ti-46) 0.0570 wt%
      22047.70c -0.0005    $ Ti-47            0.0525 wt%
      22048.70c -0.0053    $ Ti-48            0.5311 wt%
      22049.70c -0.0004    $ Ti-49            0.0398 wt%
      22050.70c -0.0004    $ Ti-50            0.0407 wt%
      26054.70c -0.0026    $ Iron (Fe-54)     0.2646 wt%
      26056.70c -0.0431    $ Fe-56            4.3066 wt%
      26057.70c -0.0010    $ Fe-57            0.1012 wt%
      26058.70c -0.0001    $ Fe-58            0.0137 wt%
c
c      Cat 277-4 (1.4586 g/cc)
c
m5     1001.70c -0.0285    $ Hydrogen         2.8475 wt%
       5010.70c -0.0066    $ Boron (B-10)     0.6591 wt%
       5011.70c -0.0297    $ Boron (B-11)     2.9726 wt%
       6000.70c -0.0136    $ Carbon (C)       1.3609 wt%
       7014.70c -0.0001    $ Nitrogen (N)     0.0100 wt%
       8016.70c -0.5325    $ Oxygen (O-16)   53.2515 wt%
       8017.70c -0.0015    $ Oxygen (17&18)   0.1450 wt%
      11023.70c -0.0008    $ Sodium (Na)      0.0833 wt%
      12024.70c -0.0019    $ Magnesium (Mg-24)0.1867 wt%
      12025.70c -0.0002    $ Mg-25            0.0246 wt%
      12026.70c -0.0003    $ Mg-26            0.0282 wt%
      13027.70c -0.2769    $ Al              27.6937 wt%
      14028.70c -0.0161    $ Silicon (Si-28)  1.6075 wt%
      14029.70c -0.0008    $ Si-29            0.0846 wt%
      14030.70c -0.0006    $ Si-30            0.0577 wt%
      16032.70c -0.0021    $ Sulfur (S-32)    0.2071 wt%
      16033.70c -0.00002   $ S-33             0.0017 wt%
      16034.70c -0.0001    $ S-34             0.0098 wt%
      16036.70c -0.0000002 $ S-36             0.00002 wt%
      20040.70c -0.0811    $ Calcium (Ca-40)  8.1125 wt%
      20042.70c -0.0006    $ Ca-42            0.0569 wt%
      20043.70c -0.0001    $ Ca-43            0.0121 wt%
      20044.70c -0.0019    $ Ca-44            0.1920 wt%
      20046.70c -0.000004  $ Ca-46            0.0004 wt%
      20048.70c -0.0002    $ Ca-48            0.0188 wt%
      26054.70c -0.0002    $ Iron (Fe-54)     0.0212 wt%
      26056.70c -0.0035    $ Fe-56            0.3453 wt%
      26057.70c -0.00008   $ Fe-57            0.0081 wt%
      26058.70c -0.00001   $ Fe-58            0.0011 wt%
```

```
c
c       air (1.225e-3 g/cc)
c
m6      7014.70c  -0.755   $ Nitrogen (N-14) 75.5000 wt%
        8016.70c  -0.232   $ Oxygen (O-16)   23.2000 wt%
       18000.70c  -0.013   $ Argon (Ar-40)    1.3000 wt%
c
c    source in ES-3100 - cylindrical shape at the top of CV
c                        (H = 15.1003 cm; R = 6.35 cm)
c
c   photon source - 3.011e+06 photons/sec/gm basis
c   material used - 36 kg HEU
c   dose conversion factor (mrem/hr)/(photons/cm2-s) used
c   source term, wgt = 3.011e+06 * 36.0e+03  = 1.0840e+11
c
sdef pos=0 0 76.13649 rad=d1 ext=d2  erg=d3 axs=0 0 1 wgt=1.0840e+11
c
c  source position
c
si1    0.0      6.35         $ radial
sp1    -21       1
si2    0.0     15.1003       $ axial
sp2     0        1
c
c  ORIGEN photon spectrum
c
si3     5.00e-03     1.00e-02    1.50e-02     2.00e-02    2.50e-02     3.00e-02
        4.00e-02     5.00e-02    6.00e-02     7.00e-02    8.00e-02     9.00e-02
        1.00e-01     2.00e-01    3.00e-01     4.00e-01    5.00e-01     6.00e-01
        7.00e-01     8.00e-01    9.00e-01     1.00e+00    1.10e+00     1.20e+00
        1.30e+00     1.40e+00    1.50e+00     1.60e+00    1.70e+00     1.80e+00
        1.90e+00     2.00e+00    2.10e+00     2.20e+00    2.30e+00     2.40e+00
        2.50e+00     2.60e+00    2.70e+00     2.80e+00    2.90e+00     3.00e+00
        3.50e+00     4.00e+00    5.00e+00     6.50e+00    8.00e+00    10.00e+00
sp3     0.0          8.515e+04   1.700e+06    7.313e+03   3.595e+03    1.230e+05
        5.112e+03    6.605e+03   2.147e+05    1.779e+03   1.941e+04    1.085e+05
        2.244e+05    1.328e+05   5.245e+04    2.819e+05   1.556e+04    1.225e+04
        1.485e+02    2.705e+03   1.802e+03    4.068e+02   2.527e+02    2.157e+01
        2.105e+01    2.990e+01   1.300e+01    1.386e+02   4.719e+02    5.522e+00
        2.999e+01    4.918e+00   1.599e-02    1.308e-02   7.152e-02    5.321e-04
        1.584e-02    6.552e-05   1.062e+04    1.108e-02   1.917e-04    3.408e-04
        6.039e-01    3.876e-01   2.959e-03    1.134e-03   2.131e-04    4.388e-05
c
fq0 f s d
c
c  volume detector at the bottom surface of the drum
c
f4:p 501             $ bottom surface volume detector
f14:p 502            $ top surface volume detector
f24:p 551            $ 1 m from bottom surface  - volume detector
f34:p 552            $ 1 m from top surface  - volume detector
c
c  segmented volume detectors for primary photons
c
c  side surface
c
f114:p 109
fs114  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310
       -311 -312 -313 -314 -315 -316 -317 -318 -319 -320
       -321 -322 -323 -324 -325 -326 -327 -328 -329 -330
       -331 -332 -333 -334 -335 -336 -337 -338 -339 -340
```

```
       -341 -342 -343 -344 -345 -346 -347 -348 -349 -350
       -351 -352 -353 -354 -355 -356 -357 -358 -359 -360
       -361 -362 -363 -364 -365 -366 -367 -368 -369 -370
       -371 -372 -373 -374 -375 -376 -377
c
c  1 m from side surface
c
f134:p  111
fs134  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310
       -311 -312 -313 -314 -315 -316 -317 -318 -319 -320
       -321 -322 -323 -324 -325 -326 -327 -328 -329 -330
       -331 -332 -333 -334 -335 -336 -337 -338 -339 -340
       -341 -342 -343 -344 -345 -346 -347 -348 -349 -350
       -351 -352 -353 -354 -355 -356 -357 -358 -359 -360
       -361 -362 -363 -364 -365 -366 -367 -368 -369 -370
       -371 -372 -373 -374 -375 -376 -377
c
c  point detectors for primary photons
c
f5:p    23.4299  0.0     83.68664  0.0     $ side surface - detector
f15:p    0.0     0.0    108.83739  0.0     $ top surface - detector
f25:p    0.0     0.0     -0.1      0.0     $ bottom surface - detector
f35:p  123.3299  0.0     83.68664  0.0     $ 1m from side surface - detector
f45:p    0.0     0.0    208.73739  0.0     $ 1m from top surface - detector
f55:p    0.0     0.0   -100.0      0.0     $ 1m from bottom surface - detector
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                  (mrem/hr)/(photons/cm2-s)
c
de0         0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df0      3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
         6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
         1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
         3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
         5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
         1.03e-2   1.18e-2   1.33e-2
c
prdmp  j  10000000 0 10
ctme 5000
```

5.5.2.3 NCT for 36-kg uranium metal neutron and secondary photon top and side dose-rate calculations (cylinder configuration source moved to the top of CV)

```
neutron_top.inp - ES-3100: 2015 HEU model (neutrons and secondary photons)
c
c    NCT configuration
c    (top dose rate calculations)
c    source in cylindrical form sitting at the top of CV for
c    top dose rate calculations for 2015 calculation Revision
c
c    mcnp geometry model (CV and outside) is identical to criticality model
c    (KENO Model).
c    47 energy groups are used for the photon spectrum.  In the older version,
c    18 energy groups were used.
```

```
c    surface detectors are placed 0.1 cm and 100 cm way from the surfaces
c    and detectors are placed on the side, top, and bottom.
c    point detectors are used for dose rate calculations (used for results).
c    segmented volume detectors are used for side dose rate calculations (for checking).
c    volume detectors are used to check bottom and top dose rate calculations.
c    ANSI/ANS-6.1.1-1977 Dose conversion factors are used,
c    multiplied by 1000 to convert from rem to mrem
c
c   mode n p - (neutrons and secondary photons)
c
c    --------------
c     Cell Cards
c    --------------
c
    1     1   -18.82    -1       imp:n,p=1 $ source cylinder
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51     2   -7.92     -51      imp:n,p=1 $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61     4   -0.321    -61      imp:n,p=1 $ bottom kaolite
   62     2   -7.92     -62 61   imp:n,p=1 $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71     2   -7.92     -71      imp:n,p=1 $ bottom liner
   72     4   -0.321    -72 71   imp:n,p=1 $ bottom liner+kaolite
   73     2   -7.92     -73 72   imp:n,p=1 $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81     0             -81      imp:n,p=1 $ void
   82     3   -1.2      -82 81   imp:n,p=1 $ void+pad
   83     2   -7.92     -83 82   imp:n,p=1 $ void+pad+liner
   84     5   -1.4586   -84 83   imp:n,p=1 $ void+pad+liner+277-4
   85     2   -7.92     -85 84   imp:n,p=1 $ void+pad+liner+277-4+liner
   86     4   -0.321    -86 85   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite
   87     2   -7.92     -87 86   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91     2   -7.92     -91      imp:n,p=1 $ cv bottom
   92     0             -92 91   imp:n,p=1 $ cv bottom+void
   93     2   -7.92     -93 92   imp:n,p=1 $ cv bottom+void+liner
   94     5   -1.4586   -94 93   imp:n,p=1 $ cv bottom+void+liner+277-4
   95     2   -7.92     -95 94   imp:n,p=1 $ cv bottom+void+liner+277-4+liner
   96     4   -0.321    -96 95   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite
   97     2   -7.92     -97 96   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101     0             -101 #1   imp:n,p=1 $ cv void
  102     2   -7.92     -102 101  imp:n,p=1 $ cv void+ss
  103     0             -103 102  imp:n,p=1 $ cv void+ss+void
  104     2   -7.92     -104 103  imp:n,p=1 $ cv void+ss+void+liner
  105     5   -1.4586   -105 104  imp:n,p=1 $ cv void+ss+void+liner+277-4
  106     2   -7.92     -106 105  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner
  107     4   -0.321    -107 106  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite
  108     2   -7.92     -108 107  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite+drum
```

```
  109     0             -109 108  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110     0             -110 109  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111     0             -111 110  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.5857 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
c
  112     0             -112 #1   imp:n,p=1 $ cv void
  113     2   -7.92     -113 112  imp:n,p=1 $ cv void+ss
  114     0             -114 113  imp:n,p=1 $ cv void+ss+void
  115     2   -7.92     -115 114  imp:n,p=1 $ cv void+ss+void+liner
  116     4   -0.321    -116 115  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  117     2   -7.92     -117 116  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 4) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122     0             -122 #1   imp:n,p=1 $ cv void
  123     2   -7.92     -123 122  imp:n,p=1 $ cv void+ss
  124     0             -124 123  imp:n,p=1 $ cv void+ss+void
  125     2   -7.92     -125 124  imp:n,p=1 $ cv void+ss+void+liner
  126     4   -0.321    -126 125  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  127     2   -7.92     -127 126  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132     0             -132 #1   imp:n,p=1 $ cv void
  133     2   -7.92     -133 132  imp:n,p=1 $ cv void+ss
  134     3   -1.20     -134 133  imp:n,p=1 $ cv void+ss+rubber
  135     0             -135 134  imp:n,p=1 $ cv void+ss+rubber+void
  136     2   -7.92     -136 135  imp:n,p=1 $ cv void+ss+rubber+void+liner
  137     4   -0.321    -137 136  imp:n,p=1 $ cv void+ss+rubber+void+liner+kaolite
  138     2   -7.92     -138 137  imp:n,p=1 $ cv +void+ss+rubber+void+liner+kaolite+drum
c
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (middle section of CV flange)
c
  141     2   -7.92     -141 #1   imp:n,p=1 $ ss
  142     3   -1.20     -142 141  imp:n,p=1 $ ss+rubber
  143     0             -143 142  imp:n,p=1 $ ss+rubber+void
  144     2   -7.92     -144 143  imp:n,p=1 $ ss+rubber+void+liner
  145     4   -0.321    -145 144  imp:n,p=1 $ ss+rubber+void+liner+kaolite
  146     2   -7.92     -146 145  imp:n,p=1 $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151     3   -1.20     -151      imp:n,p=1 $ rubber
  152     0             -152 151  imp:n,p=1 $ rubber+void
  153     2   -7.92     -153 152  imp:n,p=1 $ rubber+void+liner
  154     4   -0.321    -154 153  imp:n,p=1 $ rubber+void+liner+kaolite
  155     2   -7.92     -155 154  imp:n,p=1 $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161     0             -161      imp:n,p=1 $ void
  162     2   -7.92     -162 161  imp:n,p=1 $ void+liner
```

```
  163     4   -0.321    -163 162  imp:n,p=1 $ void+liner+kaolite
  164     2   -7.92     -164 163  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171     0             -171      imp:n,p=1 $ void
  172     2   -7.92     -172 171  imp:n,p=1 $ void+liner
  173     4   -0.321    -173 172  imp:n,p=1 $ void+liner+kaolite
  174     2   -7.92     -174 173  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181     0             -181      imp:n,p=1 $ void
  182     2   -7.92     -182 181  imp:n,p=1 $ void+liner
  183     4   -0.321    -183 182  imp:n,p=1 $ void+liner+kaolite
  184     2   -7.92     -184 183  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191     2   -7.92     -191      imp:n,p=1 $ ss (liner)
  192     0             -192 191  imp:n,p=1 $ ss+void
  193     2   -7.92     -193 192  imp:n,p=1 $ ss+void+liner
  194     4   -0.321    -194 193  imp:n,p=1 $ ss+void+liner+kaolite
  195     2   -7.92     -195 194  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201     4   -0.321    -201      imp:n,p=1 $ kaolite
  202     2   -7.92     -202 201  imp:n,p=1 $ kaolite+liner
  203     0             -203 202  imp:n,p=1 $ kaolite+liner+void
  204     2   -7.92     -204 203  imp:n,p=1 $ kaolite+liner+void+liner
  205     4   -0.321    -205 204  imp:n,p=1 $ kaolite+liner+void+liner+kaolite
  206     2   -7.92     -206 205  imp:n,p=1 $ kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211     4   -0.321    -211      imp:n,p=1 $ kaolite
  212     2   -7.92     -212 211  imp:n,p=1 $ kaolite+liner
  213     0             -213 212  imp:n,p=1 $ kaolite+liner+void
  214     2   -7.92     -214 213  imp:n,p=1 $ kaolite+liner+void+liner
  215     2   -7.92     -215 214  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  216     4   -0.321    -216 215  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite
  217     2   -7.92     -217 216  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221     4   -0.321    -221      imp:n,p=1 $ kaolite
  222     2   -7.92     -222 221  imp:n,p=1 $ kaolite+liner
  223     0             -223 222  imp:n,p=1 $ kaolite+liner+void
  224     2   -7.92     -224 223  imp:n,p=1 $ kaolite+liner+void+liner
  225     2   -7.92     -225 224  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  226     2   -7.92     -226 225  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231     2   -7.92     -231      imp:n,p=1 $ liner
  232     0             -232 231  imp:n,p=1 $ liner+void
  233     2   -7.92     -233 232  imp:n,p=1 $ liner+void+liner
  234     2   -7.92     -234 233  imp:n,p=1 $ liner+void+liner+iron-angle
  235     2   -7.92     -235 234  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
```

```
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241     0             -241      imp:n,p=1 $ liner+void
  242     2   -7.92     -242 241  imp:n,p=1 $ liner+void+liner
  243     2   -7.92     -243 242  imp:n,p=1 $ liner+void+liner+iron-angle
  244     2   -7.92     -244 243  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251     2   -7.92     -251      imp:n,p=1 $ ss lid
  252     0             -252 251  imp:n,p=1 $ ss lid+void
  253     2   -7.92     -253 252  imp:n,p=1 $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261     0             -261 #502      imp:n,p=1 $ void
  262     2   -7.92     -262 261  imp:n,p=1 $ void+ss lid
  263     0             -263 262  imp:n,p=1 $ void+ss lid+void
  264     2   -7.92     -264 263  imp:n,p=1 $ void+ss lid+void+drum
c
c   Put volume source for top and bottom detectors
c
  501     0             -501      imp:n,p=1 $ bottom surface detector
  502     0             -502      imp:n,p=1 $ top surface detector
  551     0             -551      imp:n,p=1 $ 1 m from bottom surface - detector
  552     0             -552      imp:n,p=1 $ 1 m from top surface - detector
c
  998     0             -999      51 62 73 87 97 111 117 127 138 146 155
                                  164 174 184 195 206 217 226 235 244 253
                                  264 501 502 551 552
                                  imp:n,p=1 $ inside boundary
  999     0              999      imp:n,p=0 $ outside world

c    ------------------
c    Surface Cards
c    ------------------
c
    1  rcc  0.0 0.0 76.13649   0.0 0.0  15.1003  6.35 $ cylinder source top of cv
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51  rcc  0.0 0.0  0.0     0.0 0.0 0.2667   23.3299  $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.1775  $ bottom kaolite
   62  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.3299  $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  11.0744  $ bottom liner
   72  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.1775  $ bottom liner+kaolite
   73  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.3299  $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    3.1750  $ void
   82  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    7.9248  $ void+pad
   83  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    8.0772  $ void+pad+liner
   84  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   10.9220  $ void+pad+liner+277-4
   85  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   11.0744  $ void+pad+liner+277-4+liner
```

```
   86  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.1775  $ void+pad+liner+277-4+liner+kaolite
   87  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.3299  $
void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    6.6802  $ cv bottom
   92  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    7.9248  $ cv bottom+void
   93  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    8.0772  $ cv bottom+void+liner
   94  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   10.9220  $ cv bottom+void+liner+277-4
   95  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   11.0744  $ cv bottom+void+liner+277-4+liner
   96  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.1775  $ cv
bottom+void+liner+277-4+liner+kaolite
   97  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.3299  $ cv
bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.4262  $ cv void
  102  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.6802  $ cv void+ss
  103  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  7.9248  $ cv void+ss+void
  104  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  8.0772  $ cv void+ss+void+liner
  105  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 10.9220  $ cv void+ss+void+liner+277-4
  106  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 11.0744  $ cv void+ss+void+liner+277-4+liner
  107  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.1775  $ cv
void+ss+void+liner+277-4+liner+kaolite
  108  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum
  109  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 24.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 123.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 124.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.58579 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
c
  112  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.4262  $ cv void
  113  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.6802  $ cv void+ss
  114  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  7.9248  $ cv void+ss+void
  115  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 11.0744  $ cv void+ss+void+liner
  116  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.1775  $ cv void+ss+void+liner+kaolite
  117  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 5) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.4262  $ cv void
  123  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.6802  $ cv void+ss
  124  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 10.9220  $ cv void+ss+void
  125  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 11.0744  $ cv void+ss+void+liner
  126  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.1775  $ cv void+ss+void+liner+kaolite
  127  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  6.4262  $ cv void
  133  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  9.5250  $ cv void+ss
  134  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.0330  $ cv void+ss+rubber
```

```
  135  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.9220  $ cv void+ss+rubber+void
  136  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 11.0744  $ cv void+ss+rubber+void+liner
  137  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.1775  $ cv void+ss+rubber+void+liner+kaolite
  138  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.3299  $ cv
void+ss+rubber+void+liner+kaolite+drum
c
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (lower section of CV flange)
c
  141  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210  9.5250  $ ss
  142  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.0330  $ ss+rubber
  143  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.9220  $ ss+rubber+void
  144  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 11.0744  $ ss+rubber+void+liner
  145  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.1775  $ ss+rubber+void+liner+kaolite
  146  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.3299  $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.0330  $ rubber
  152  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.9220  $ rubber+void
  153  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 11.0744  $ rubber+void+liner
  154  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.1775  $ rubber+void+liner+kaolite
  155  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.3299  $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 10.9220  $ void
  162  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 11.0744  $ void+liner
  163  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.1775  $ void+liner+kaolite
  164  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 10.9220  $ void
  172  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 18.7579  $ void+liner
  173  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.1775  $ void+liner+kaolite
  174  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.6055  $ void
  182  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.7579  $ void+liner
  183  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.1775  $ void+liner+kaolite
  184  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.3299  $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.2499   $ ss (liner)
  192  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.6055   $ ss+void
  193  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.7579   $ ss+void+liner
  194  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.1775   $ ss+void+liner+kaolite
  195  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.3299   $ ss+void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.0975  $ kaolite
  202  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.2499  $ kaolite +liner
  203  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.6055  $ kaolite+liner+void
  204  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.7579  $ kaolite+liner+void+liner
  205  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.1775  $ kaolite+liner+void+liner+kaolite
```

```
  206  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.3299  $
kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.0975  $ kaolite
  212  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.2499  $ kaolite +liner
  213  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.6055  $ kaolite+liner+void
  214  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.7579  $ kaolite+liner+void+liner
  215  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  19.3929  $ kaolite+liner+void+liner+iron-angle
  216  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.1775  $
kaolite+liner+void+liner+iron-angle+kaolite
  217  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.3299  $
kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.0975  $ kaolite
  222  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.2499  $ kaolite +liner
  223  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.6055  $ kaolite+liner+void
  224  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.7579  $ kaolite+liner+void+liner
  225  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.1775  $ kaolite+liner+void+liner+iron-angle
  226  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.3299  $
kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.2499  $ ss liner
  232  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.6055  $ ss liner+void
  233  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.7579  $ ss liner+void+liner
  234  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.1775  $ ss liner+void+liner+iron-angle
  235  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.3299  $ ss liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.6055  $ void
  242  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.7579  $ void+liner
  243  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.1775  $ void+liner+iron-angle
  244  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.3299  $ void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1140  $ ss lid
  252  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1775  $ ss lid+void
  253  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.3299  $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  22.9616  $ void
  262  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1140  $ void+ss lid
  263  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1775  $ void+ss lid+void
  264  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.3299  $ void+ss lid+void+drum
c
c   Segmented side volume detectors
c
  301  pz 13
  302  pz 14
  303  pz 15
  304  pz 16
  305  pz 17
  306  pz 18
```

```
307  pz 19
308  pz 20
309  pz 21
310  pz 22
311  pz 23
312  pz 24
313  pz 25
314  pz 26
315  pz 27
316  pz 28
317  pz 29
318  pz 30
319  pz 31
320  pz 32
321  pz 33
322  pz 34
323  pz 35
324  pz 36
325  pz 37
326  pz 38
327  pz 39
328  pz 40
329  pz 41
330  pz 42
331  pz 43
332  pz 44
333  pz 45
334  pz 46
335  pz 47
336  pz 48
337  pz 49
338  pz 50
339  pz 51
340  pz 52
341  pz 53
342  pz 54
343  pz 55
344  pz 56
345  pz 57
346  pz 58
347  pz 59
348  pz 60
349  pz 61
350  pz 62
351  pz 63
352  pz 64
353  pz 65
354  pz 66
355  pz 67
356  pz 68
357  pz 69
358  pz 70
359  pz 71
360  pz 72
361  pz 73
362  pz 74
363  pz 75
364  pz 76
365  pz 77
366  pz 78
367  pz 79
```

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  368  pz 80
  369  pz 81
  370  pz 82
  371  pz 83
  372  pz 84
  373  pz 85
  374  pz 86
  375  pz 87
  376  pz 88
  377  pz 89
c
c   Put volume source for top and bottom detectors
c
  501  rcc 0.0 0.0 -0.5  0.0 0.0  0.5  1.0          $ bottom surface vol detector
  502  rcc 0.0 0.0 108.73739  0.0 0.0  0.5  1.0     $ top surface vol detector
  551  rcc 0.0 0.0 -100.5  0.0 0.0  0.5  1.0        $ 1 m from bottom surface - vol detector
  552  rcc 0.0 0.0 208.73739  0.0 0.0  0.5  1.0     $ 1 m from top surface - vol detector
c
  999  sph  0.0 0.0  0.000  999.0                         $ boundary
c

c    ----------------------
c    Data Cards
c    ----------------------
mode  n p
c
c      uranium metal (18.82 g/cc)
c
m1    92235.70c  -0.9500    $ U-235           95.0000  wt%
      92238.70c  -0.0500    $ U-238            5.0000  wt%
c
c      ss 304 (7.92 g/cc)
c
m2     6000.70c  -0.00080    $ Carbon(C)        0.0800  wt%
      14028.70c  -0.00919    $ Silicon(Si-28)   0.9187  wt%
      14029.70c  -0.00048    $ Si-29            0.0483  wt%
      14030.70c  -0.00033    $ Si-30            0.0330  wt%
      15031.70c  -0.00045    $ Phosphorus(P)    0.0450  wt%
      24050.70c  -0.00793    $ Cromium (Cr-50)  0.7930  wt%
      24052.70c  -0.15903    $ Cr-52           15.9029  wt%
      24053.70c  -0.01838    $ Cr-53            1.8380  wt%
      24054.70c  -0.00466    $ Cr-54            0.4661  wt%
      25055.70c  -0.02000    $ Manganese (Mn)   2.0000  wt%
      26054.70c  -0.03860    $ Iron (Fe-54)     3.8602  wt%
      26056.70c  -0.62838    $ Fe-56           62.8377  wt%
      26057.70c  -0.01477    $ Fe-57            1.4772  wt%
      26058.70c  -0.00200    $ Fe-58            0.2000  wt%
      28058.70c  -0.06384    $ Nickel (Ni-58)   6.3838  wt%
      28060.70c  -0.02544    $ Ni-60            2.5437  wt%
      28061.70c  -0.00112    $ Ni-61            0.1124  wt%
      28062.70c  -0.00364    $ Ni-62            0.3643  wt%
      28064.70c  -0.00096    $ Ni-64            0.0958  wt%
c
c      rubber foam (1.20 g/cc)
c
m3     1001.70c  -0.08157    $ Hydrogen (H)     8.1573 wt%
       6000.70c  -0.32377    $ Carbon (C)      32.3767 wt%
       8016.70c  -0.21520    $ Oxygen (O-16)   21.5196 wt%
       8017.70c  -0.00059    $ O-17 & O-18      0.0586 wt%
      14028.70c  -0.34806    $ Silicon(Si-28)  34.8061 wt%
      14029.70c  -0.01831    $ Si-29            1.8314 wt%
```

```
      14030.70c  -0.01250    $ Si-30            1.2503 wt%
c
c      kaolite (0.321 g/cc)
c
m4     8016.70c -0.4092    $ Oxygen (O-16)   40.9231 wt%
       8017.70c -0.0011    $ Oxygen (17&18)   0.1114 wt%
      11023.70c -0.0148    $ Sodium (Na)      1.4837 wt%
      12024.70c -0.0616    $ Magnesium (Mg-24)6.1579 wt%
      12025.70c -0.0081    $ Mg-25            0.8121 wt%
      12026.70c -0.0093    $ Mg-26            0.9298 wt%
      13027.70c -0.0508    $ Al               5.0808 wt%
      14028.70c -0.1576    $ Silicon (Si-28) 15.7596 wt%
      14029.70c -0.0083    $ Si-29            0.8292 wt%
      14030.70c -0.0057    $ Si-30            0.5661 wt%
      20040.70c -0.2121    $ Calcium (Ca-40) 21.2086 wt%
      20042.70c -0.0015    $ Ca-42            0.1490 wt%
      20043.70c -0.0003    $ Ca-43            0.0318 wt%
      20044.70c -0.0050    $ Ca-44            0.5031 wt%
      20046.70c -0.00001   $ Ca-46            0.0010 wt%
      20048.70c -0.0005    $ Ca-48            0.0491 wt%
      22046.70c -0.0006    $ Titanium (Ti-46) 0.0570 wt%
      22047.70c -0.0005    $ Ti-47            0.0525 wt%
      22048.70c -0.0053    $ Ti-48            0.5311 wt%
      22049.70c -0.0004    $ Ti-49            0.0398 wt%
      22050.70c -0.0004    $ Ti-50            0.0407 wt%
      26054.70c -0.0026    $ Iron (Fe-54)     0.2646 wt%
      26056.70c -0.0431    $ Fe-56            4.3066 wt%
      26057.70c -0.0010    $ Fe-57            0.1012 wt%
      26058.70c -0.0001    $ Fe-58            0.0137 wt%
c
c      Cat 277-4 (1.4586 g/cc)
c
m5     1001.70c -0.0285    $ Hydrogen         2.8475 wt%
       5010.70c -0.0066    $ Boron (B-10)     0.6591 wt%
       5011.70c -0.0297    $ Boron (B-11)     2.9726 wt%
       6000.70c -0.0136    $ Carbon (C)       1.3609 wt%
       7014.70c -0.0001    $ Nitrogen (N)     0.0100 wt%
       8016.70c -0.5325    $ Oxygen (O-16)   53.2515 wt%
       8017.70c -0.0015    $ Oxygen (17&18)   0.1450 wt%
      11023.70c -0.0008    $ Sodium (Na)      0.0833 wt%
      12024.70c -0.0019    $ Magnesium (Mg-24)0.1867 wt%
      12025.70c -0.0002    $ Mg-25            0.0246 wt%
      12026.70c -0.0003    $ Mg-26            0.0282 wt%
      13027.70c -0.2769    $ Al              27.6937 wt%
      14028.70c -0.0161    $ Silicon (Si-28)  1.6075 wt%
      14029.70c -0.0008    $ Si-29            0.0846 wt%
      14030.70c -0.0006    $ Si-30            0.0577 wt%
      16032.70c -0.0021    $ Sulfur (S-32)    0.2071 wt%
      16033.70c -0.00002   $ S-33             0.0017 wt%
      16034.70c -0.0001    $ S-34             0.0098 wt%
      16036.70c -0.0000002 $ S-36             0.00002 wt%
      20040.70c -0.0811    $ Calcium (Ca-40)  8.1125 wt%
      20042.70c -0.0006    $ Ca-42            0.0569 wt%
      20043.70c -0.0001    $ Ca-43            0.0121 wt%
      20044.70c -0.0019    $ Ca-44            0.1920 wt%
      20046.70c -0.000004  $ Ca-46            0.0004 wt%
      20048.70c -0.0002    $ Ca-48            0.0188 wt%
      26054.70c -0.0002    $ Iron (Fe-54)     0.0212 wt%
      26056.70c -0.0035    $ Fe-56            0.3453 wt%
      26057.70c -0.00008   $ Fe-57            0.0081 wt%
      26058.70c -0.00001   $ Fe-58            0.0011 wt%
```

```
c
c       air (1.225e-3 g/cc)
c
m6      7014.70c  -0.755   $ Nitrogen (N-14) 75.5000 wt%
        8016.70c  -0.232   $ Oxygen (O-16)   23.2000 wt%
       18000.70c  -0.013   $ Argon (Ar-40)    1.3000 wt%
c
c    source in ES-3100 - cylindrical shape at the top of CV
c                        (H = 15.1003 cm; R = 6.35 cm)
c
c   neutron source - 2.129e-01 neutrons/sec/gm basis
c   material used - 36 kg HEU
c   dose conversion factor (mrem/hr)/(neutrons/cm2-s) used
c   source term, wgt = 2.129e-01 * 36.0e+03  = 7.6644e+03
c
sdef pos=0 0 76.13649 rad=d1 ext=d2  erg=d3 axs=0 0 1 wgt=7.6644e+03
c
c  source position
c
si1    0.0      6.35         $ radial
sp1    -21       1
si2    0.0     15.1003       $ axial
sp2     0        1
c
c  ORIGEN neutron spectrum
c
si3     5.83e-04     3.04e-03    1.50e-02     1.11e-01    4.08e-01
        9.07e-01     1.42e+00    1.83e+00     3.01e+00    6.38e+00    20.00e+00
c
sp3     0.0          7.034e-06   8.280e-05    1.790e-03   8.973e-03
        1.572e-02    2.205e-02   2.510e-02    1.042e-01   3.430e-02    7.260e-04
c
fq0 f s d
c
c  volume detector for neutron at the bottom surface of the drum
c
f4:n 501             $ bottom surface volume detector
f14:n 502            $ top surface volume detector
f24:n 551            $ 1 m from bottom surface  - volume detector
f34:n 552            $ 1 m from top surface  - volume detector
c
c  segmented volume detectors for neutrons
c
c  side surface
c
f114:n 109
fs114  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310
       -311 -312 -313 -314 -315 -316 -317 -318 -319 -320
       -321 -322 -323 -324 -325 -326 -327 -328 -329 -330
       -331 -332 -333 -334 -335 -336 -337 -338 -339 -340
       -341 -342 -343 -344 -345 -346 -347 -348 -349 -350
       -351 -352 -353 -354 -355 -356 -357 -358 -359 -360
       -361 -362 -363 -364 -365 -366 -367 -368 -369 -370
       -371 -372 -373 -374 -375 -376 -377
c
c  1 m from side surface
c
f134:n  111
fs134  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310
       -311 -312 -313 -314 -315 -316 -317 -318 -319 -320
       -321 -322 -323 -324 -325 -326 -327 -328 -329 -330
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       -331 -332 -333 -334 -335 -336 -337 -338 -339 -340
       -341 -342 -343 -344 -345 -346 -347 -348 -349 -350
       -351 -352 -353 -354 -355 -356 -357 -358 -359 -360
       -361 -362 -363 -364 -365 -366 -367 -368 -369 -370
       -371 -372 -373 -374 -375 -376 -377
c
c  point detectors for neutrons
c
f5:n    23.4299  0.0     83.68664  0.0     $ side surface - detector
f15:n    0.0     0.0    108.83739  0.0     $ top surface - detector
f25:n    0.0     0.0     -0.1      0.0     $ bottom surface - detector
f35:n  123.3299  0.0     83.68664  0.0     $ 1m from side surface - detector
f45:n    0.0     0.0    208.73739  0.0     $ 1m from top surface - detector
f55:n    0.0     0.0   -100.0      0.0     $ 1m from bottom surface - detector
c
c ANSI/ANS-6.1.1-1977 neutron flux to dose rate conversion factor
c                                  (mrem/hr)/(neutrons/cm2-s)
c
de0      2.5e-08   1.0e-07   1.0e-06   1.0e-05   1.0e-04   1.0e-3    1.0e-02
         1.0e-01   5.0e-01   1.0       2.5       5.0       7.0       10.0
         14.0      20.0
c
df0      3.67e-03  3.67e-03  4.46e-03  4.54e-03  4.18e-03  3.76e-03  3.56e-03
         2.17e-02  9.26e-02  1.32e-01  1.25e-01  1.56e-01  1.47e-01  1.47e-01
         2.08e-01  2.27e-01
c
c  point detectors for secondary photons
c
f505:p   23.4299  0.0     83.68664  0.0     $ side surface - detector
f515:p    0.0     0.0    108.83739  0.0     $ top surface - detector
f525:p    0.0     0.0     -0.1      0.0     $ bottom surface - detector
f535:p  123.3299  0.0     83.68664  0.0     $ 1m from side surface - detector
f545:p    0.0     0.0    208.73739  0.0     $ 1m from top surface - detector
f555:p    0.0     0.0   -100.0      0.0     $ 1m from bottom surface - detector
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                  (mrem/hr)/(photons/cm2-s)
c
de505       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df505    3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
         6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
         1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
         3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
         5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
         1.03e-2   1.18e-2   1.33e-2
c
de515       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df515    3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
         6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
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          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
c
de525       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df525     3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
c
de535       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df535     3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
c
de545       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df545     3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
c
de555       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df555     3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
```

```
c
prdmp  j  10000000 0 10
ctme 2000
```

5.5.2.4 HAC for 36-kg uranium metal neutron and secondary photon side dose-rate calculations (cylindrical hemi-shell configuration source moved towards x-axis in CV)

```
neutron_hemishell.inp - ES-3100: 2015 HEU detailed model
c                (neutrons & sec photons)
c                U-metal case (76.2 cm ht cylindrical hemishell
c                density = 18.82 g/cc; IR=4.9337 cm; OR=6.35 cm)
c    configuration
c    (side dose rate calculations)
c    source in cylindrical hemishell form sitting at the bottom of CV for
c    side dose rate calculations for 2015 Revision
c
c    mcnp geometry model (CV and outside) is identical to criticality model
c    (KENO Model).
c    47 energy groups are used for the photon spectrum.  In the older version,
c    18 energy groups were used.
c    surface detectors are placed 0.1 cm and 100 cm way from the surfaces
c    and detectors are placed on the side, top, and bottom.
c    point detectors are used for dose rate calculations (used for results).
c    segmented volume detectors are used for side dose rate calculations (for checking).
c    volume detectors are used to check bottom and top dose rate calculations.
c    ANSI/ANS-6.1.1-1977 Dose conversion factors are used,
c    multiplied by 1000 to convert from rem to mrem
c
c   mode n p - (neutrons and secondary photons)
c
c    --------------
c     Cell Cards
c    --------------
c
    1     0             -1 401      imp:n,p=1 $ inner void
    2     1   -18.82    -2 1 401    imp:n,p=1 $ source shell
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51     2   -7.92     -51      imp:n,p=1 $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61     4   -0.321    -61      imp:n,p=1 $ bottom kaolite
   62     2   -7.92     -62 61   imp:n,p=1 $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71     2   -7.92     -71      imp:n,p=1 $ bottom liner
   72     4   -0.321    -72 71   imp:n,p=1 $ bottom liner+kaolite
   73     2   -7.92     -73 72   imp:n,p=1 $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81     0             -81      imp:n,p=1 $ void
   82     3   -1.2      -82 81   imp:n,p=1 $ void+pad
   83     2   -7.92     -83 82   imp:n,p=1 $ void+pad+liner
   84     5   -1.4586   -84 83   imp:n,p=1 $ void+pad+liner+277-4
   85     2   -7.92     -85 84   imp:n,p=1 $ void+pad+liner+277-4+liner
   86     4   -0.321    -86 85   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite
```

```
   87     2   -7.92     -87 86   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91     2   -7.92     -91      imp:n,p=1 $ cv bottom
   92     0              -92 91   imp:n,p=1 $ cv bottom+void
   93     2   -7.92     -93 92   imp:n,p=1 $ cv bottom+void+liner
   94     5   -1.4586   -94 93   imp:n,p=1 $ cv bottom+void+liner+277-4
   95     2   -7.92     -95 94   imp:n,p=1 $ cv bottom+void+liner+277-4+liner
   96     4   -0.321    -96 95   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite
   97     2   -7.92     -97 96   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101     0              -101 #1 #2  imp:n,p=1 $ cv void
  102     2   -7.92     -102 101  imp:n,p=1 $ cv void+ss
  103     0              -103 102  imp:n,p=1 $ cv void+ss+void
  104     2   -7.92     -104 103  imp:n,p=1 $ cv void+ss+void+liner
  105     5   -1.4586   -105 104  imp:n,p=1 $ cv void+ss+void+liner+277-4
  106     2   -7.92     -106 105  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner
  107     4   -0.321    -107 106  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite
  108     2   -7.92     -108 107  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite+drum
  109     0              -109 108  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110     0              -110 109  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111     0              -111 110  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.5857 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
c
c 111     0              -111      imp:n,p=1 $ cv void (to be filled by content can)
  112     0              -112      imp:n,p=1 $ cv void
  113     2   -7.92     -113 112  imp:n,p=1 $ cv void+ss
  114     0              -114 113  imp:n,p=1 $ cv void+ss+void
  115     2   -7.92     -115 114  imp:n,p=1 $ cv void+ss+void+liner
  116     4   -0.321    -116 115  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  117     2   -7.92     -117 116  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 4) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122     0              -122      imp:n,p=1 $ cv void
  123     2   -7.92     -123 122  imp:n,p=1 $ cv void+ss
  124     0              -124 123  imp:n,p=1 $ cv void+ss+void
  125     2   -7.92     -125 124  imp:n,p=1 $ cv void+ss+void+liner
  126     4   -0.321    -126 125  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  127     2   -7.92     -127 126  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132     0              -132      imp:n,p=1 $ cv void
  133     2   -7.92     -133 132  imp:n,p=1 $ cv void+ss
  134     3   -1.20     -134 133  imp:n,p=1 $ cv void+ss+rubber
  135     0              -135 134  imp:n,p=1 $ cv void+ss+rubber+void
  136     2   -7.92     -136 135  imp:n,p=1 $ cv void+ss+rubber+void+liner
  137     4   -0.321    -137 136  imp:n,p=1 $ cv void+ss+rubber+void+liner+kaolite
  138     2   -7.92     -138 137  imp:n,p=1 $ cv +void+ss+rubber+void+liner+kaolite+drum
c
```

```
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (middle section of CV flange)
c
  141     2   -7.92     -141      imp:n,p=1 $ ss
  142     3   -1.20     -142 141  imp:n,p=1 $ ss+rubber
  143     0             -143 142  imp:n,p=1 $ ss+rubber+void
  144     2   -7.92     -144 143  imp:n,p=1 $ ss+rubber+void+liner
  145     4   -0.321    -145 144  imp:n,p=1 $ ss+rubber+void+liner+kaolite
  146     2   -7.92     -146 145  imp:n,p=1 $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151     3   -1.20     -151      imp:n,p=1 $ rubber
  152     0             -152 151  imp:n,p=1 $ rubber+void
  153     2   -7.92     -153 152  imp:n,p=1 $ rubber+void+liner
  154     4   -0.321    -154 153  imp:n,p=1 $ rubber+void+liner+kaolite
  155     2   -7.92     -155 154  imp:n,p=1 $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161     0             -161      imp:n,p=1 $ void
  162     2   -7.92     -162 161  imp:n,p=1 $ void+liner
  163     4   -0.321    -163 162  imp:n,p=1 $ void+liner+kaolite
  164     2   -7.92     -164 163  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171     0             -171      imp:n,p=1 $ void
  172     2   -7.92     -172 171  imp:n,p=1 $ void+liner
  173     4   -0.321    -173 172  imp:n,p=1 $ void+liner+kaolite
  174     2   -7.92     -174 173  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181     0             -181      imp:n,p=1 $ void
  182     2   -7.92     -182 181  imp:n,p=1 $ void+liner
  183     4   -0.321    -183 182  imp:n,p=1 $ void+liner+kaolite
  184     2   -7.92     -184 183  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191     2   -7.92     -191      imp:n,p=1 $ ss (liner)
  192     0             -192 191  imp:n,p=1 $ ss+void
  193     2   -7.92     -193 192  imp:n,p=1 $ ss+void+liner
  194     4   -0.321    -194 193  imp:n,p=1 $ ss+void+liner+kaolite
  195     2   -7.92     -195 194  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201     4   -0.321    -201      imp:n,p=1 $ kaolite
  202     2   -7.92     -202 201  imp:n,p=1 $ kaolite+liner
  203     0             -203 202  imp:n,p=1 $ kaolite+liner+void
  204     2   -7.92     -204 203  imp:n,p=1 $ kaolite+liner+void+liner
  205     4   -0.321    -205 204  imp:n,p=1 $ kaolite+liner+void+liner+kaolite
  206     2   -7.92     -206 205  imp:n,p=1 $ kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211     4   -0.321    -211      imp:n,p=1 $ kaolite
  212     2   -7.92     -212 211  imp:n,p=1 $ kaolite+liner
```

```
  213     0             -213 212  imp:n,p=1 $ kaolite+liner+void
  214     2   -7.92     -214 213  imp:n,p=1 $ kaolite+liner+void+liner
  215     2   -7.92     -215 214  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  216     4   -0.321    -216 215  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite
  217     2   -7.92     -217 216  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221     4   -0.321    -221      imp:n,p=1 $ kaolite
  222     2   -7.92     -222 221  imp:n,p=1 $ kaolite+liner
  223     0             -223 222  imp:n,p=1 $ kaolite+liner+void
  224     2   -7.92     -224 223  imp:n,p=1 $ kaolite+liner+void+liner
  225     2   -7.92     -225 224  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  226     2   -7.92     -226 225  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231     2   -7.92     -231      imp:n,p=1 $ liner
  232     0             -232 231  imp:n,p=1 $ liner+void
  233     2   -7.92     -233 232  imp:n,p=1 $ liner+void+liner
  234     2   -7.92     -234 233  imp:n,p=1 $ liner+void+liner+iron-angle
  235     2   -7.92     -235 234  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241     0             -241      imp:n,p=1 $ liner+void
  242     2   -7.92     -242 241  imp:n,p=1 $ liner+void+liner
  243     2   -7.92     -243 242  imp:n,p=1 $ liner+void+liner+iron-angle
  244     2   -7.92     -244 243  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251     2   -7.92     -251      imp:n,p=1 $ ss lid
  252     0             -252 251  imp:n,p=1 $ ss lid+void
  253     2   -7.92     -253 252  imp:n,p=1 $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261     0             -261 #502      imp:n,p=1 $ void
  262     2   -7.92     -262 261  imp:n,p=1 $ void+ss lid
  263     0             -263 262  imp:n,p=1 $ void+ss lid+void
  264     2   -7.92     -264 263  imp:n,p=1 $ void+ss lid+void+drum
c
c   Put volume source for top and bottom detectors
c
  501     0             -501      imp:n,p=1 $ bottom surface detector
  502     0             -502      imp:n,p=1 $ top surface detector
  551     0             -551      imp:n,p=1 $ 1 m from bottom surface - detector
  552     0             -552      imp:n,p=1 $ 1 m from top surface - detector
c
  998     0             -999      51 62 73 87 97 111 117 127 138 146 155
                                  164 174 184 195 206 217 226 235 244 253
                                  264 501 502 551 552
                                  imp:n,p=1 $ inside boundary
  999     0              999      imp:n,p=0 $ outside world

c    ------------------
c    Surface Cards
c    ------------------
c
    1  rcc  0.0 0.0 12.4968   0.0 0.0  76.20   4.9337  $ inner radius cylindrical shell source
```

```
    2  rcc  0.0 0.0 12.4968   0.0 0.0  76.20   6.35    $ outer radius cylindrical shell source
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51  rcc  0.0 0.0  0.0     0.0 0.0 0.2667   23.3299  $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.1775  $ bottom kaolite
   62  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.3299  $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  11.0744  $ bottom liner
   72  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.1775  $ bottom liner+kaolite
   73  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.3299  $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    3.1750  $ void
   82  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    7.9248  $ void+pad
   83  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    8.0772  $ void+pad+liner
   84  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   10.9220  $ void+pad+liner+277-4
   85  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   11.0744  $ void+pad+liner+277-4+liner
   86  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.1775  $ void+pad+liner+277-4+liner+kaolite
   87  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.3299  $
void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    6.6802  $ cv bottom
   92  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    7.9248  $ cv bottom+void
   93  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    8.0772  $ cv bottom+void+liner
   94  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   10.9220  $ cv bottom+void+liner+277-4
   95  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   11.0744  $ cv bottom+void+liner+277-4+liner
   96  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.1775  $ cv
bottom+void+liner+277-4+liner+kaolite
   97  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.3299  $ cv
bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.4262  $ cv void
  102  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.6802  $ cv void+ss
  103  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  7.9248  $ cv void+ss+void
  104  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  8.0772  $ cv void+ss+void+liner
  105  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 10.9220  $ cv void+ss+void+liner+277-4
  106  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 11.0744  $ cv void+ss+void+liner+277-4+liner
  107  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.1775  $ cv
void+ss+void+liner+277-4+liner+kaolite
  108  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum
  109  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 24.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 123.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 124.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.58579 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
```

```
c
  112  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.4262  $ cv void
  113  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.6802  $ cv void+ss
  114  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  7.9248  $ cv void+ss+void
  115  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 11.0744  $ cv void+ss+void+liner
  116  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.1775  $ cv void+ss+void+liner+kaolite
  117  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 5) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.4262  $ cv void
  123  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.6802  $ cv void+ss
  124  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 10.9220  $ cv void+ss+void
  125  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 11.0744  $ cv void+ss+void+liner
  126  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.1775  $ cv void+ss+void+liner+kaolite
  127  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  6.4262  $ cv void
  133  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  9.5250  $ cv void+ss
  134  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.0330  $ cv void+ss+rubber
  135  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.9220  $ cv void+ss+rubber+void
  136  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 11.0744  $ cv void+ss+rubber+void+liner
  137  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.1775  $ cv void+ss+rubber+void+liner+kaolite
  138  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.3299  $ cv
void+ss+rubber+void+liner+kaolite+drum
c
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (lower section of CV flange)
c
  141  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210  9.5250  $ ss
  142  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.0330  $ ss+rubber
  143  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.9220  $ ss+rubber+void
  144  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 11.0744  $ ss+rubber+void+liner
  145  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.1775  $ ss+rubber+void+liner+kaolite
  146  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.3299  $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.0330  $ rubber
  152  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.9220  $ rubber+void
  153  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 11.0744  $ rubber+void+liner
  154  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.1775  $ rubber+void+liner+kaolite
  155  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.3299  $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 10.9220  $ void
  162  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 11.0744  $ void+liner
  163  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.1775  $ void+liner+kaolite
  164  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 10.9220  $ void
  172  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 18.7579  $ void+liner
  173  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.1775  $ void+liner+kaolite
```

```
  174  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.6055  $ void
  182  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.7579  $ void+liner
  183  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.1775  $ void+liner+kaolite
  184  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.3299  $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.2499   $ ss (liner)
  192  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.6055   $ ss+void
  193  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.7579   $ ss+void+liner
  194  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.1775   $ ss+void+liner+kaolite
  195  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.3299   $ ss+void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.0975  $ kaolite
  202  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.2499  $ kaolite +liner
  203  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.6055  $ kaolite+liner+void
  204  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.7579  $ kaolite+liner+void+liner
  205  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.1775  $ kaolite+liner+void+liner+kaolite
  206  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.3299  $
kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.0975  $ kaolite
  212  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.2499  $ kaolite +liner
  213  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.6055  $ kaolite+liner+void
  214  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.7579  $ kaolite+liner+void+liner
  215  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  19.3929  $ kaolite+liner+void+liner+iron-angle
  216  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.1775  $
kaolite+liner+void+liner+iron-angle+kaolite
  217  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.3299  $
kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.0975  $ kaolite
  222  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.2499  $ kaolite +liner
  223  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.6055  $ kaolite+liner+void
  224  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.7579  $ kaolite+liner+void+liner
  225  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.1775  $ kaolite+liner+void+liner+iron-angle
  226  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.3299  $
kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.2499  $ ss liner
  232  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.6055  $ ss liner+void
  233  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.7579  $ ss liner+void+liner
  234  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.1775  $ ss liner+void+liner+iron-angle
  235  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.3299  $ ss liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.6055  $ void
  242  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.7579  $ void+liner
```

```
  243  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.1775  $ void+liner+iron-angle
  244  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.3299  $ void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1140  $ ss lid
  252  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1775  $ ss lid+void
  253  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.3299  $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  22.9616  $ void
  262  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1140  $ void+ss lid
  263  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1775  $ void+ss lid+void
  264  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.3299  $ void+ss lid+void+drum
c
c   Segmented side volume detectors
c
  301  pz 13
  302  pz 14
  303  pz 15
  304  pz 16
  305  pz 17
  306  pz 18
  307  pz 19
  308  pz 20
  309  pz 21
  310  pz 22
  311  pz 23
  312  pz 24
  313  pz 25
  314  pz 26
  315  pz 27
  316  pz 28
  317  pz 29
  318  pz 30
  319  pz 31
  320  pz 32
  321  pz 33
  322  pz 34
  323  pz 35
  324  pz 36
  325  pz 37
  326  pz 38
  327  pz 39
  328  pz 40
  329  pz 41
  330  pz 42
  331  pz 43
  332  pz 44
  333  pz 45
  334  pz 46
  335  pz 47
  336  pz 48
  337  pz 49
  338  pz 50
  339  pz 51
  340  pz 52
  341  pz 53
  342  pz 54
  343  pz 55
```

```
  344  pz 56
  345  pz 57
  346  pz 58
  347  pz 59
  348  pz 60
  349  pz 61
  350  pz 62
  351  pz 63
  352  pz 64
  353  pz 65
  354  pz 66
  355  pz 67
  356  pz 68
  357  pz 69
  358  pz 70
  359  pz 71
  360  pz 72
  361  pz 73
  362  pz 74
  363  pz 75
  364  pz 76
  365  pz 77
  366  pz 78
  367  pz 79
  368  pz 80
  369  pz 81
  370  pz 82
  371  pz 83
  372  pz 84
  373  pz 85
  374  pz 86
  375  pz 87
  376  pz 88
  377  pz 89
c
c   plane perpendicular to x-axis
c
  401  px 0
c
c   Put volume source for top and bottom detectors
c
  501  rcc 0.0 0.0 -0.5  0.0 0.0  0.5  1.0          $ bottom surface vol detector
  502  rcc 0.0 0.0 108.73739  0.0 0.0  0.5  1.0     $ top surface vol detector
  551  rcc 0.0 0.0 -100.5  0.0 0.0  0.5  1.0        $ 1 m from bottom surface - vol detector
  552  rcc 0.0 0.0 208.73739  0.0 0.0  0.5  1.0     $ 1 m from top surface - vol detector
c
  999  sph  0.0 0.0  0.000  999.0                          $ boundary
c

c    ----------------------
c    Data Cards
c    ----------------------
mode  n p
c
c      uranium metal (18.82 g/cc)
c
m1    92235.70c  -0.9500    $ U-235           95.0000  wt%
      92238.70c  -0.0500    $ U-238            5.0000  wt%
c
c      ss 304 (7.92 g/cc)
c
```

```
m2     6000.70c  -0.00080    $ Carbon(C)         0.0800  wt%
      14028.70c  -0.00919    $ Silicon(Si-28)    0.9187  wt%
      14029.70c  -0.00048    $ Si-29             0.0483  wt%
      14030.70c  -0.00033    $ Si-30             0.0330  wt%
      15031.70c  -0.00045    $ Phosphorus(P)     0.0450  wt%
      24050.70c  -0.00793    $ Cromium (Cr-50)   0.7930  wt%
      24052.70c  -0.15903    $ Cr-52            15.9029  wt%
      24053.70c  -0.01838    $ Cr-53             1.8380  wt%
      24054.70c  -0.00466    $ Cr-54             0.4661  wt%
      25055.70c  -0.02000    $ Manganese (Mn)    2.0000  wt%
      26054.70c  -0.03860    $ Iron (Fe-54)      3.8602  wt%
      26056.70c  -0.62838    $ Fe-56            62.8377  wt%
      26057.70c  -0.01477    $ Fe-57             1.4772  wt%
      26058.70c  -0.00200    $ Fe-58             0.2000  wt%
      28058.70c  -0.06384    $ Nickel (Ni-58)    6.3838  wt%
      28060.70c  -0.02544    $ Ni-60             2.5437  wt%
      28061.70c  -0.00112    $ Ni-61             0.1124  wt%
      28062.70c  -0.00364    $ Ni-62             0.3643  wt%
      28064.70c  -0.00096    $ Ni-64             0.0958  wt%
c
c      rubber foam (1.20 g/cc)
c
m3     1001.70c  -0.08157    $ Hydrogen (H)      8.1573 wt%
       6000.70c  -0.32377    $ Carbon (C)       32.3767 wt%
       8016.70c  -0.21520    $ Oxygen (O-16)    21.5196 wt%
       8017.70c  -0.00059    $ O-17 & O-18       0.0586 wt%
      14028.70c  -0.34806    $ Silicon(Si-28)   34.8061 wt%
      14029.70c  -0.01831    $ Si-29             1.8314 wt%
      14030.70c  -0.01250    $ Si-30             1.2503 wt%
c
c      kaolite (0.321 g/cc)
c
m4     8016.70c -0.4092    $ Oxygen (O-16)   40.9231 wt%
       8017.70c -0.0011    $ Oxygen (17&18)   0.1114 wt%
      11023.70c -0.0148    $ Sodium (Na)      1.4837 wt%
      12024.70c -0.0786    $ Magnesium (Mg-24)6.1579 wt%
      12025.70c -0.0081    $ Mg-25            0.8121 wt%
      12026.70c -0.0093    $ Mg-26            0.9298 wt%
      13027.70c -0.0508    $ Al               5.0808 wt%
      14028.70c -0.1576    $ Silicon (Si-28) 15.7596 wt%
      14029.70c -0.0083    $ Si-29            0.8292 wt%
      14030.70c -0.0057    $ Si-30            0.5661 wt%
      20040.70c -0.2121    $ Calcium (Ca-40) 21.2086 wt%
      20042.70c -0.0015    $ Ca-42            0.1490 wt%
      20043.70c -0.0003    $ Ca-43            0.0318 wt%
      20044.70c -0.0050    $ Ca-44            0.5031 wt%
      20046.70c -0.00001   $ Ca-46            0.0010 wt%
      20048.70c -0.0005    $ Ca-48            0.0491 wt%
      22046.70c -0.0006    $ Titanium (Ti-46) 0.0570 wt%
      22047.70c -0.0005    $ Ti-47            0.0525 wt%
      22048.70c -0.0053    $ Ti-48            0.5311 wt%
      22049.70c -0.0004    $ Ti-49            0.0398 wt%
      22050.70c -0.0004    $ Ti-50            0.0407 wt%
      26054.70c -0.0026    $ Iron (Fe-54)     0.2646 wt%
      26056.70c -0.0431    $ Fe-56            4.3066 wt%
      26057.70c -0.0010    $ Fe-57            0.1012 wt%
      26058.70c -0.0001    $ Fe-58            0.0137 wt%
c
c      Cat 277-4 (1.4586 g/cc)
c
m5     1001.70c -0.0285    $ Hydrogen         2.8475 wt%
```

```
        5010.70c -0.0066    $ Boron (B-10)     0.6591 wt%
        5011.70c -0.0297    $ Boron (B-11)     2.9726 wt%
        6000.70c -0.0136    $ Carbon (C)       1.3609 wt%
        7014.70c -0.0001    $ Nitrogen (N)     0.0100 wt%
        8016.70c -0.5325    $ Oxygen (O-16)   53.2515 wt%
        8017.70c -0.0015    $ Oxygen (17&18)   0.1450 wt%
       11023.70c -0.0008    $ Sodium (Na)      0.0833 wt%
       12024.70c -0.0019    $ Magnesium (Mg-24)0.1867 wt%
       12025.70c -0.0002    $ Mg-25            0.0246 wt%
       12026.70c -0.0003    $ Mg-26            0.0282 wt%
       13027.70c -0.2769    $ Al              27.6937 wt%
       14028.70c -0.0161    $ Silicon (Si-28)  1.6075 wt%
       14029.70c -0.0008    $ Si-29            0.0846 wt%
       14030.70c -0.0006    $ Si-30            0.0577 wt%
       16032.70c -0.0021    $ Sulfur (S-32)    0.2071 wt%
       16033.70c -0.00002   $ S-33             0.0017 wt%
       16034.70c -0.0001    $ S-34             0.0098 wt%
       16036.70c -0.0000002 $ S-36             0.00002 wt%
       20040.70c -0.0811    $ Calcium (Ca-40)  8.1125 wt%
       20042.70c -0.0006    $ Ca-42            0.0569 wt%
       20043.70c -0.0001    $ Ca-43            0.0121 wt%
       20044.70c -0.0019    $ Ca-44            0.1920 wt%
       20046.70c -0.000004  $ Ca-46            0.0004 wt%
       20048.70c -0.0002    $ Ca-48            0.0188 wt%
       26054.70c -0.0002    $ Iron (Fe-54)     0.0212 wt%
       26056.70c -0.0035    $ Fe-56            0.3453 wt%
       26057.70c -0.00008   $ Fe-57            0.0081 wt%
       26058.70c -0.00001   $ Fe-58            0.0011 wt%
c
c       air (1.225e-3 g/cc)
c
m6      7014.70c  -0.755   $ Nitrogen (N-14) 75.5000 wt%
        8016.70c  -0.232   $ Oxygen (O-16)   23.2000 wt%
       18000.70c  -0.013   $ Argon (Ar-40)    1.3000 wt%
c
c      uranium metal (10.960 g/cc - variable)
c
m7     8016.70c  -0.1198    $ O               11.9800  wt%
      92235.70c  -0.8362    $ U-235           83.6200  wt%
      92238.70c  -0.0440    $ U-238            4.4000  wt%
c
c    source in ES-3100 - cylindrical hemishell at the bottom of CV
c                        (H = 76.2 cm; IR = 4.9337 cm; OR = 6.35 cm)
c
c   neutron source - 2.129e-01 neutron/sec/gm basis
c   material used - 36 kg HEU
c   dose conversion factor (mrem/hr)/(neutrons/cm2-s) used
c   source term, wgt = 2.129e-01 * 36.0e+03  = 7.6644e+03
c
sdef cell=2 pos=0 0 12.4968 rad=d1 ext=d2  erg=d3 axs=0 0 1 wgt=7.6644e+03
c
c  source position
c
si1    4.9337   6.35         $ radial
sp1    -21       1
si2    0.0     76.20         $ axial
sp2     0        1
c
c  ORIGEN neutron spectrum
c
si3     5.83e-04     3.04e-03    1.50e-02     1.11e-01    4.08e-01
```

```
        9.07e-01     1.42e+00    1.83e+00     3.01e+00    6.38e+00    20.00e+00
c
sp3     0.0          7.034e-06   8.280e-05    1.790e-03   8.973e-03
        1.572e-02    2.205e-02   2.510e-02    1.042e-01   3.430e-02    7.260e-04
c
fq0 f s d
c
c  point detectors for neutrons
c
f5:n    23.4299  0.0     50.5968   0.0     $ side surface - detector
f15:n    0.0     0.0    108.83739  0.0     $ top surface - detector
f25:n    0.0     0.0     -0.1      0.0     $ bottom surface - detector
f35:n  123.3299  0.0     50.5968   0.0     $ 1m from side surface - detector
f45:n    0.0     0.0    208.73739  0.0     $ 1m from top surface - detector
f55:n    0.0     0.0   -100.0      0.0     $ 1m from bottom surface - detector
c
c ANSI/ANS-6.1.1-1977 neutron flux to dose rate conversion factor
c                                  (mrem/hr)/(neutrons/cm2-s)
c
de0      2.5e-08   1.0e-07   1.0e-06   1.0e-05   1.0e-04   1.0e-3    1.0e-02
         1.0e-01   5.0e-01   1.0       2.5       5.0       7.0       10.0
         14.0      20.0
c
df0      3.67e-03  3.67e-03  4.46e-03  4.54e-03  4.18e-03  3.76e-03  3.56e-03
         2.17e-02  9.26e-02  1.32e-01  1.25e-01  1.56e-01  1.47e-01  1.47e-01
         2.08e-01  2.27e-01
c
c  point detectors for secondary photons
c
f505:p   23.4299  0.0     50.5968   0.0     $ side surface - detector
f515:p    0.0     0.0    108.83739  0.0     $ top surface - detector
f525:p    0.0     0.0     -0.1      0.0     $ bottom surface - detector
f535:p  123.3299  0.0     50.5968   0.0     $ 1m from side surface - detector
f545:p    0.0     0.0    208.73739  0.0     $ 1m from top surface - detector
f555:p    0.0     0.0   -100.0      0.0     $ 1m from bottom surface - detector
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                  (mrem/hr)/(photons/cm2-s)
c
de505       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df505    3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
         6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
         1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
         3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
         5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
         1.03e-2   1.18e-2   1.33e-2
c
de515       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df515    3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
```

```
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
c
de525       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40      0.45      0.50      0.55
            0.60      0.65      0.70       0.8       1.0       1.4       1.8
             2.2       2.6       2.8      3.25      3.75      4.25      4.75
            5.00      5.25      5.75      6.25      6.75      7.50       9.0
            11.0      13.0      15.0
c
df525     3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
c
de535       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40      0.45      0.50      0.55
            0.60      0.65      0.70       0.8       1.0       1.4       1.8
             2.2       2.6       2.8      3.25      3.75      4.25      4.75
            5.00      5.25      5.75      6.25      6.75      7.50       9.0
            11.0      13.0      15.0
c
df535     3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
c
de545       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40      0.45      0.50      0.55
            0.60      0.65      0.70       0.8       1.0       1.4       1.8
             2.2       2.6       2.8      3.25      3.75      4.25      4.75
            5.00      5.25      5.75      6.25      6.75      7.50       9.0
            11.0      13.0      15.0
c
df545     3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
c
de555       0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40      0.45      0.50      0.55
            0.60      0.65      0.70       0.8       1.0       1.4       1.8
             2.2       2.6       2.8      3.25      3.75      4.25      4.75
            5.00      5.25      5.75      6.25      6.75      7.50       9.0
            11.0      13.0      15.0
c
df555     3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
          6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
          1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
          3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
          5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
          1.03e-2   1.18e-2   1.33e-2
```

```
c
prdmp  j  10000000 0 10
ctme 2000
```

5.5.2.5 NCT for 24-kg uranium oxide photon side dose-rate calculations (cylinder configuration source)

```
photon_side8.inp- ES-3100: 2015 HEU detailed model (primary photons)
c                 UO2 case (47.365 cm ht cylindrical
c                 density = 4.0 g/cc; OR=6.35 cm)
c    configuration
c    (bottom dose rate calculations)
c    source in cylindricalshell form sitting at the bottom of CV for
c    side dose rate calculations for 2015 Revision
c
c    mcnp geometry model (CV and outside) is identical to criticality model
c    (KENO Model).
c    47 energy groups are used for the photon spectrum.  In the older version,
c    18 energy groups were used.
c    surface detectors are placed 0.1 cm and 100 cm way from the surfaces
c    and detectors are placed on the side, top, and bottom.
c    point detectors are used for dose rate calculations (used for results).
c    segmented volume detectors are used for side dose rate calculations (for checking).
c    volume detectors are used to check bottom and top dose rate calculations.
c    ANSI/ANS-6.1.1-1977 Dose conversion factors are used,
c    multiplied by 1000 to convert from rem to mrem
c
c    segmented volume detectors are placed
c
c   mode p - (primary  photons)
c
c    --------------
c     Cell Cards
c    --------------
c
    1     7   -4.0      -1       imp:n,p=1 $ source shell
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51     2   -7.92     -51      imp:n,p=1 $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61     4   -0.321    -61      imp:n,p=1 $ bottom kaolite
   62     2   -7.92     -62 61   imp:n,p=1 $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71     2   -7.92     -71      imp:n,p=1 $ bottom liner
   72     4   -0.321    -72 71   imp:n,p=1 $ bottom liner+kaolite
   73     2   -7.92     -73 72   imp:n,p=1 $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81     0             -81      imp:n,p=1 $ void
   82     3   -1.2      -82 81   imp:n,p=1 $ void+pad
   83     2   -7.92     -83 82   imp:n,p=1 $ void+pad+liner
   84     5   -1.4586   -84 83   imp:n,p=1 $ void+pad+liner+277-4
   85     2   -7.92     -85 84   imp:n,p=1 $ void+pad+liner+277-4+liner
   86     4   -0.321    -86 85   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite
```

```
   87     2   -7.92     -87 86   imp:n,p=1 $ void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91     2   -7.92     -91      imp:n,p=1 $ cv bottom
   92     0              -92 91   imp:n,p=1 $ cv bottom+void
   93     2   -7.92     -93 92   imp:n,p=1 $ cv bottom+void+liner
   94     5   -1.4586   -94 93   imp:n,p=1 $ cv bottom+void+liner+277-4
   95     2   -7.92     -95 94   imp:n,p=1 $ cv bottom+void+liner+277-4+liner
   96     4   -0.321    -96 95   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite
   97     2   -7.92     -97 96   imp:n,p=1 $ cv bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101     0              -101 #1   imp:n,p=1 $ cv void
  102     2   -7.92     -102 101  imp:n,p=1 $ cv void+ss
  103     0              -103 102  imp:n,p=1 $ cv void+ss+void
  104     2   -7.92     -104 103  imp:n,p=1 $ cv void+ss+void+liner
  105     5   -1.4586   -105 104  imp:n,p=1 $ cv void+ss+void+liner+277-4
  106     2   -7.92     -106 105  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner
  107     4   -0.321    -107 106  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite
  108     2   -7.92     -108 107  imp:n,p=1 $ cv void+ss+void+liner+277-4+liner+kaolite+drum
  109     0              -109 108  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110     0              -110 109  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111     0              -111 110  imp:n,p=1 $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.5857 cm level (height - 0.1524 cm)
c   (ss liner top of sillicone rubber)
c
c 111     0              -111      imp:n,p=1 $ cv void (to be filled by content can)
  112     0              -112      imp:n,p=1 $ cv void
  113     2   -7.92     -113 112  imp:n,p=1 $ cv void+ss
  114     0              -114 113  imp:n,p=1 $ cv void+ss+void
  115     2   -7.92     -115 114  imp:n,p=1 $ cv void+ss+void+liner
  116     4   -0.321    -116 115  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  117     2   -7.92     -117 116  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 4) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122     0              -122      imp:n,p=1 $ cv void
  123     2   -7.92     -123 122  imp:n,p=1 $ cv void+ss
  124     0              -124 123  imp:n,p=1 $ cv void+ss+void
  125     2   -7.92     -125 124  imp:n,p=1 $ cv void+ss+void+liner
  126     4   -0.321    -126 125  imp:n,p=1 $ cv void+ss+void+liner+kaolite
  127     2   -7.92     -127 126  imp:n,p=1 $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132     0              -132      imp:n,p=1 $ cv void
  133     2   -7.92     -133 132  imp:n,p=1 $ cv void+ss
  134     3   -1.20     -134 133  imp:n,p=1 $ cv void+ss+rubber
  135     0              -135 134  imp:n,p=1 $ cv void+ss+rubber+void
  136     2   -7.92     -136 135  imp:n,p=1 $ cv void+ss+rubber+void+liner
  137     4   -0.321    -137 136  imp:n,p=1 $ cv void+ss+rubber+void+liner+kaolite
  138     2   -7.92     -138 137  imp:n,p=1 $ cv +void+ss+rubber+void+liner+kaolite+drum
c
```

```
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (middle section of CV flange)
c
  141     2   -7.92     -141      imp:n,p=1 $ ss
  142     3   -1.20     -142 141  imp:n,p=1 $ ss+rubber
  143     0             -143 142  imp:n,p=1 $ ss+rubber+void
  144     2   -7.92     -144 143  imp:n,p=1 $ ss+rubber+void+liner
  145     4   -0.321    -145 144  imp:n,p=1 $ ss+rubber+void+liner+kaolite
  146     2   -7.92     -146 145  imp:n,p=1 $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151     3   -1.20     -151      imp:n,p=1 $ rubber
  152     0             -152 151  imp:n,p=1 $ rubber+void
  153     2   -7.92     -153 152  imp:n,p=1 $ rubber+void+liner
  154     4   -0.321    -154 153  imp:n,p=1 $ rubber+void+liner+kaolite
  155     2   -7.92     -155 154  imp:n,p=1 $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161     0             -161      imp:n,p=1 $ void
  162     2   -7.92     -162 161  imp:n,p=1 $ void+liner
  163     4   -0.321    -163 162  imp:n,p=1 $ void+liner+kaolite
  164     2   -7.92     -164 163  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171     0             -171      imp:n,p=1 $ void
  172     2   -7.92     -172 171  imp:n,p=1 $ void+liner
  173     4   -0.321    -173 172  imp:n,p=1 $ void+liner+kaolite
  174     2   -7.92     -174 173  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181     0             -181      imp:n,p=1 $ void
  182     2   -7.92     -182 181  imp:n,p=1 $ void+liner
  183     4   -0.321    -183 182  imp:n,p=1 $ void+liner+kaolite
  184     2   -7.92     -184 183  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191     2   -7.92     -191      imp:n,p=1 $ ss (liner)
  192     0             -192 191  imp:n,p=1 $ ss+void
  193     2   -7.92     -193 192  imp:n,p=1 $ ss+void+liner
  194     4   -0.321    -194 193  imp:n,p=1 $ ss+void+liner+kaolite
  195     2   -7.92     -195 194  imp:n,p=1 $ void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201     4   -0.321    -201      imp:n,p=1 $ kaolite
  202     2   -7.92     -202 201  imp:n,p=1 $ kaolite+liner
  203     0             -203 202  imp:n,p=1 $ kaolite+liner+void
  204     2   -7.92     -204 203  imp:n,p=1 $ kaolite+liner+void+liner
  205     4   -0.321    -205 204  imp:n,p=1 $ kaolite+liner+void+liner+kaolite
  206     2   -7.92     -206 205  imp:n,p=1 $ kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211     4   -0.321    -211      imp:n,p=1 $ kaolite
  212     2   -7.92     -212 211  imp:n,p=1 $ kaolite+liner
```

```
  213     0             -213 212  imp:n,p=1 $ kaolite+liner+void
  214     2   -7.92     -214 213  imp:n,p=1 $ kaolite+liner+void+liner
  215     2   -7.92     -215 214  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  216     4   -0.321    -216 215  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite
  217     2   -7.92     -217 216  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221     4   -0.321    -221      imp:n,p=1 $ kaolite
  222     2   -7.92     -222 221  imp:n,p=1 $ kaolite+liner
  223     0             -223 222  imp:n,p=1 $ kaolite+liner+void
  224     2   -7.92     -224 223  imp:n,p=1 $ kaolite+liner+void+liner
  225     2   -7.92     -225 224  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle
  226     2   -7.92     -226 225  imp:n,p=1 $ kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231     2   -7.92     -231      imp:n,p=1 $ liner
  232     0             -232 231  imp:n,p=1 $ liner+void
  233     2   -7.92     -233 232  imp:n,p=1 $ liner+void+liner
  234     2   -7.92     -234 233  imp:n,p=1 $ liner+void+liner+iron-angle
  235     2   -7.92     -235 234  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241     0             -241      imp:n,p=1 $ liner+void
  242     2   -7.92     -242 241  imp:n,p=1 $ liner+void+liner
  243     2   -7.92     -243 242  imp:n,p=1 $ liner+void+liner+iron-angle
  244     2   -7.92     -244 243  imp:n,p=1 $ liner+void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251     2   -7.92     -251      imp:n,p=1 $ ss lid
  252     0             -252 251  imp:n,p=1 $ ss lid+void
  253     2   -7.92     -253 252  imp:n,p=1 $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261     0             -261 #502      imp:n,p=1 $ void
  262     2   -7.92     -262 261  imp:n,p=1 $ void+ss lid
  263     0             -263 262  imp:n,p=1 $ void+ss lid+void
  264     2   -7.92     -264 263  imp:n,p=1 $ void+ss lid+void+drum
c
c   Put volume source for top and bottom detectors
c
  501     0             -501      imp:n,p=1 $ bottom surface detector
  502     0             -502      imp:n,p=1 $ top surface detector
  551     0             -551      imp:n,p=1 $ 1 m from bottom surface - detector
  552     0             -552      imp:n,p=1 $ 1 m from top surface - detector
c
  998     0             -999      51 62 73 87 97 111 117 127 138 146 155
                                  164 174 184 195 206 217 226 235 244 253
                                  264 501 502 551 552
                                  imp:n,p=1 $ inside boundary
  999     0              999      imp:n,p=0 $ outside world

c    ------------------
c    Surface Cards
c    ------------------
c
```

```
    1  rcc  0.0 0.0 12.4968   0.0 0.0  47.365   6.35    $ outer radius cylindrical shell
source
c
c   drum bottom - at 0.0 cm level (height - 0.2667 cm)
c
   51  rcc  0.0 0.0  0.0     0.0 0.0 0.2667   23.3299  $ drum bottom
c
c   bottom kaolite - at 0.2667 cm level (height - 10.8585 cm)
c
   61  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.1775  $ bottom kaolite
   62  rcc  0.0 0.0  0.2667  0.0 0.0 10.8585  23.3299  $ bottom kaolite+drum
c
c   bottom inner liner - at 11.1252 cm level (height - 0.3048 cm)
c
   71  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  11.0744  $ bottom liner
   72  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.1775  $ bottom liner+kaolite
   73  rcc  0.0 0.0 11.1252  0.0 0.0  0.3048  23.3299  $ bottom liner+kaolite+drum
c
c   bottom rubber pad - at 11.4300 cm level (height - 0.4318 cm)
c
   81  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    3.1750  $ void
   82  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    7.9248  $ void+pad
   83  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318    8.0772  $ void+pad+liner
   84  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   10.9220  $ void+pad+liner+277-4
   85  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   11.0744  $ void+pad+liner+277-4+liner
   86  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.1775  $ void+pad+liner+277-4+liner+kaolite
   87  rcc  0.0 0.0 11.4300  0.0 0.0 0.4318   23.3299  $
void+pad+liner+277-4+liner+kaolite+drum
c
c   CV bottom (section 1) - at 11.8618 cm level (height - 0.6350 cm)
c
   91  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    6.6802  $ cv bottom
   92  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    7.9248  $ cv bottom+void
   93  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350    8.0772  $ cv bottom+void+liner
   94  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   10.9220  $ cv bottom+void+liner+277-4
   95  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   11.0744  $ cv bottom+void+liner+277-4+liner
   96  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.1775  $ cv
bottom+void+liner+277-4+liner+kaolite
   97  rcc  0.0 0.0 11.8618  0.0 0.0 0.6350   23.3299  $ cv
bottom+void+liner+277-4+liner+kaolite+drum
c
c   CV (section 2) at 12.4968 cm level (height - 77.08899 cm)
c
  101  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.4262  $ cv void
  102  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  6.6802  $ cv void+ss
  103  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  7.9248  $ cv void+ss+void
  104  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899  8.0772  $ cv void+ss+void+liner
  105  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 10.9220  $ cv void+ss+void+liner+277-4
  106  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 11.0744  $ cv void+ss+void+liner+277-4+liner
  107  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.1775  $ cv
void+ss+void+liner+277-4+liner+kaolite
  108  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 23.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum
  109  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 24.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1
  110  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 123.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp
  111  rcc  0.0 0.0 12.4968  0.0 0.0 77.08899 124.3299  $ cv
void+ss+void+liner+277-4+liner+kaolite+drum+dt1+sp+dt2
c
c   CV (section 3) at 89.58579 cm level (height - 0.1524 cm)
```

```
c   (ss liner top of sillicone rubber)
c
  112  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.4262  $ cv void
  113  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  6.6802  $ cv void+ss
  114  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524  7.9248  $ cv void+ss+void
  115  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 11.0744  $ cv void+ss+void+liner
  116  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.1775  $ cv void+ss+void+liner+kaolite
  117  rcc  0.0 0.0 89.58579  0.0 0.0  0.1524 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 5) at 89.73819 cm level (height - 0.2286 cm)
c   (gap between Cat 277-4 & CV top section)
c
  122  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.4262  $ cv void
  123  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286  6.6802  $ cv void+ss
  124  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 10.9220  $ cv void+ss+void
  125  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 11.0744  $ cv void+ss+void+liner
  126  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.1775  $ cv void+ss+void+liner+kaolite
  127  rcc  0.0 0.0 89.73819  0.0 0.0  0.2286 23.3299  $ cv void+ss+void+liner+kaolite+drum
c
c   CV (section 6) at 89.96679 cm level (height - 1.27 cm)
c   (lower section of CV flange)
c
  132  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  6.4262  $ cv void
  133  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700  9.5250  $ cv void+ss
  134  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.0330  $ cv void+ss+rubber
  135  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 10.9220  $ cv void+ss+rubber+void
  136  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 11.0744  $ cv void+ss+rubber+void+liner
  137  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.1775  $ cv void+ss+rubber+void+liner+kaolite
  138  rcc  0.0 0.0 89.96679  0.0 0.0  1.2700 23.3299  $ cv
void+ss+rubber+void+liner+kaolite+drum
c
c   CV (section 7) at 91.23679 cm level (height - 2.921 cm)
c   (lower section of CV flange)
c
  141  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210  9.5250  $ ss
  142  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.0330  $ ss+rubber
  143  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 10.9220  $ ss+rubber+void
  144  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 11.0744  $ ss+rubber+void+liner
  145  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.1775  $ ss+rubber+void+liner+kaolite
  146  rcc  0.0 0.0 91.23679  0.0 0.0  2.9210 23.3299  $ ss+rubber+void+liner+kaolite+drum
c
c   CV (section 8) at 94.15779 cm level (height - 0.762 cm)
c   (top section of CV flange)
c
  151  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.0330  $ rubber
  152  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 10.9220  $ rubber+void
  153  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 11.0744  $ rubber+void+liner
  154  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.1775  $ rubber+void+liner+kaolite
  155  rcc  0.0 0.0 94.15779  0.0 0.0  0.7620 23.3299  $ rubber+void+liner+kaolite+drum
c
c   Top of CV (section 1) at 94.91979 cm level (height - 0.254 cm)
c
  161  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 10.9220  $ void
  162  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 11.0744  $ void+liner
  163  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.1775  $ void+liner+kaolite
  164  rcc  0.0 0.0 94.91979  0.0 0.0  0.2540 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 2) at 95.17379 cm level (height - 0.1524 cm)
c
  171  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 10.9220  $ void
  172  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 18.7579  $ void+liner
```

```
  173  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.1775  $ void+liner+kaolite
  174  rcc  0.0 0.0 95.17379  0.0 0.0  0.1524 23.3299  $ void+liner+kaolite+drum
c
c   Top of CV (section 3) at 95.32619 cm level (height - 0.34036 cm)
c
  181  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.6055  $ void
  182  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 18.7579  $ void+liner
  183  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.1775  $ void+liner+kaolite
  184  rcc  0.0 0.0 95.32619  0.0 0.0  0.34036 23.3299  $ void+liner+kaolite+drum
c
c   Kaolite plug bottom ss  at 95.66655 cm level (height - 0.1524 cm)
c
  191  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.2499   $ ss (liner)
  192  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.6055   $ ss+void
  193  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 18.7579   $ ss+void+liner
  194  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.1775   $ ss+void+liner+kaolite
  195  rcc  0.0 0.0 95.66655  0.0 0.0  0.1524 23.3299   $ ss+void+liner+kaolite+drum
c
c   Kaolite top plug bottom section  at 95.81895 cm level (height - 7.68604 cm)
c
  201  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.0975  $ kaolite
  202  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.2499  $ kaolite +liner
  203  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.6055  $ kaolite+liner+void
  204  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 18.7579  $ kaolite+liner+void+liner
  205  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.1775  $ kaolite+liner+void+liner+kaolite
  206  rcc  0.0 0.0 95.81895  0.0 0.0  7.68604 23.3299  $
kaolite+liner+void+liner+kaolite+drum
c
c   Kaolite top plug (iron angle bottom section) at 103.50499 cm level (height - 4.4450 cm)
c
  211  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.0975  $ kaolite
  212  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.2499  $ kaolite +liner
  213  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.6055  $ kaolite+liner+void
  214  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  18.7579  $ kaolite+liner+void+liner
  215  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  19.3929  $ kaolite+liner+void+liner+iron-angle
  216  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.1775  $
kaolite+liner+void+liner+iron-angle+kaolite
  217  rcc 0.0 0.0 103.50499  0.0 0.0  4.4450  23.3299  $
kaolite+liner+void+liner+iron-angle+kaolite+drum
c
c   Kaolite top plug (iron angle top section) at 107.94999 cm level (height - 0.1118 cm)
c
  221  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.0975  $ kaolite
  222  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.2499  $ kaolite +liner
  223  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.6055  $ kaolite+liner+void
  224  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  18.7579  $ kaolite+liner+void+liner
  225  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.1775  $ kaolite+liner+void+liner+iron-angle
  226  rcc 0.0 0.0 107.94999  0.0 0.0  0.11176  23.3299  $
kaolite+liner+void+liner+iron-angle+drum
c
c   Kaolite top plug (iron angle top section) at 108.06175 cm level (height - 0.1524 cm)
c
  231  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.2499  $ ss liner
  232  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.6055  $ ss liner+void
  233  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  18.7579  $ ss liner+void+liner
  234  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.1775  $ ss liner+void+liner+iron-angle
  235  rcc 0.0 0.0 108.06175  0.0 0.0  0.1524  23.3299  $ ss liner+void+liner+iron-angle+drum
c
c   Gap above Kaolite top plug at 108.21415 cm level (height - 0.37084 cm)
c
  241  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.6055  $ void
```

```
  242  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  18.7579  $ void+liner
  243  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.1775  $ void+liner+iron-angle
  244  rcc 0.0 0.0 108.21415  0.0 0.0  0.37084  23.3299  $ void+liner+iron-angle+drum
c
c   Top ss lid at 108.58499 cm level (height - 0.1524 cm)
c
  251  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1140  $ ss lid
  252  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.1775  $ ss lid+void
  253  rcc 0.0 0.0 108.58499  0.0 0.0  0.1524  23.3299  $ ss lid+void+drum
c
c   Top ss lid at 108.73739 cm level (height - 1.7526 cm)
c
  261  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  22.9616  $ void
  262  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1140  $ void+ss lid
  263  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.1775  $ void+ss lid+void
  264  rcc 0.0 0.0 108.73739  0.0 0.0  1.7526  23.3299  $ void+ss lid+void+drum
c
c   Segmented side volume detectors
c
  301  pz 13
  302  pz 14
  303  pz 15
  304  pz 16
  305  pz 17
  306  pz 18
  307  pz 19
  308  pz 20
  309  pz 21
  310  pz 22
  311  pz 23
  312  pz 24
  313  pz 25
  314  pz 26
  315  pz 27
  316  pz 28
  317  pz 29
  318  pz 30
  319  pz 31
  320  pz 32
  321  pz 33
  322  pz 34
  323  pz 35
  324  pz 36
  325  pz 37
  326  pz 38
  327  pz 39
  328  pz 40
  329  pz 41
  330  pz 42
  331  pz 43
  332  pz 44
  333  pz 45
  334  pz 46
  335  pz 47
  336  pz 48
  337  pz 49
  338  pz 50
  339  pz 51
  340  pz 52
  341  pz 53
  342  pz 54
```

```
  343  pz 55
  344  pz 56
  345  pz 57
  346  pz 58
  347  pz 59
  348  pz 60
  349  pz 61
  350  pz 62
  351  pz 63
  352  pz 64
  353  pz 65
  354  pz 66
  355  pz 67
  356  pz 68
  357  pz 69
  358  pz 70
  359  pz 71
  360  pz 72
  361  pz 73
  362  pz 74
  363  pz 75
  364  pz 76
  365  pz 77
  366  pz 78
  367  pz 79
  368  pz 80
  369  pz 81
  370  pz 82
  371  pz 83
  372  pz 84
  373  pz 85
  374  pz 86
  375  pz 87
  376  pz 88
  377  pz 89
c
c   Put volume source for top and bottom detectors
c
  501  rcc 0.0 0.0 -0.5  0.0 0.0  0.5  1.0          $ bottom surface vol detector
  502  rcc 0.0 0.0 108.73739  0.0 0.0  0.5  1.0     $ top surface vol detector
  551  rcc 0.0 0.0 -100.5  0.0 0.0  0.5  1.0        $ 1 m from bottom surface - vol detector
  552  rcc 0.0 0.0 208.73739  0.0 0.0  0.5  1.0     $ 1 m from top surface - vol detector
c
  999  sph  0.0 0.0  0.000  999.0                         $ boundary
c

c    ----------------------
c    Data Cards
c    ----------------------
mode  p
c
c      uranium metal (18.82 g/cc)
c
m1    92235.70c  -0.9500    $ U-235           95.0000  wt%
      92238.70c  -0.0500    $ U-238            5.0000  wt%
c
c      ss 304 (7.92 g/cc)
c
m2     6000.70c  -0.00080    $ Carbon(C)        0.0800  wt%
      14028.70c  -0.00919    $ Silicon(Si-28)   0.9187  wt%
      14029.70c  -0.00048    $ Si-29            0.0483  wt%
```

```
      14030.70c  -0.00033    $ Si-30            0.0330  wt%
      15031.70c  -0.00045    $ Phosphorus(P)    0.0450  wt%
      24050.70c  -0.00793    $ Cromium (Cr-50)  0.7930  wt%
      24052.70c  -0.15903    $ Cr-52           15.9029  wt%
      24053.70c  -0.01838    $ Cr-53            1.8380  wt%
      24054.70c  -0.00466    $ Cr-54            0.4661  wt%
      25055.70c  -0.02000    $ Manganese (Mn)   2.0000  wt%
      26054.70c  -0.03860    $ Iron (Fe-54)     3.8602  wt%
      26056.70c  -0.62838    $ Fe-56           62.8377  wt%
      26057.70c  -0.01477    $ Fe-57            1.4772  wt%
      26058.70c  -0.00200    $ Fe-58            0.2000  wt%
      28058.70c  -0.06384    $ Nickel (Ni-58)   6.3838  wt%
      28060.70c  -0.02544    $ Ni-60            2.5437  wt%
      28061.70c  -0.00112    $ Ni-61            0.1124  wt%
      28062.70c  -0.00364    $ Ni-62            0.3643  wt%
      28064.70c  -0.00096    $ Ni-64            0.0958  wt%
c
c      rubber foam (1.20 g/cc)
c
m3     1001.70c  -0.08157    $ Hydrogen (H)     8.1573 wt%
       6000.70c  -0.32377    $ Carbon (C)      32.3767 wt%
       8016.70c  -0.21520    $ Oxygen (O-16)   21.5196 wt%
       8017.70c  -0.00059    $ O-17 & O-18      0.0586 wt%
      14028.70c  -0.34806    $ Silicon(Si-28)  34.8061 wt%
      14029.70c  -0.01831    $ Si-29            1.8314 wt%
      14030.70c  -0.01250    $ Si-30            1.2503 wt%
c
c      kaolite (0.321 g/cc)
c
m4     8016.70c -0.4092    $ Oxygen (O-16)   40.9231 wt%
       8017.70c -0.0011    $ Oxygen (17&18)   0.1114 wt%
      11023.70c -0.0148    $ Sodium (Na)      1.4837 wt%
      12024.70c -0.0786    $ Magnesium (Mg-24)6.1579 wt%
      12025.70c -0.0081    $ Mg-25            0.8121 wt%
      12026.70c -0.0093    $ Mg-26            0.9298 wt%
      13027.70c -0.0508    $ Al               5.0808 wt%
      14028.70c -0.1576    $ Silicon (Si-28) 15.7596 wt%
      14029.70c -0.0083    $ Si-29            0.8292 wt%
      14030.70c -0.0057    $ Si-30            0.5661 wt%
      20040.70c -0.2121    $ Calcium (Ca-40) 21.2086 wt%
      20042.70c -0.0015    $ Ca-42            0.1490 wt%
      20043.70c -0.0003    $ Ca-43            0.0318 wt%
      20044.70c -0.0050    $ Ca-44            0.5031 wt%
      20046.70c -0.00001   $ Ca-46            0.0010 wt%
      20048.70c -0.0005    $ Ca-48            0.0491 wt%
      22046.70c -0.0006    $ Titanium (Ti-46) 0.0570 wt%
      22047.70c -0.0005    $ Ti-47            0.0525 wt%
      22048.70c -0.0053    $ Ti-48            0.5311 wt%
      22049.70c -0.0004    $ Ti-49            0.0398 wt%
      22050.70c -0.0004    $ Ti-50            0.0407 wt%
      26054.70c -0.0026    $ Iron (Fe-54)     0.2646 wt%
      26056.70c -0.0431    $ Fe-56            4.3066 wt%
      26057.70c -0.0010    $ Fe-57            0.1012 wt%
      26058.70c -0.0001    $ Fe-58            0.0137 wt%
c
c      Cat 277-4 (1.4586 g/cc)
c
m5     1001.70c -0.0285    $ Hydrogen         2.8475 wt%
       5010.70c -0.0066    $ Boron (B-10)     0.6591 wt%
       5011.70c -0.0297    $ Boron (B-11)     2.9726 wt%
       6000.70c -0.0136    $ Carbon (C)       1.3609 wt%
```

```
       7014.70c -0.0001    $ Nitrogen (N)     0.0100 wt%
       8016.70c -0.5325    $ Oxygen (O-16)   53.2515 wt%
       8017.70c -0.0015    $ Oxygen (17&18)   0.1450 wt%
      11023.70c -0.0008    $ Sodium (Na)      0.0833 wt%
      12024.70c -0.0019    $ Magnesium (Mg-24)0.1867 wt%
      12025.70c -0.0002    $ Mg-25            0.0246 wt%
      12026.70c -0.0003    $ Mg-26            0.0282 wt%
      13027.70c -0.2769    $ Al              27.6937 wt%
      14028.70c -0.0161    $ Silicon (Si-28)  1.6075 wt%
      14029.70c -0.0008    $ Si-29            0.0846 wt%
      14030.70c -0.0006    $ Si-30            0.0577 wt%
      16032.70c -0.0021    $ Sulfur (S-32)    0.2071 wt%
      16033.70c -0.00002   $ S-33             0.0017 wt%
      16034.70c -0.0001    $ S-34             0.0098 wt%
      16036.70c -0.0000002 $ S-36             0.00002 wt%
      20040.70c -0.0811    $ Calcium (Ca-40)  8.1125 wt%
      20042.70c -0.0006    $ Ca-42            0.0569 wt%
      20043.70c -0.0001    $ Ca-43            0.0121 wt%
      20044.70c -0.0019    $ Ca-44            0.1920 wt%
      20046.70c -0.000004  $ Ca-46            0.0004 wt%
      20048.70c -0.0002    $ Ca-48            0.0188 wt%
      26054.70c -0.0002    $ Iron (Fe-54)     0.0212 wt%
      26056.70c -0.0035    $ Fe-56            0.3453 wt%
      26057.70c -0.00008   $ Fe-57            0.0081 wt%
      26058.70c -0.00001   $ Fe-58            0.0011 wt%
c
c       air (1.225e-3 g/cc)
c
m6      7014.70c  -0.755   $ Nitrogen (N-14) 75.5000 wt%
        8016.70c  -0.232   $ Oxygen (O-16)   23.2000 wt%
       18000.70c  -0.013   $ Argon (Ar-40)    1.3000 wt%
c
c      uranium oxide (10.960 g/cc - variable)
c
m7     8016.70c  -0.1198    $ O               11.9800  wt%
      92235.70c  -0.8362    $ U-235           83.6200  wt%
      92238.70c  -0.0440    $ U-238            4.4000  wt%
c
c    source in ES-3100 - cylindrical at the bottom of CV
c                        (H = 63.153 cm; R = 6.35 cm)
c
c   photon source - 3.011e+06 photons/sec/gm basis
c   material used - 24 kg UO2 (21.126 kg U-mass)
c   dose conversion factor (mrem/hr)/(photons/cm2-s) used
c   source term, wgt = 3.011e+06 * 21.126e+03  = 6.361039e+10
c
sdef pos=0 0 12.4968 rad=d1 ext=d2  erg=d3 axs=0 0 1 wgt=6.361039e+10
c
c  source position
c
si1    0.00     6.35         $ radial
sp1    -21       1
si2    0.0     47.365        $ axial
sp2     0        1
c
c  ORIGEN photon spectrum
c
si3     5.00e-03     1.00e-02    1.50e-02     2.00e-02    2.50e-02     3.00e-02
        4.00e-02     5.00e-02    6.00e-02     7.00e-02    8.00e-02     9.00e-02
        1.00e-01     2.00e-01    3.00e-01     4.00e-01    5.00e-01     6.00e-01
        7.00e-01     8.00e-01    9.00e-01     1.00e+00    1.10e+00     1.20e+00
```

```
        1.30e+00     1.40e+00    1.50e+00     1.60e+00    1.70e+00     1.80e+00
        1.90e+00     2.00e+00    2.10e+00     2.20e+00    2.30e+00     2.40e+00
        2.50e+00     2.60e+00    2.70e+00     2.80e+00    2.90e+00     3.00e+00
        3.50e+00     4.00e+00    5.00e+00     6.50e+00    8.00e+00    10.00e+00
sp3     0.0          8.515e+04   1.700e+06    7.313e+03   3.595e+03    1.230e+05
        5.112e+03    6.605e+03   2.147e+05    1.779e+03   1.941e+04    1.085e+05
        2.244e+05    1.328e+05   5.245e+04    2.819e+05   1.556e+04    1.225e+04
        1.485e+02    2.705e+03   1.802e+03    4.068e+02   2.527e+02    2.157e+01
        2.105e+01    2.990e+01   1.300e+01    1.386e+02   4.719e+02    5.522e+00
        2.999e+01    4.918e+00   1.599e-02    1.308e-02   7.152e-02    5.321e-04
        1.584e-02    6.552e-05   1.062e+04    1.108e-02   1.917e-04    3.408e-04
        6.039e-01    3.876e-01   2.959e-03    1.134e-03   2.131e-04    4.388e-05
c
c  volume detector at the bottom surface of the drum
c
f4:p  501            $ bottom surface volume detector
f14:p 502            $ top surface volume detector
f24:p 551            $ 1 m from bottom surface  - volume detector
f34:p 552            $ 1 m from top surface  - volume detector
c
c  segmented volume detectors for primary photons
c  (13 cm through 99 cm)
c
c  side surface
c
f114:p 109
fs114  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310
       -311 -312 -313 -314 -315 -316 -317 -318 -319 -320
       -321 -322 -323 -324 -325 -326 -327 -328 -329 -330
       -331 -332 -333 -334 -335 -336 -337 -338 -339 -340
       -341 -342 -343 -344 -345 -346 -347 -348 -349 -350
       -351 -352 -353 -354 -355 -356 -357 -358 -359 -360
       -361 -362 -363 -364 -365 -366 -367 -368 -369 -370
       -371 -372 -373 -374 -375 -376 -377
c
c  1 m from side surface
c
f134:p  111
fs134  -301 -302 -303 -304 -305 -306 -307 -308 -309 -310
       -311 -312 -313 -314 -315 -316 -317 -318 -319 -320
       -321 -322 -323 -324 -325 -326 -327 -328 -329 -330
       -331 -332 -333 -334 -335 -336 -337 -338 -339 -340
       -341 -342 -343 -344 -345 -346 -347 -348 -349 -350
       -351 -352 -353 -354 -355 -356 -357 -358 -359 -360
       -361 -362 -363 -364 -365 -366 -367 -368 -369 -370
       -371 -372 -373 -374 -375 -376 -377
c
fq0 f s d
c
c  point detectors for primary photons
c
f5:p    23.4299  0.0     36.1793   0.0     $ side surface - detector
f15:p    0.0     0.0    108.83739  0.0     $ top surface - detector
f25:p    0.0     0.0     -0.1      0.0     $ bottom surface - detector
f35:p  123.3299  0.0     36.1793   0.0     $ 1m from side surface - detector
f45:p    0.0     0.0    208.73739  0.0     $ 1m from top surface - detector
f55:p    0.0     0.0   -100.0      0.0     $ 1m from bottom surface - detector
c
c ANSI/ANS-6.1.1-1977 photon flux to dose rate conversion factor
c                                  (mrem/hr)/(photons/cm2-s)
c
```

```
de0         0.01      0.03      0.05      0.07       0.1      0.15      0.20
            0.25      0.30      0.35      0.40       0.45     0.50      0.55
            0.60      0.65      0.70      0.8        1.0      1.4       1.8
            2.2       2.6       2.8       3.25       3.75     4.25      4.75
            5.00      5.25      5.75      6.25       6.75     7.50      9.0
           11.0      13.0      15.0
c
df0      3.96e-3   5.82e-4   2.90e-4   2.58e-4   2.83e-4   3.79e-4   5.01e-4
         6.31e-4   7.59e-4   8.78e-4   9.85e-4   1.08e-3   1.17e-3   1.27e-3
         1.36e-3   1.44e-3   1.52e-3   1.68e-3   1.98e-3   2.51e-3   2.99e-3
         3.42e-3   3.82e-3   4.01e-3   4.41e-3   4.83e-3   5.23e-3   5.60e-3
         5.80e-3   6.01e-3   6.37e-3   6.74e-3   7.11e-3   7.66e-3   8.77e-3
         1.03e-2   1.18e-2   1.33e-2
c
prdmp  j  50000000 0 10
ctme 1000
```

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SECTION 5 REFERENCES

10 CFR 71, *Packaging and Transportation of Radioactive Material*, January 2015.

49 CFR, *Transportation*, October 2014.

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LA-UR-03-1987, *MCNP—A General Monte Carlo N-Particle Transport Code,* Version 5, Volume 1: Overview and Theory, Los Alamos National Laboratory, Los Alamos, N.M., Apr. 24, 2003 (Revised Feb. 1, 2008).

NUREG/CR-0200 (ORNL/NUREG/CSD-2/V2/R7), *ORIGEN-S: SCALE System Module to Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation Source Terms*, Rev. 7, Vol. II, Sect. F7, UT-Battelle, Oak Ridge National Laboratory, May 2004. ORIGEN-S is a SCALE module.

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6. CRITICALITY EVALUATION

This section describes the criticality safety evaluation of the Y-12 National Security Complex (Y-12) Model ES-3100 package with solid highly enriched uranium (HEU) metal or alloys (specific information for alloys are addressed in Sects. 6.2.1, 6.2.4, 6.3.2, 6.4, 6.4.1, and 6.6.1), or HEU oxide, or highly enriched uranyl nitrate crystals (UNX). HEU metal or alloy may be in the form of solid shapes (cylinders, bars, buttons, billets, slugs, unirradiated TRIGA fuel), broken metal, turnings, fines, powder, or content of an unspecified geometric shape and characterized as broken metal. Distinguished from TRIGA contents, the research reactor related contents covered under this criticality evaluation are fuel elements or fuel components, broken metal, U alloys, or oxides.

A variety of similar materials from various reactor programs were added under a subsequent revision of the criticality safety evaluation (Appendix 6.9.8). These additional contents include bare, clad or canned uranium metal alloy or oxide in various shapes as pellets, rods, plates, bundled components and fuel assemblies. Compounds of uranium include uranium tetrafluoride, uranyl fluoride, uranium carbide, and uranium nitride. The physical form of these uranium compounds is described as powder, beads, and ash. Both content moisture and content uniformity are not defined. The criticality evaluation has been updated as discussed in Appendices 6.9.9 and 6.9.11.

Physical testing of Type-B fissile material packages for surface transportation conducted in accordance with the physical testing requirements of 10 CFR 71 is limited to the ES-3100 packaging and non-fissile dummy contents. Consequently, analytic methods are used to demonstrate compliance of the ES-3100 package with the applicable performance requirements in 10 CFR 71. The specific requirements investigated for compliance in this evaluation are contained in 10 CFR 71.55, "General Requirements of all Fissile Material Packages," and 10 CFR 71.59, "Standards for Arrays of Fissile Material Packages." Physical testing of Type-B fissile material packages transported by air is not conducted for the ES-3100. Analytic methods are also used to demonstrate compliance of the ES-3100 package with the requirements of 10 CFR 71.55(f). This is accomplished by demonstrating compliance of the package with the more stringent requirements of the International Atomic Energy Agency (IAEA) for situations where the conditions of the fissile material package following the tests cannot be demonstrated (TS-G-1.1, Sect. 680.2).

6.1 DESCRIPTION OF THE CRITICALITY DESIGN

6.1.1 Design Features

The principal design feature of interest in the criticality evaluation of the Model ES-3100 package is the containment/outer drum system (Drawing M2E801580A031, Appendix 1.3.7). The ES-3100 package uses a single containment system (Drawing M2E801580A011, Appendix 1.3.7) to contain the HEU contents. The containment is a high-integrity, watertight, post-load leak-testable, stainless-steel vessel (Fig. 1.3). The outer drum system (Drawing M2E801580A001, Appendix 1.3.7) is a recessed, double-compartment body with a removable top for insertion and removal of the containment vessel. The body weldment liner outer cavity and the top plug weldment contain Kaolite 1600 (Kaolite), a thermal insulation material that protects the containment vessel from thermal absorption, shock and impact. The body weldment liner inner cavity contains a neutron poison, "277-4," which serves as a strong neutron absorber. Other sections of this report (Sects. 2, 3, and 4) demonstrate the integrity of the ES-3100 package [i.e., that this single containment vessel remains intact and watertight under the Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC)].

Typical shipping configurations inside the ES-3100 containment vessel are illustrated in Fig. 1.4. The 277-4 canned spacers will only be used for contents shipped in metal convenience cans. Three 4.25-in.-diam × 10.0-in.-tall or six 4.25-in.-diam × 4.88-in.-tall convenience cans separated by can pads may be placed inside the 31-in.-tall cavity of the ES-3100 containment vessel (Drawing M2E801580A035, Appendix 1.3.7). Other can arrangements fit inside the containment vessel, such as three 4.25-in.-diam × 8.75-in.-tall or five 4.25-in.-diam × 4.88-in.-tall convenience cans. Both of these can arrangements include can pads and 277-4 canned spacers with overall dimensions of 4.25-in. diam × 1.82-in. height (Drawing M2E801580A043, Appendix 1.3.7). Nickel alloy cans are ~3-in. diam × 4.75-in. tall. Up to three Teflon bottles (4.69-in. diam × 9.4-in. tall) or three polyethylene bottles (4.94-in. diam × 8.7-in. tall) will fit inside the containment vessel; however, 277-4 canned spacers are not used with these configurations. If closed convenience cans with an outer diameter >4.25 in. are used, at least 55 $in.^3$ of free or void volume must exist inside the containment vessel to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC.

A modified convenience can may be used to package the TRIGA and research reactor related contents that do not fit inside these containers. A 17.5-in.- or 30-in.-tall convenience can is constructed from two 4.25-in.-diam × 8.75-in.-tall or three 10-in. cans brazed together. The research reactor fuel elements and fuel components that cannot be packaged in these convenience cans due to their overall dimensions will be bundled together and protected on each end with an open-ended convenience can having an outer diameter ≤ 5 in. Solid form HEU contents (i.e., spheres, cylinders, bars, slugs, etc.) that will not fit in a 4.25-in. convenience can may be bagged only with no convenience can required around the content. For contents that are bagged only, stainless-steel metal scrubbers may be placed on the top and bottom of this assembly inside the containment vessel. For these bagged contents, the void volume requirement stated in Loading Restriction 8 (Sect. 1.2.2.8) must still be satisfied.

Credit is not taken in this criticality analysis for fissile material spacing provided by the presence of the convenience cans or bottles inside the containment vessel. These containers are not manufactured to the American Society of Mechanical Engineers *Boiler and Pressure Vessel Code*, Sect. III, Subsection NG, or better.

6.1.2 Codes and Standards

Testing conducted in accordance with the physical testing requirements of 10 CFR 71 demonstrated that water leakage into the containment is not a credible event under the NCT and HAC. As directed, credit for the high-integrity, watertight containment is not taken in this criticality evaluation per discussions held at public meetings at the U.S. Nuclear Regulatory Commission (Docket 71-9315).

Liquid HEU is not being shipped in the ES-3100. With the exception of UNX crystals, the other uranium contents being shipped are not soluble in water and do not form solutions. The hypothetical occurrence of uranyl nitrate solution is evaluated as a consequence of evaluating the presence of water inside the containment vessel. Thus, uranyl nitrate solution is evaluated even though it is not shipped as an approved package content in the ES-3100.

10 CFR 71.55(b) requires the evaluation of water leakage into the containment vessel or leakage of liquid contents out of the containment vessel and other conditions that produce maximum reactivity in the single package. For solid uranium contents, water leakage conditions are simulated by flooding all regions outside and inside of the containment vessel, including the sealed convenience cans. For liquid uranium "contents," water leakage conditions are simulated by flooding all regions outside the containment vessel except the containment vessel well. The uranyl nitrate (UN) solution resides inside both the containment vessel well and the containment vessel, including the Teflon bottles. Per 10 CFR 71.55(b), a flooded containment vessel under full water reflection is also evaluated. Under such leakage conditions, the calculated neutron multiplication factor ($k_{eff} + 2\sigma$) for the ES-3100 package with

HEU contents is lower than the upper subcritical limit (USL) for a subcritical system. Water inleakage into the containment vessel or liquid content leakage out of the containment vessel will not produce a criticality in the containment vessel of a disassembled package or an assembled single package. Therefore, the Model ES-3100 shipping package complies with all of the requirements of 10 CFR 71.55(b) and (d).

While the loss of containment is deemed incredible by merit of the results of the physical tests performed under 10 CFR 71.71 and 10 CFR 71.73, credit for the high-integrity, watertight containment is not taken in the single package analysis [10 CFR 71.55(d) and (e)]. Only partial credit is taken in the package array analysis (10 CFR 71.59). In both the single package and package array analyses, the containment vessel is flooded with water. This fictitious "evaluation" water provides moderation to such an extent as to cause maximum reactivity of the content consistent with the chemical and physical form of the material present. While UN crystals are soluble in water, leakage of UN solution out of the containment vessel for undamaged packages under 10 CFR 71.59 (a)(1) or damaged packages under 10 CFR 71.59 (a)(2) is not considered credible during NCT or HAC based on results for tests specified in 10 CFR 71.71 and 10 CFR 71.73. Because credit for the high-integrity, watertight containment is not fully taken in the criticality evaluation, the fissile mass loading limits are very conservative.

The NCT tests under 10 CFR 71.71 and the HAC tests under 10 CFR 71.73 demonstrate that containment is not breached. Nevertheless, containment vessel flooding is assumed in the criticality calculations performed for the derivation of fissile material loading limits. The 7.1–10.1 kg quantities of evaluation water in both the NCT and HAC criticality calculations are not actually present in the containment vessel. Simulation of this condition in the criticality calculations produces fissile material content that is more reactive than actual.

The 7.1–10.1 kg quantity of evaluation water does not necessarily bound reasonable amounts of hydrogenous packing material present inside the containment vessel when the fissile material is in particulate form (primarily HEU oxides and UNX crystals) or must be evaluated as particulate matter (broken metal). Packing materials include can pads, polyethylene bags, vinyl tape, and polyethylene or Teflon bottles, if used. An administrative criticality control is used to restrict the amount of hydrogenous packing material normally present inside the containment vessel (Item 7 in Sect. 6.2.4).

Under NCT and HAC, three parameters that affect criticality and may vary during transport of the Model ES-3100 package are the number of packages transported, the amount of water present in the package, and the volatile (organic material) contents of the package. The number of packages transported is limited by the criticality safety index (CSI) established by this criticality evaluation. Both the amount of water present in the package and the volatile (organic material) contents of the package are parameters for the following reasons. First, volatile materials can be driven off at the high temperatures of HAC. Second, the inherent water content of the Kaolite in NCT and the water absorption by the Kaolite in HAC are unknowns. These parameters determine a variety of competing effects that govern the fission process, including, but not limited to, mass, moderation, absorption, and reflection. To ensure that all effects are adequately included in this criticality evaluation, the range of these parameters is evaluated.

It is possible for accidents to be significantly more severe in the air transport mode than in the surface transport mode. Thus, the performance requirements for packages designed to be transported by air are more stringent. These requirements address separate aspects of the accident assessment and apply only to the criticality evaluation of an individual package under isolation (TS-G-1.1). For a fissile material package designed to be transported by air, 10 CFR 71.55(f) requires that the criticality evaluation demonstrate that the package be subcritical assuming reflection by 20 cm (7.9 in.) of water but no water inleakage when subjected to the sequential application of the HAC free drop and crush tests of 10 CFR 71.73(c)(1 and 2) and the modified puncture and thermal tests of 10 CFR 71.55(f)(1)(iii and iv).

10 CFR 71.55(f)(2) requires the criticality evaluation demonstrate that the package be subcritical, assuming reflection by 20 cm (7.9 in.) of water but no water inleakage, when subjected to an impact on an unyielding surface of 90 m/s normal to the surface.

The ES-3100 package was not subjected to physical testing of Type-C fissile material packages transported by air as specified in IAEA TS-R-1, Sect. 680. Instead, analytic methods are used to demonstrate compliance of the ES-3100 package with the requirements of 10 CFR 71.55(f). This is accomplished by demonstrating compliance of the package with the more stringent requirements imposed by the IAEA for situations where the conditions of the fissile material package following the tests cannot be demonstrated (TS-G-1.1, Sect. 680.2). Section 680.2 of TS-G-1.1 states that worst-case assumptions regarding the geometric arrangement of the package and contents should be made in the criticality evaluation taking into account all moderating and structural components of the packaging. The assumptions should be in conformity with the potential worst-case effects of the mechanical and thermal tests, and all package orientations should be considered for the analysis. Subcriticality must be demonstrated after due consideration of such aspects as the efficiency of the moderator, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes, and temperature effects. Given that the requirements of 10 CFR 71.55(f) mirror the IAEA requirements of TS-R-1, Sect. 680, for Type B(U) fissile material packages, this approach is considered an acceptable one.

6.1.3 Summary of the Criticality Evaluation

The following criticality evaluation shows that the Model ES-3100 package with designated content satisfies the requirements of 10 CFR 71.55 and 71.59 for surface transport, and of 10 CFR 71.55(f) for air transport. Designated contents are **solid** HEU metal or alloy of specified shape (cylinders, bars, buttons, billets, slugs, and unirradiated TRIGA fuel), broken metal, turnings, fines, or powder; **solid** HEU metal or alloy of unspecified geometric shape and characterized as broken metal; HEU product or skull oxides; or UNX crystals. HEU skull oxides are distinguished from product oxides (UO_2, U_3O_8, or UO_3) as being a residue of graphite and oxidized uranium (U_3O_8) recovered in the casting process. The criticality evaluation of these contents is addressed in the main subsections of this chapter. The criticality evaluation of the contents not covered under the initial evaluation is addressed in Appendices 6.9.8, 6.9.9, and 6.9.11 as explained therein.

Tables 6.1a–6.1f pertain to surface-only modes of transportation. The column headings across the tables identify content and 277-4 canned spacer configurations. The tables are organized into groups of rows, which identify the defining calculations for addressing the performance requirements of 10 CFR 71.55(b), 71.55(d), 71.55(e), or 71.59 (see "Conditions" column). The defining calculations are also discussed in Sects. 6.4, 6.5, or 6.6, as appropriate. The KENO V.a input listings for the calculations are provided in Appendix 6.9.7. The rows within the groups cite the specific requirements stated in the CFR paragraphs and provide details regarding how these conditions are addressed or treated in the defining calculations for each content and 277-4 canned spacer configuration listed in a table column. Results of the criticality evaluation are summarized in Tables 6.1a and 6.1b for **solid** HEU metal in the form of specified shape (cylinders, bars, buttons, billets, and slugs); Table 6.1c for HEU broken metal or **solid** HEU metal of unspecified geometric shape and characterized as broken metal; Table 6.1d for HEU metal in the form of turnings, fines, or powder; Table 6.1e for HEU product and skull oxide; and Table 6.1f for UNX crystals and unirradiated TRIGA reactor fuel elements.

Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars

Conditions	Cylinders ($d \leq 3.24$ in.) no can spacers	Cylinders ($d \leq 3.24$ in.) with can spacers	Square bars ($l,w \leq 2.29$ in.) no can spacers	Cylinders ($3.24 < d \leq 4.25$ in.) no can spacers	Cylinders ($3.24 < d \leq 4.25$ in.) with can spacers
General requirements for each fissile package (§71.55)					
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b")	$k_{eff} + 2\sigma \leq 0.9228$ cvcrcyt11_21_1	$k_{eff} + 2\sigma \leq 0.8866$ cvcrcyt11_36_2	$k_{eff} + 2\sigma \leq 0.8787$ cvcrsqt11_36_1	$k_{eff} + 2\sigma \leq 0.9215$ cvcrcyct11_17_1	$k_{eff} + 2\sigma \leq 0.9202$ cvcrcyct11_32_2
(1) the most reactive credible configuration consistent with the chemical and physical form of the material,	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 21,000-g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, with can spacers, 36,000-g ^{235}U	3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000-g ^{235}U	3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, no can spacers, 17,000-g ^{235}U	3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, with can spacers, 32,000-g ^{235}U
(2) moderation by water to the most reactive credible extent,	Flooding of the containment vessel	Same	Same	Same	Same
(3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging.	30.48-cm H_2O surrounding the containment vessel	Same	Same	Same	Same

Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars

Conditions	Cylinders ($d \leq 3.24$ in.) no can spacers	Cylinders ($d \leq 3.24$ in.) with can spacers	Square bars ($l,w \leq 2.29$ in.) no can spacers	Cylinders ($3.24 < d \leq 4.25$ in.) no can spacers	Cylinders ($3.24 < d \leq 4.25$ in.) with can spacers
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d")					
(1) the contents would be subcritical,	$k_{eff} + 2\sigma \leq 0.9035$ ncsrcyt11_21_1_15	$k_{eff} + 2\sigma \leq 0.8731$ ncsrcyt11_36_2_15	$k_{eff} + 2\sigma \leq 0.8652$ ncsrsqt11_36_1_15	$k_{eff} + 2\sigma \leq 0.8941$ ncsrcyct11_17_1_15	$k_{eff} + 2\sigma \leq 0.8946$ ncsrcyct11_32_2_15
(2) the geometric form of the package contents would not be substantially altered,	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 21,000-g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, with can spacers, 36,000-g ^{235}U	3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000-g ^{235}U	3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, no can spacers, 17,000-g ^{235}U	3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, with can spacers, 32,000-g ^{235}U
(3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material,	Moderation is present to such an extent as to cause maximum reactivity	Same	Same	Same	Same
(4) there will be no substantial reduction in the effectiveness of the packaging	30.48-cm H_2O surrounding the drum (d=18.37 in., h=43.5 in.)	Same	Same	Same	Same

Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars

Conditions	Cylinders ($d \leq 3.24$ in.) no can spacers	Cylinders ($d \leq 3.24$ in.) with can spacers	Square bars ($l,w \leq 2.29$ in.) no can spacers	Cylinders ($3.24 < d \leq 4.25$ in.) no can spacers	Cylinders ($3.24 < d \leq 4.25$ in.) with can spacers
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e")	$k_{eff} + 2\sigma \leq 0.9044$ hcsrcyt12_21_1_15	$k_{eff} + 2\sigma \leq 0.8734$ hcsrcyt12_36_2_15	$k_{eff} + 2\sigma \leq 0.8642$ hcsrsqt12_36_1_15	$k_{eff} + 2\sigma \leq 0.8979$ hcsrcyct12_17_1_15	$k_{eff} + 2\sigma \leq 0.8977$ hcsrcyct12_32_2_15
(1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents,	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 21,000-g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, with can spacers, 36,000-g ^{235}U	3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000-g ^{235}U	3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, no can spacers, 17,000-g ^{235}U	3 stacked cylinders (d = 4.25 in.) 1 cylinder per convenience can, with can spacers, 32,000-g ^{235}U
(2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content,	Flooding of the package	Same	Same	Same	Same
(3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package.	30.48-cm H_2O surrounding the reduced diameter drum (d=17.20 in., h=43.5 in.)	Same	Same	Same	Same

Table 6.1a. Summary of criticality evaluation for solid HEU metal cylinders and bars

Conditions	Cylinders ($d \leq 3.24$ in.) no can spacers	Cylinders ($d \leq 3.24$ in.) with can spacers	Square bars ($l,w \leq 2.29$ in.) no can spacers	Cylinders ($3.24 < d \leq 4.25$ in.) no can spacers	Cylinders ($3.24 < d \leq 4.25$ in.) with can spacers
Standards for arrays of fissile material packages (§71.59)					
" . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water:" (Paragraph "a")					
Transport index based on nuclear criticality control, CSI = 0.0	**Load-limited to 18,000-g ^{235}U, no can spacers**	**Load-limited to 30,000-g ^{235}U, can spacers**	**Load-limited to 30,000-g ^{235}U, no can spacers**	**Load-limited to 15,000-g ^{235}U, no can spacers**	**Load-limited to 25,000-g ^{235}U, can spacers**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	$k_{eff} + 2\sigma \leq 0.9237$ nciacyt11_18_1_3	$k_{eff} + 2\sigma \leq 0.9195$ nciacyt11_30_2_3	$k_{eff} + 2\sigma \leq 0.9219$ nciasqt11_30_1_3	$k_{eff} + 2\sigma \leq 0.8992$ nciacyct11_15_1_3	$k_{eff} + 2\sigma \leq 0.9147$ nciacyct11_25_2_3
(2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation,	$k_{eff} + 2\sigma \leq 0.9230$ hciacyt12_18_1_3	$k_{eff} + 2\sigma \leq 0.9220$ hciacyt12_30_2_3	$k_{eff} + 2\sigma \leq 0.9221$ hciasqt12_30_1_3	$k_{eff} + 2\sigma \leq 0.8986$ hciacyct12_15_1_3	$k_{eff} + 2\sigma \leq 0.9156$ hciacyct12_25_2_3
(3) the value of "N" not <0.5.	$N(1,2) = \infty$	Same	Same	Same	Same
Transport index based on nuclear criticality control, CSI = 0.0			**Load-limited to 36,000-g ^{235}U, can spacers**		
(1) five times "N" undamaged packages			$k_{eff} + 2\sigma \leq 0.8961$ nciasqt11_36_2_3		
(2) two times "N" damaged packages, ...			$k_{eff} + 2\sigma \leq 0.8946$ hciasqt12_36_2_3		
(3) the value of "N"			$N(1,2) = \infty$		

Table 6.1b. Summary of criticality evaluation for solid HEU metal slugs

Conditions	Slugs, no can spacers enr. ≤ 100% ≤ 18,277-g ^{235}U	Slugs with can spacers 80% < enr. ≤ 100% < 36,555-g ^{235}U	Slugs with can spacers enr. ≤ 80% < 36,555-g ^{235}U
General requirements for each fissile package (§71.55)			
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b")	$k_{eff} + 2\sigma \leq 0.9098$ cvcr5st11_1_1	$k_{eff} + 2\sigma \leq 0.9029$ cvcr5st11_2_2	
(1) the most reactive credible configuration consistent with the chemical and physical form of the material,	Cluster of 5 slugs (d = 1.5625 in., h = 2.0625 in.) per convenience can, no can spacers, 18,277-g ^{235}U	Cluster of 10 slugs stacked 2 high per convenience can, can spacers, 36,555-g ^{235}U	
(2) moderation by water to the most reactive credible extent,	Flooding of the containment vessel	Same	
(3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging.	30.48-cm H_2O surrounding the containment vessel	Same	
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d")			
(1) the contents would be subcritical,	$k_{eff} + 2\sigma \leq 0.8834$ ncsr5st11_1_1_15	$k_{eff} + 2\sigma \leq 0.8781$ ncsr5st11_2_2_15	
(2) the geometric form of the package contents would not be substantially altered,	Cluster of 5 slugs (d = 1.5625 in., h = 2.0625 in.) per convenience can, no can spacers, 18,277-g ^{235}U	Cluster of 10 slugs stacked 2 high per convenience can, can spacers, 36,555-g ^{235}U	
(3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material,	Moderation is present to such an extent as to cause maximum reactivity	Same	
(4) there will be no substantial reduction in the effectiveness of the packaging	30.48-cm H_2O surrounding the drum (d=18.37 in., h=43.5 in.)	Same	

Table 6.1b. Summary of criticality evaluation for solid HEU metal slugs

Conditions	Slugs, no can spacers enr. ≤ 100% ≤ 18,277-g ^{235}U	Slugs with can spacers 80% < enr. ≤ 100% < 36,555-g ^{235}U	Slugs with can spacers enr. ≤ 80% < 36,555-g ^{235}U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e")	$k_{eff} + 2\sigma \leq 0.8860$ hcsr5st12_1_1_15	$k_{eff} + 2\sigma \leq 0.8772$ hcsr5st12_2_2_15	
(1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents,	Cluster of 5 slugs (d = 1.5625 in., h = 2.0625 in.) per convenience can, no can spacers, 18,277-g ^{235}U	Cluster of 10 slugs stacked 2 high per convenience can, can spacers, 36,555-g ^{235}U	
(2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content,	Flooding of the package	Same	
(3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package.	30.48-cm H_2O surrounding the reduced diameter drum (d=17.20 in., h=43.5 in.)	Same	

Table 6.1b. Summary of criticality evaluation for solid HEU metal slugs

Conditions	Slugs, no can spacers enr. ≤ 100% ≤ 18,277-g ^{235}U	Slugs with can spacers 80% < enr. ≤ 100% < 36,555-g ^{235}U	Slugs with can spacers enr. ≤ 80% < 36,555-g ^{235}U
Standards for arrays of fissile material packages (§71.59)			
" . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a")			
Transport index based on nuclear criticality control, CSI = 0.0	**Load-limited to enr. ≤ 95%, 17,374-g ^{235}U, no can spacers**	**Load-limited to 80% < enr. ≤ 95% 24,324-g ^{235}U, can spacers**	**Load-limited to enr. ≤ 80%, 29,318-g ^{235}U, can spacers**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	$k_{eff} + 2\sigma \leq 0.9077$ ncia5st11_1_1_7_3	$k_{eff} + 2\sigma \leq 0.8936$ ncia70st11_2_7_3	$k_{eff} + 2\sigma \leq 0.9085$ ncia5est11_2_2_5_3
(2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation,	$k_{eff} + 2\sigma \leq 0.9029$ hcia5est12_1_1_7_3	$k_{eff} + 2\sigma \leq 0.8946$ hcia70st12_2_7_3	$k_{eff} + 2\sigma \leq 0.9100$ hcia5est12_2_2_5_3
(3) the value of "N" not <0.5.	N(1,2) = ∞	Same	Same
Transport index based on nuclear criticality control, CSI = 0.4	**Load-limited to enr. ≤ 95%, 17,374-g ^{235}U, no can spacers**	**Load-limited to 80% < enr. ≤ 95% 34,749-g ^{235}U, can spacers**	**Load-limited to enr. ≤ 80%, 29,318-g ^{235}U, can spacers**
(1) five times "N" undamaged packages	Bounded by CSI=0	$k_{eff} + 2\sigma \leq 0.9200$ ncf15est11_2_2_7_3	$k_{eff} + 2\sigma \leq 0.8643$ ncf15est11_2_2_5_3
(2) two times "N" damaged packages, ...	Bounded by CSI=0	$k_{eff} + 2\sigma \leq 0.9056$ hcf25est12_2_2_7_3	$k_{eff} + 2\sigma \leq 0.8556$ hcf25est12_2_2_5_3
(3) the value of "N"	N(1,2) = 202/162	Same	Same

Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal

Conditions	95% < enr. ≤ 100% ≤ 25,894-g ^{235}U	90% < enr. ≤95% ≤ 27,252-g ^{235}U	80% < enr. ≤90% ≤ 28,334-g ^{235}U	70% < enr. ≤80% ≤ 28,184-g ^{235}U	60% < enr. ≤70% ≤ 24,693-g ^{235}U	enr. ≤60% ≤ 35,320-g U
General requirements for each fissile package (§71.55)						
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b")	$k_{eff} + 2\sigma \leq 0.9181$ cvr3lha_26_1_8_15	$k_{eff} + 2\sigma \leq 0.9206$ cvr3lha_29_1_7_15	$k_{eff} + 2\sigma \leq 0.9224$ cvr3lha_32_1_6_15	$k_{eff} + 2\sigma \leq 0.8927$ cvr3lha_36_1_5_15	$k_{eff} + 2\sigma \leq 0.8620$ cvr3lha_36_1_4_15	$k_{eff} + 2\sigma \leq 0.8289$ cvr3lha_36_1_3_15
(1) the most reactive credible configuration consistent with the chemical and physical form of the material,	A mixture of HEU metal and water is homogenized over the internal volume of an assumed content lattice, one per can location. The square footprint of the content lattice is circumscribed by the inner wall of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. See Appendix 6.9.3, Sect. 6.9.3.1, for justification of the content model.					
(2) moderation by water to the most reactive credible extent,	Flooding of the containment vessel					
(3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging.	30.48-cm H_2O surrounding the containment vessel					

Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal

Conditions	95% < enr. ≤ 100% ≤ 25,894-g ^{235}U	90% < enr. ≤95% ≤ 27,252-g ^{235}U	80% < enr. ≤90% ≤ 28,334-g ^{235}U	70% < enr. ≤80% ≤ 28,184-g ^{235}U	60% < enr. ≤70% ≤ 24,693-g ^{235}U	enr. ≤60% ≤ 35,320-g U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d")						
(1) the contents would be subcritical,	$k_{eff} + 2\sigma \leq 0.8908$ ncsrbmt11_36_1_15					
(2) the geometric form of the package contents would not be substantially altered,	A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used.					
(3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material,	Moderation is present to such an extent as to cause maximum reactivity					
(4) there will be no substantial reduction in the effectiveness of the packaging	30.48-cm H_2O surrounding the drum (d = 18.37 in., h = 43.5 in.)					

Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal

Conditions	95% < enr. ≤ 100% ≤ 25,894-g ^{235}U	90% < enr. ≤95% ≤ 27,252-g ^{235}U	80% < enr. ≤90% ≤ 28,334-g ^{235}U	70% < enr. ≤80% ≤ 28,184-g ^{235}U	60% < enr. ≤70% ≤ 24,693-g ^{235}U	enr. ≤60% ≤ 35,320-g U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e")	$k_{eff} + 2\sigma \leq 0.8912$ hcsrbmt12_36_1_15					
(1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents,	A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used.					
(2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content,	Flooding of the package					
(3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package.	30.48-cm H_2O surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.)					

Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal

Conditions	95% < enr. ≤ 100% ≤ 25,894-g ^{235}U	90% < enr. ≤95% ≤ 27,252-g ^{235}U	80% < enr. ≤90% ≤ 28,334-g ^{235}U	70% < enr. ≤80% ≤ 28,184-g ^{235}U	60% < enr. ≤70% ≤ 24,693-g ^{235}U	enr. ≤60% ≤ 35,320-g U
Standards for arrays of fissile material packages (§71.59)						
" . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a")						
Transport index based on nuclear criticality control, CSI = 0.0	**Can spacers required**	**Can spacers required**	**Can spacers required**	**Load-limited to 2,967-g ^{235}U, no can spacers**	**Load-limited to 3,249-g ^{235}U, no can spacers**	**Load-limited to 5,577-g U, no can spacers**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9213$ nciabmt11_4_1_5_3	$k_{eff} + 2\sigma \leq 0.9207$ nciabmt11_5_1_4_3	$k_{eff} + 2\sigma \leq 0.9152$ nciabmt11_6_1_3_3
(2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation,	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9248$ hciabmt12_4_1_5_3	$k_{eff} + 2\sigma \leq 0.9235$ hciabmt12_5_1_4_3	$k_{eff} + 2\sigma \leq 0.9127$ hciabmt12_6_1_3_3
(3) the value of "N" cannot be <0.5.	Not applicable	Not applicable	Not applicable	$N(1,2) = \infty$	Same	Same

Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal

Conditions	95% < enr. ≤ 100% ≤ 25,894-g ^{235}U	90% < enr. ≤95% ≤ 27,252-g ^{235}U	80% < enr. ≤90% ≤ 28,334-g ^{235}U	70% < enr. ≤80% ≤ 28,184-g ^{235}U	60% < enr. ≤70% ≤ 24,693-g ^{235}U	enr. ≤60% ≤ 35,320-g U
Transport index based on nuclear criticality control, CSI = 0.0	**Load-limited to 2,774-g ^{235}U, can spacers**	**Load-limited to 3,516-g ^{235}U, can spacers**	**Load-limited to 3,333-g ^{235}U, can spacers**	**Load-limited to 4,450-g ^{235}U, can spacers**	**Load-limited to 5,198-g ^{235}U, can spacers**	**Load-limited to 11,154-g U, can spacers**
(1) five times "N" undamaged packages . . .	$k_{eff} + 2\sigma \leq 0.9041$ nciabmt11_3_2_8_3	$k_{eff} + 2\sigma \leq 0.9199$ nciabmt11_4_2_7_3	$k_{eff} + 2\sigma \leq 0.9084$ nciabmt11_4_2_6_3	$k_{eff} + 2\sigma \leq 0.9224$ nciabmt11_6_2_5_3	$k_{eff} + 2\sigma \leq 0.9218$ nciabmt11_8_2_4_3	$k_{eff} + 2\sigma \leq 0.9181$ nciabmt11_12_2_3_3
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.9050$ hciabmt12_3_2_8_3	$k_{eff} + 2\sigma \leq 0.9237$ hciabmt12_4_2_7_3	$k_{eff} + 2\sigma \leq 0.9091$ hciabmt12_4_2_6_3	$k_{eff} + 2\sigma \leq 0.9230$ hciabmt12_6_2_5_3	$k_{eff} + 2\sigma \leq 0.9209$ hciabmt12_8_2_4_3	$k_{eff} + 2\sigma \leq 0.9205$ hciabmt12_12_2_3_3
(3) the value of "N" . . .	N(1,2) = ∞	Same	Same	Same	Same	Same
Transport index based on nuclear criticality control, CSI = 0.4	**Can spacers required**	**Can spacers required**	**Can spacers required**	**Load-limited to 5,192-g ^{235}U, no can spacers**	**Load-limited to 5,848-g ^{235}U, no can spacers**	**Load-limited to 14,872-g U, no can spacers**
(1) five times "N" undamaged packages	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9235$ ncf1bmt11_7_1_5_3	$k_{eff} + 2\sigma \leq 0.9216$ ncf1bmt11_9_1_4_3	$k_{eff} + 2\sigma \leq 0.9225$ ncf1bmt11_15_1_3_3
(2) two times "N" damaged packages, ...	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9064$ hcf2bmt12_8_1_5_3	$k_{eff} + 2\sigma \leq 0.9118$ hcf2bmt12_12_1_4_3	$k_{eff} + 2\sigma \leq 0.9072$ hcf2bmt12_18_1_3_3
(3) the value of "N" . . .	Not applicable	Not applicable	Not applicable	N(1,2) = 202/162	Same	Same
Transport index based on nuclear criticality control, CSI = 0.4	**Load-limited to 5,549-g ^{235}U, can spacers**	**Load-limited to 6,154-g ^{235}U, can spacers**	**Load-limited to 7,500-g ^{235}U, can spacers**	**Load-limited to 8,900-g ^{235}U, can spacers**	**Load-limited to 12,996-g ^{235}U, can spacers**	**Load-limited to 28,813-g U, can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.9241$ ncf1bmt11_6_2_8_3	$k_{eff} + 2\sigma \leq 0.9220$ ncf1bmt11_7_2_7_3	$k_{eff} + 2\sigma \leq 0.9203$ ncf1bmt11_9_2_6_3	$k_{eff} + 2\sigma \leq 0.9187$ ncf1bmt11_12_2_5_3	$k_{eff} + 2\sigma \leq 0.9245$ ncf1bmt11_19_2_4_3	$k_{eff} + 2\sigma \leq 0.9235$ ncf1bmt11_29_2_3_3
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.9244$ hcf2bmt12_8_2_8_3	$k_{eff} + 2\sigma \leq 0.9232$ hcf2bmt12_11_2_7_3	$k_{eff} + 2\sigma \leq 0.9192$ hcf2bmt12_12_2_6_3	$k_{eff} + 2\sigma \leq 0.8964$ hcf2bmt12_12_2_5_3	$k_{eff} + 2\sigma \leq 0.9005$ hcf2bmt12_19_2_4_3	$k_{eff} + 2\sigma \leq 0.9112$ hcf2bmt12_36_2_3_3
(3) the value of "N"	N(1,2) = 202/162	Same	Same	Same	Same	Same

Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal

Conditions	95% < enr. ≤ 100% ≤ 25,894-g ^{235}U	90% < enr. ≤95% ≤ 27,252-g ^{235}U	80% < enr. ≤90% ≤ 28,334-g ^{235}U	70% < enr. ≤80% ≤ 28,184-g ^{235}U	60% < enr. ≤70% ≤ 24,693-g ^{235}U	enr. ≤60% ≤ 35,320-g U
Transport index based on nuclear criticality control, CSI = 0.8	**Can spacers required**	**Can spacers required**	**Can spacers required**	**Load-limited to 8,900-g ^{235}U, no can spacers**	**Load-limited to 13,646-g ^{235}U, no can spacers**	**Load-limited to 28,814-g U, no can spacers**
(1) five times "N" undamaged packages	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9216$ ncf2bmt11_12_1_5_3	$k_{eff} + 2\sigma \leq 0.9234$ ncf2bmt11_20_1_4_3	$k_{eff} + 2\sigma \leq 0.9205$ ncf2bmt11_29_1_3_3
(2) two times "N" damaged packages, ...	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9012$ hcf3bmt12_12_1_5_3	$k_{eff} + 2\sigma \leq 0.9065$ hcf3bmt12_20_1_4_3	$k_{eff} + 2\sigma \leq 0.9022$ hcf3bmt12_29_1_3_3
(3) the value of "N"	Not applicable	Not applicable	Not applicable	Same	Same	Same
Transport index based on nuclear criticality control, CSI = 0.8	**Load-limited to 9,248-g ^{235}U, can spacers**	**Load-limited to 10,549-g ^{235}U, can spacers**	**Load-limited to 12,500-g ^{235}U, can spacers**	**Load-limited to 16,317-g ^{235}U, can spacers**	**Load-limited to 20,793-g ^{235}U, can spacers**	**35,320-g U, can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.9233$ ncf2bmt11_10_2_8_3	$k_{eff} + 2\sigma \leq 0.9221$ ncf2bmt11_12_2_7_3	$k_{eff} + 2\sigma \leq 0.9220$ ncf2bmt11_14_2_6_3	$k_{eff} + 2\sigma \leq 0.9193$ ncf2bmt11_21_2_5_3	$k_{eff} + 2\sigma \leq 0.9233$ ncf2bmt11_30_2_4_3	$k_{eff} + 2\sigma \leq 0.9064$ ncf2bmt11_36_2_3_3
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.9090$ hcf3bmt12_10_2_8_3	$k_{eff} + 2\sigma \leq 0.9005$ hcf3bmt12_12_2_7_3	$k_{eff} + 2\sigma \leq 0.9042$ hcf3bmt12_14_2_6_3	$k_{eff} + 2\sigma \leq 0.9022$ hcf3bmt12_21_2_5_3	$k_{eff} + 2\sigma \leq 0.9019$ hcf3bmt12_30_2_4_3	$k_{eff} + 2\sigma \leq 0.8850$ hcf3bmt12_36_2_3_3
(3) the value of "N"	N(1,2) = 64/73	Same	Same	Same	Same	Same
Transport index based on nuclear criticality control, CSI = 2.0 [a]	**Can spacers required**	**Can spacers required**	**Can spacers required**	**Load-limited to 17,059-g ^{235}U, no can spacers**	**Load-limited to 21,444-g ^{235}U, no can spacers**	**35,320-g U, no can spacers**
(1) five times "N" undamaged packages	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9223$ ncf3bmt11_22_1_5_3	$k_{eff} + 2\sigma \leq 0.9216$ ncf3bmt11_31_1_4_3	$k_{eff} + 2\sigma \leq 0.9045$ ncf3bmt11_36_1_3_3
(2) two times "N" damaged packages, ...	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.8852$ hcf4bmt12_22_1_5_3	$k_{eff} + 2\sigma \leq 0.8858$ hcf4bmt12_31_1_4_3	$k_{eff} + 2\sigma \leq 0.8705$ hcf4bmt12_36_1_3_3
(3) the value of "N"	Not applicable	Not applicable	Not applicable	N(1,2) = 29/25	Same	Same

Table 6.1c. Summary of criticality evaluation for HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal

Conditions	95% < enr. ≤ 100% ≤ 25,894-g ^{235}U	90% < enr. ≤95% ≤ 27,252-g ^{235}U	80% < enr. ≤90% ≤ 28,334-g ^{235}U	70% < enr. ≤80% ≤ 28,184-g ^{235}U	60% < enr. ≤70% ≤ 24,693-g ^{235}U	enr. ≤60% ≤ 35,320-g U
Transport index based on nuclear criticality control, CSI = 2.0 [a]	**Load-limited to 13,872-g ^{235}U, can spacers**	**Load-limited to 18,461-g ^{235}U, can spacers**	**Load-limited to 20,000-g ^{235}U, can spacers**	**Load-limited to 25,218-g ^{235}U, can spacers**	**24,692-g ^{235}U, can spacers**	**35,320-g U, can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.9204$ ncf3bmt11_14_2_8_3	$k_{eff} + 2\sigma \leq 0.9239$ ncf3bmt11_20_2_7_3	$k_{eff} + 2\sigma \leq 0.9213$ ncf3bmt11_23_2_6_3	$k_{eff} + 2\sigma \leq 0.9216$ ncf3bmt11_32_2_5_3	$k_{eff} + 2\sigma \leq 0.9035$ ncf3bmt11_36_2_4_3	$k_{eff} + 2\sigma \leq 0.8745$ ncf3bmt11_36_2_3_3
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.8877$ hcf4bmt12_14_2_8_3	$k_{eff} + 2\sigma \leq 0.8914$ hcf4bmt12_20_2_7_3	$k_{eff} + 2\sigma \leq 0.8851$ hcf4bmt12_23_2_6_3	$k_{eff} + 2\sigma \leq 0.8884$ hcf4bmt12_32_2_5_3	$k_{eff} + 2\sigma \leq 0.8684$ hcf4bmt12_36_2_4_3	$k_{eff} + 2\sigma \leq 0.8412$ hcf4bmt12_36_2_3_3
(3) the value of "N"	N(1,2) = 29/25	Same	Same	Same	Same	Same
Transport index based on nuclear criticality control, CSI = 3.2 b	**Can spacers required**	**Can spacers required**	**Can spacers required**	**Load-limited to 27,443-g ^{235}U, no can spacers**	**24,692-g ^{235}U, no can spacers**	**35,320-g U, no can spacers**
(1) five times "N" undamaged packages	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9226$ ncf5bmt11_35_1_5_3	$k_{eff} + 2\sigma \leq 0.9030$ ncf5bmt11_36_1_4_3	$k_{eff} + 2\sigma \leq 0.8743$ ncf5bmt11_36_1_3_3
(2) two times "N" damaged packages, ...	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.9052$ hcf5bmt12_35_1_5_3	$k_{eff} + 2\sigma \leq 0.8819$ hcf5bmt12_36_1_4_3	$k_{eff} + 2\sigma \leq 0.8542$ hcf5bmt12_36_1_3_3
(3) the value of "N"	Not applicable	Not applicable	Not applicable	N(1,2) = 16/24	Same	Same
Transport index based on nuclear criticality control, CSI = 3.2 [b]	**Load-limited to 24,969-g ^{235}U, can spacers**	**Load-limited to 26,373-g ^{235}U, can spacers**	**28,334-g ^{235}U, can spacers**	**28,184-g ^{235}U, can spacers**	**24,692-g ^{235}U, can spacers**	**35,320-g U, can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.9249$ nctf5bmt11_25_2_8_3	$k_{eff} + 2\sigma \leq 0.9196$ nctf5bmt11_28_2_7_3	$k_{eff} + 2\sigma \leq 0.9246$ nctf5bmt11_35_2_6_3	$k_{eff} + 2\sigma \leq 0.8974$ nctf5bmt11_36_2_5_3	$k_{eff} + 2\sigma \leq 0.8736$ nctf5bmt11_36_2_4_3	$k_{eff} + 2\sigma \leq 0.8445$ nctf5bmt11_36_2_3_3
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.9089$ hctf5bmt12_25_2_8_3	$k_{eff} + 2\sigma \leq 0.8981$ hctf5bmt12_28_2_7_3	$k_{eff} + 2\sigma \leq 0.9032$ hctf5bmt12_35_2_6_3	$k_{eff} + 2\sigma \leq 0.8804$ hctf5bmt12_36_2_5_3	$k_{eff} + 2\sigma \leq 0.8532$ hctf5bmt12_36_2_4_3	$k_{eff} + 2\sigma \leq 0.8265$ hctf5bmt12_36_2_3_3
(3) the value of "N"	N(1,2) = 16/24	Same	Same	Same	Same	Same

[a] Neutron multiplication factors and "N" are shown for an NCT array size of 7×7×3 and an HAC array size of 5×5×2; both arrays are nearly cubic arrangements. An HAC array size is not available for CSI=1.8; therefore, CSI for NCT at 1.8 is rounded up to 2.0 as shown.

[b] Neutron multiplication factors and "N" are shown for an NCT array size of 27×3 and an HAC array size of 16×3; where packages in the planar dimension are in explicit triangular-pitch arrangement and stacked three high in the vertical direction. An NCT array size of 81 packages gives a CSI value of 3.12 (50 / 16), while an HAC array size of 48 packages gives a CSI value of 2.08 (50 / 24). The specified CSI value of 3.2 is the larger of the two numbers rounded up to the nearest tenth decimal place as shown.

Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 7,398-g ^{235}U	90% < enr. ≤ 95% ≤ 10,549-g ^{235}U	80% < enr. ≤ 90% ≤ 14,167-g ^{235}U	70% < enr. ≤ 80% ≤ 19,284-g ^{235}U	60% < enr. ≤ 70% ≤ 24,693-g ^{235}U	enr. ≤ 60% ≤ 35,320-g U
General requirements for each fissile package (§71.55)						
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b")	$k_{eff} + 2\sigma \leq 0.9226$ cvr3cha_8_1_8_15	$k_{eff} + 2\sigma \leq 0.9245$ cvr3cha_12_1_7_15	$k_{eff} + 2\sigma \leq 0.9243$ cvr3cha_16_1_6_15	$k_{eff} + 2\sigma \leq 0.9225$ cvr3cha_25_1_5_15	$k_{eff} + 2\sigma \leq 0.9198$ cvr3cha_36_1_4_15	$k_{eff} + 2\sigma \leq 0.9004$ cvr3cha_36_1_3_15
(1) the most reactive credible configuration consistent with the chemical and physical form of the material,	A mixture of water and HEU metal as turnings, fines, or powder is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. See Appendix 6.9.3, Sect. 6.9.3.1, for justification of the content model.					
(2) moderation by water to the most reactive credible extent,	Flooding of the containment vessel					
(3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging.	30.48-cm H_2O surrounding the containment vessel					

Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 7,398-g ^{235}U	90% < enr. ≤ 95% ≤ 10,549-g ^{235}U	80% < enr. ≤ 90% ≤ 14,167-g ^{235}U	70% < enr. ≤ 80% ≤ 19,284-g ^{235}U	60% < enr. ≤ 70% ≤ 24,693-g ^{235}U	enr. ≤ 60% ≤ 35,320-g U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d")						
(1) the contents would be subcritical,	$k_{eff} + 2\sigma \leq 0.8908$ ncsrbmt11_36_1_15					
(2) the geometric form of the package contents would not be substantially altered,	A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used.					
(3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material,	Moderation is present to such an extent as to cause maximum reactivity					
(4) there will be no substantial reduction in the effectiveness of the packaging	30.48-cm H_2O surrounding the drum (d = 18.37 in., h = 43.5 in.)					

Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 7,398-g ^{235}U	90% < enr. ≤ 95% ≤ 10,549-g ^{235}U	80% < enr. ≤ 90% ≤ 14,167-g ^{235}U	70% < enr. ≤ 80% ≤ 19,284-g ^{235}U	60% < enr. ≤ 70% ≤ 24,693-g ^{235}U	enr. ≤ 60% ≤ 35,320-g U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e")	$k_{eff} + 2\sigma \leq 0.8912$ hcsrbmt12_36_1_15					
(1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents,	A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used.					
(2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content,	Flooding of the package					
(3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package.	30.48-cm H_2O surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.)					

Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 7,398-g ^{235}U	90% < enr. ≤ 95% ≤ 10,549-g ^{235}U	80% < enr. ≤ 90% ≤ 14,167-g ^{235}U	70% < enr. ≤ 80% ≤ 19,284-g ^{235}U	60% < enr. ≤ 70% ≤ 24,693-g ^{235}U	enr. ≤ 60% ≤ 35,320-g U
Standards for arrays of fissile material packages (§71.59)						
" . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a")						
Transport index based on nuclear criticality control, CSI = 0.0	– [c]	– [c]	– [c]	**Load-limited to 2,967-g ^{235}U, no can spacers**	**Load-limited to 3,249-g ^{235}U, no can spacers**	**Load-limited to 5,577-g U, no can spacers**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9213$ nciabmt11_4_1_5_3	$k_{eff} + 2\sigma \leq 0.9207$ nciabmt11_5_1_4_3	$k_{eff} + 2\sigma \leq 0.9152$ nciabmt11_6_1_3_3
(2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation,	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9248$ hciabmt12_4_1_5_3	$k_{eff} + 2\sigma \leq 0.9235$ hciabmt12_5_1_4_3	$k_{eff} + 2\sigma \leq 0.9127$ hciabmt12_6_1_3_3
(3) the value of "N" cannot be <0.5.	– [c]	– [c]	– [c]	N(1,2) = ∞	Same	Same

Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 7,398-g ^{235}U	90% < enr. ≤ 95% ≤ 10,549-g ^{235}U	80% < enr. ≤ 90% ≤ 14,167-g ^{235}U	70% < enr. ≤ 80% ≤ 19,284-g ^{235}U	60% < enr. ≤ 70% ≤ 24,693-g ^{235}U	enr. ≤ 60% ≤ 35,320-g U
Transport index based on nuclear criticality control, CSI = 0.4	– [c]	– [c]	– [c]	**Load-limited to 5,192-g ^{235}U, no can spacers**	**Load-limited to 5,848-g ^{235}U, no can spacers**	**Load-limited to 14,872-g U, no can spacers**
(1) five times "N" undamaged packages	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9235$ ncf1bmt11_7_1_5_3	$k_{eff} + 2\sigma \leq 0.9216$ ncf1bmt11_9_1_4_3	$k_{eff} + 2\sigma \leq 0.9225$ ncf1bmt11_15_1_3_3
(2) two times "N" damaged packages, ...	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9064$ hcf2bmt12_8_1_5_3	$k_{eff} + 2\sigma \leq 0.9118$ hcf2bmt12_12_1_4_3	$k_{eff} + 2\sigma \leq 0.9072$ hcf2bmt12_18_1_3_3
(3) the value of "N" . . .	– [c]	– [c]	– [c]	N(1,2) = 202/162	Same	Same
Transport index based on nuclear criticality control, CSI = 0.8	– [c]	– [c]	– [c]	**Load-limited to 8,900-g ^{235}U, no can spacers**	**Load-limited to 13,646-g ^{235}U, no can spacers**	**Load-limited to 28,814-g U, no can spacers**
(1) five times "N" undamaged packages	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9216$ ncf2bmt11_12_1_5_3	$k_{eff} + 2\sigma \leq 0.9234$ ncf2bmt11_20_1_4_3	$k_{eff} + 2\sigma \leq 0.9205$ ncf2bmt11_29_1_3_3
(2) two times "N" damaged packages, ...	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9012$ hcf3bmt12_12_1_5_3	$k_{eff} + 2\sigma \leq 0.9065$ hcf3bmt12_20_1_4_3	$k_{eff} + 2\sigma \leq 0.9022$ hcf3bmt12_29_1_3_3
(3) the value of "N"	– [c]	– [c]	– [c]	N(1,2) = 64/73	Same	Same
Transport index based on nuclear criticality control, CSI = 2.0 [a]	– [c]	– [c]	– [c]	**Load-limited to 17,059-g ^{235}U, no can spacers**	**Load-limited to 21,444-g ^{235}U, no can spacers**	**35,320-g U, no can spacers**
(1) five times "N" undamaged packages	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9223$ ncf3bmt11_22_1_5_3	$k_{eff} + 2\sigma \leq 0.9216$ ncf3bmt11_31_1_4_3	$k_{eff} + 2\sigma \leq 0.9045$ ncf3bmt11_36_1_3_3
(2) two times "N" damaged packages, ...	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.8852$ hcf4bmt12_22_1_5_3	$k_{eff} + 2\sigma \leq 0.8858$ hcf4bmt12_31_1_4_3	$k_{eff} + 2\sigma \leq 0.8705$ hcf4bmt12_36_1_3_3
(3) the value of "N"	– [c]	– [c]	– [c]	N(1,2) = 29/25	Same	Same

Table 6.1d. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 7,398-g ^{235}U	90% < enr. ≤ 95% ≤ 10,549-g ^{235}U	80% < enr. ≤ 90% ≤ 14,167-g ^{235}U	70% < enr. ≤ 80% ≤ 19,284-g ^{235}U	60% < enr. ≤ 70% ≤ 24,693-g ^{235}U	enr. ≤ 60% ≤ 35,320-g U
Transport index based on nuclear criticality control, CSI = 3.2 [b]	– [c]	– [c]	– [c]	**Load-limited to 19,284-g ^{235}U, no can spacers**	**24,692-g ^{235}U, no can spacers**	**35,320-g U, no can spacers**
(1) five times "N" undamaged packages	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9226$ nctf5bmt11_35_1_5_3	$k_{eff} + 2\sigma \leq 0.9030$ nctf5bmt11_36_1_4_3	$k_{eff} + 2\sigma \leq 0.8743$ nctf5bmt11_36_1_3_3
(2) two times "N" damaged packages, ...	– [c]	– [c]	– [c]	$k_{eff} + 2\sigma \leq 0.9052$ hctf5bmt12_35_1_5_3	$k_{eff} + 2\sigma \leq 0.8819$ hctf5bmt12_36_1_4_3	$k_{eff} + 2\sigma \leq 0.8542$ hctf5bmt12_36_1_3_3
(3) the value of "N"	– [c]	– [c]	– [c]	N(1,2) = 16/24	Same	Same

[a] Neutron multiplication factors and "N" are shown for an NCT array size of 7×7×3 and an HAC array size of 5×5×2; both arrays are nearly cubic arrangements. An HAC array size is not available for CSI=1.8; therefore, CSI for NCT at 1.8 is rounded up to 2.0 as shown.

[b] Neutron multiplication factors and "N" are shown for an NCT array size of 27×3 and an HAC array size of 16×3; where packages in the planar dimension are in explicit triangular-pitch arrangement and stacked three high in the vertical direction. An NCT array size of 81 packages gives a CSI value of 3.12 (50 / 16), while an HAC array size of 48 packages gives a CSI value of 2.08 (50 / 24). The specified CSI value of 3.2 is the larger of the two numbers rounded up to the nearest tenth decimal place as shown.

[c] See Appendix 6.9.11 and Table 6.9.11.53.

Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide

Conditions	HEU product oxide ≤ 21,125-g ^{235}U	HEU skull oxide [a] ≤ 15,673-g ^{235}U and ≤ 921-g C
General requirements for each fissile package (§71.55)		
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b")	$k_{eff} + 2\sigma \leq 0.9143$ cvcrpdoxt11_1_3_24_15	$k_{eff} + 2\sigma \leq 0.8497$ cvcrsk3cc_9_15_17
(1) the most reactive credible configuration consistent with the chemical and physical form of the material,	HEU oxide at the bulk density is assumed dispersed in the containment vessel, where the oxide fills the containment vessel to a height determined by the oxide mass. The oxide is saturated with water. Water fills the void region above the oxide content, but this amount of water is reduced by an amount equivalent to the volume occupied by can spacers. The can pads, spacer can, and convenience can steel are replaced by water. See Sect. 6.9.3.1 for justification of the content model.	Same
(2) moderation by water to the most reactive credible extent,	Flooding of the containment vessel	Same
(3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging.	30.48-cm H_2O surrounding the containment vessel	Same

Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide

Conditions	HEU product oxide ≤ 21,125-g ^{235}U	HEU skull oxide [a] ≤ 15,673-g ^{235}U and ≤ 921-g C
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d")		
(1) the contents would be subcritical,	$k_{eff} + 2\sigma \leq 0.8166$ ncsrpdoxt11_1_3_24	$k_{eff} + 2\sigma \leq 0.7410$ ncsrsk_9_15
(2) the geometric form of the package contents would not be substantially altered,	HEU oxide at the bulk density is assumed dispersed in the containment vessel, where the oxide fills the containment vessel to a height determined by the oxide mass. The oxide is saturated with water. Water fills the void region above the oxide content, but this amount of water is reduced by an amount equivalent to the volume occupied by can spacers. The can pads, spacer can, and convenience can steel are replaced by water.	Same
(3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material,	Moderation is present to such an extent as to cause maximum reactivity	Same
(4) there will be no substantial reduction in the effectiveness of the packaging	30.48-cm H_2O surrounding the drum (d = 18.37 in., h = 43.5 in.)	Same

Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide

Conditions	HEU product oxide ≤ 21,125-g ^{235}U	HEU skull oxide [a] ≤ 15,673-g ^{235}U and ≤ 921-g C
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e")	$k_{eff} + 2\sigma \leq 0.8187$ hcsrpdoxt12_1_3_24	$k_{eff} + 2\sigma \leq 0.7410$ hcsrsk_9_15
(1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents,	HEU oxide at the bulk density is assumed dispersed in the containment vessel, where the oxide fills the containment vessel to a height determined by the oxide mass. The oxide is saturated with water. Water fills the void region above the oxide content, but this amount of water is reduced by an amount equivalent to the volume occupied by can spacers. The can pads, spacer can, and convenience can steel are replaced by water.	Same
(2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content,	Flooding of the package	Same
(3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package.	30.48-cm H_2O surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.)	Same

Table 6.1e. Summary of criticality evaluation for HEU product and skull oxide

Conditions	HEU product oxide ≤ 21,125-g ^{235}U	HEU skull oxide [a] ≤ 15,673-g ^{235}U and ≤ 921-g C
Standards for arrays of fissile material packages (§71.59)		
" . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a")		
Transport index based on nuclear criticality control, CSI = 0.0	**Load-limited to 9,682-g ^{235}U, [b] no can spacers**	**Load-limited to 15,673-g ^{235}U, no can spacers**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	$k_{eff} + 2\sigma \leq 0.9201$ nciapdoxt11_1_1_11_3	$k_{eff} + 2\sigma \leq 0.7562$ nciask_9_15
(2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation,	$k_{eff} + 2\sigma \leq 0.9247$ hciapdoxt12_1_1_11_3	$k_{eff} + 2\sigma \leq 0.7599$ hciask_9_15
(3) the value of "N" cannot be <0.5.	$N(1,2) = \infty$	Same

[a] See Appendix 6.9.11 for removal of the carbon limit.

[b] For HEU product oxides with a bulk density ranging from ≥ 2.0 g/cm^3 to 6.54 g/cm^3 at a CSI of 0.4, the maximum ^{235}U per ES-3100 package is 12,323 g as discussed in Appendix 6.9.9.

Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements

Conditions	UNX crystals ≤ 11,303-g ^{235}U	Unirradiated TRIGA fuel elements ≤ 921-g ^{235}U
General requirements for each fissile package (§71.55)		
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b")	$k_{eff} + 2\sigma \leq 0.8630$ cvcrpunhct11_10_15	$k_{eff} + 2\sigma \leq 0.5274$ cvcrtriga_1_15
(1) the most reactive credible configuration consistent with the chemical and physical form of the material,	UNX crystals are homogenized with water over the internal volume of the containment vessel consistent with the high solubility properties of UNX. Can spacers are not used. Hydrogenous packing material represented by 500 g.	Three 5-in tall sectioned pieces of $UZrH_x$ from a cylindrical TRIGA fuel element per convenience can. Sectioned pieces arranged in triangular pitch. No can spacers. Convenience can steel replaced by water.
(2) moderation by water to the most reactive credible extent,	Flooding of the containment vessel	Same
(3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging.	30.48-cm H_2O surrounding the containment vessel	Same

Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements

Conditions	UNX crystals ≤ 11,303-g ^{235}U	Unirradiated TRIGA fuel elements ≤ 921-g ^{235}U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d")		
(1) the contents would be subcritical,	$k_{eff} + 2\sigma \leq 0.7526$ ncsrpunhct11_8_15	$k_{eff} + 2\sigma \leq 0.4950$ ncsrtriga_1_15_15
(2) the geometric form of the package contents would not be substantially altered,	UNX crystals are homogenized with water over the internal volume of the containment vessel consistent with the high solubility properties of UNX. Can spacers are not used. Hydrogenous packing material represented by 500 g.	Three 5-in tall sectioned pieces of UZrHx from a cylindrical TRIGA fuel element per convenience can. Sectioned pieces arranged in triangular pitch. No can spacers. Convenience can steel replaced by water.
(3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material,	Moderation is present to such an extent as to cause maximum reactivity	Same
(4) there will be no substantial reduction in the effectiveness of the packaging	30.48-cm H_2O surrounding the drum (d = 18.37 in., h = 43.5 in.)	Same

Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements

Conditions	UNX crystals ≤ 11,303-g ^{235}U	Unirradiated TRIGA fuel elements ≤ 921-g ^{235}U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e")	$k_{eff} + 2\sigma \leq 0.8144$ icsrpunhct12_15_15	$k_{eff} + 2\sigma \leq 0.4945$ hcsrtriga_1_15_15
(1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents,	UNX crystals are homogenized with water over the internal volume of the containment vessel consistent with the high solubility properties of UNX. Can spacers are not used. Hydrogenous packing material represented by 500 g.	Three 5-in tall sectioned pieces of UZrHx from a cylindrical TRIGA fuel element per convenience can. Sectioned pieces arranged in triangular pitch. No can spacers. Convenience can steel replaced by water.
(2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content,	Flooding of the package	Same
(3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package.	30.48-cm H_2O surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.)	Same

Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements

Conditions	UNX crystals ≤ 11,303-g ^{235}U	Unirradiated TRIGA fuel elements ≤ 921-g ^{235}U
Standards for arrays of fissile material packages (§71.59)		
" . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a")		
Transport index based on nuclear criticality control, CSI = 0.0	**Load-limited to 3297-g ^{235}U, no can spacers**	**No can spacers**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	$k_{eff} + 2\sigma \leq 0.9199$ nciapunhct11_7_3	$k_{eff} + 2\sigma \leq 0.5254$ nciatriga_1_15_3
(2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation,	$k_{eff} + 2\sigma \leq 0.9180$ hciapunhct12_7_3	$k_{eff} + 2\sigma \leq 0.5261$ hciatriga_1_15_3
(3) the value of "N" cannot be <0.5.	N(1,2) = ∞	Same
Transport index based on nuclear criticality control, CSI = 0.0	**Can spacers**	**Can spacers**
(1) five times "N" undamaged packages	Not applicable	$k_{eff} + 2\sigma \leq 0.4421$ nciatriga_2_15_3
(2) two times "N" damaged packages, ...	Not applicable	$k_{eff} + 2\sigma \leq 0.4427$ hciatriga_2_15_3
(3) the value of "N"	Not applicable	N(1,2) = ∞

Table 6.1f. Summary of criticality evaluation for UNX crystals and unirradiated TRIGA reactor fuel elements

Conditions	UNX crystals ≤ 11,303-g ^{235}U	Unirradiated TRIGA fuel elements ≤ 921-g ^{235}U
Transport index based on nuclear criticality control, CSI = 0.4	**Load-limited to 11,303-g ^{235}U, no can spacers**	**No can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.8730$ ncf1punhct11_24_3	Bounded by CSI=0
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.8423$ hcf2punhct12_24_3	Bounded by CSI=0
(3) the value of "N"	N(1,2) = 202/162	Same
Transport index based on nuclear criticality control, CSI = 0.4	**Can spacers**	**Can spacers**
(1) five times "N" undamaged packages	Not applicable	Bounded by CSI=0
(2) two times "N" damaged packages, ...	Not applicable	Bounded by CSI=0
(3) the value of "N"	Not applicable	N(1,2) = 202/162

The evaluation limits for solid HEU metal shapes are listed in the column headings appearing to the right of the "Conditions" column of Table 6.1a. Limits expressed in terms of the diameter for a cylinder and the length-width of the geometric cross section for a square bar are established by the size of the convenience can opening through which these contents are inserted. Potential fissile (^{235}U) mass loading limits for these contents are given in the information blocks where a description of the content appears for the fissile material "in the most reactive credible configuration."

The fissile (^{235}U) or uranium masses listed in the column headings of Tables 6.1b–6.1f indicate evaluation limits for the associated content configurations. In the case of slugs (Table 6.1b), the ^{235}U evaluation limits represent the fissile content contained in the slugs with maximum tolerances applied. In the case of broken metal (Table 6.1c), the ^{235}U evaluation limits represent the maximum amount of ^{235}U adequately subcritical in a flooded, reflected containment vessel as conservatively applied over the indicated range of enrichment. For HEU enrichments $\leq$ 60%, the 35.32-kg package limit on the amount of HEU to be shipped in an ES-3100 becomes the evaluation limit. Relative to the broken metal limits specified in Table 6.1c, the ^{235}U evaluation limit permissible for HEU metal in the form of turnings, fines, or powder is reduced at the higher enrichments (Table 6.1d). For HEU oxide and UNX crystals (Tables 6.1e and 6.1f), the ^{235}U evaluation limits correspond to the 24-kg package limit on the amount of HEU oxide or UNX crystals to be shipped. For HEU skull oxide (Table 6.1e), the ^{235}U evaluation limit represents a maximum derived from the evaluation of an inventory at Y-12. For unirradiated TRIGA reactor fuel elements (Table 6.1f), the ^{235}U evaluation limit represents a maximum for the fuel manufacturer's product line.

The NCT and HAC array analyses [10 CFR 71.59(a)(1) and (a)(2)] may reveal reductions in the potential loading limits for content and 277-4 canned spacer configurations initially identified in the single package calculations [10 CFR 71.55(b), (d), and (e)] of Tables 6.1a–6.1f. This occurs in order to achieve fissile material loadings which are at or below the subcritical safety limit. These reduced loading limits are identified as "**load-limited to**" values in the "CSI" rows.

Table 6.2a summarizes the fissile loading limits derived from Tables 6.1a–6.1f for surface-only transport mode. In establishing compliance with the fissile loading limit indicated in Table 6.2a for uranium alloys of aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium, the content mass of ^{235}U includes the mass of the non-uranium alloy constituents. The fissile loading limits pertaining to the air-transport mode summarized in Table 6.2b are derived from the air-transport analysis addressed in Sect. 6.7. Packages transported by air involve both surface and air modes of transportation. The loading limit for packages under mixed-mode transportation is taken as the most restrictive limit for either mode (surface or air transport).

The "no water inleakage" condition of 10 CFR 71.55(f)(1) and (f)(2) signifies that the hydrogenous material present in the package during air transport is limited to the amount present in the package when it is loaded on the aircraft for transport. The dry-baked Kaolite in the drum body weldment and drum top plug consists of vermiculite-cement constituents and 2,204.7 g of bound water. Potential sources of additional hydrogen moderator are the hydrogenous packing materials present inside the containment vessel, moisture inside the containment vessel well, and the moisture inside the Kaolite region of the package.

For establishing the loading limits for air transport, the total **free** water in wet Kaolite was conservatively evaluated up to 15 lb (6,803.8 g). Based on this evaluation, **free** water must be limited to 12 lb (5,443.1 g) for maintaining the required margin of subcriticality when shipping under the air transport loading limits specified in Table 6.2b. This requirement is specific to the Kaolite region of the ES-3100 package for two reasons. First, the hydrogenous packing material inside the containment vessel is limited to 500 g per the air transport evaluation. Second, the use of a drum covering and administrative controls (Sects. 7 and 7.1.3.1) will ensure dryness of the containment vessel well. Package operational controls and acceptance limits (Sects. 7 and 8) will ensure that a package to be used for air transport is qualified.

Table 6.2a. HEU fissile material mass loading limits (with case name) for surface-only modes of transportation

Solid HEU metal of specified geometric shape [a]						
Transport index based on nuclear criticality control	**Cylinders (d ≤ 3.24 in.)**	**Cylinders (3.24 in. < d ≤ 4.25 in.)**	**Bars**	**Slugs [b] enr. ≤ 95%**	**Slugs [c] 80% < enr. ≤ 95%**	**Slugs [c] enr. ≤ 80%**
No can spacers						
CSI = 0.0	18,000-g ^{235}U nciacyt11_18_1_3	15,000-g ^{235}U nciacyct11_15_1_3	30,000-g ^{235}U hciasqt12_30_1_3	17,374-g ^{235}U ncia5st11_1_1_7_3	–	–
With can spacers						
CSI = 0.0	30,000-g ^{235}U nciacyt11_30_2_3	25,000-g ^{235}U nciacyct11_25_2_3	36,000-g ^{235}U nciasqt11_36_2_3	–	24,324-g ^{235}U hcia70st12_2_7_3	29,318-g ^{235}U hcia5est12_2_2_5_3
CSI = 0.4	–	–	–	–	34,749-g ^{235}U [c] ncf15est11_2_2_7_3	29,318-g ^{235}U ncf15est11_2_2_5_3

HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal [a]						
Transport index based on nuclear criticality control	**95% < enr. ≤ 100%**	**90% < enr. ≤95%**	**80% < enr. ≤90%**	**70% < enr. ≤80%**	**60% < enr. ≤70%**	**Enr. ≤60%**
No can spacers						
CSI = 0.0	Can spacers required	Can spacers required	Can spacers required	2,967-g ^{235}U hciabmt12_4_1_5_3	3,249-g ^{235}U hciabmt12_5_1_4_3	5,576-g U nciabmt11_6_1_3_3
CSI = 0.4	Can spacers required	Can spacers required	Can spacers required	5,192-g ^{235}U ncf1bmt11_7_1_5_3	5,848-g ^{235}U ncf1bmt11_9_1_4_3	14,872-g U ncf1bmt11_15_1_3_3
CSI = 0.8	Can spacers required	Can spacers required	Can spacers required	8,900-g ^{235}U ncf2bmt11_12_1_5_3	13,646-g ^{235}U ncf2bmt11_20_1_4_3	28,814-g U ncf2bmt11_29_1_3_3
CSI = 2.0	Can spacers required	Can spacers required	Can spacers required	17,059-g ^{235}U ncf3bmt11_22_1_5_3	21,444-g ^{235}U ncf3bmt11_31_1_4_3	35,320-g U ncf3bmt11_36_1_3_3
CSI = 3.2	Can spacers required	Can spacers required	Can spacers required	27,443-g ^{235}U ncf5bmt11_35_1_5_3	24,692-g ^{235}U ncf5bmt11_36_1_4_3	35,320-g U ncf5bmt11_36_1_3_3

Table 6.2a. HEU fissile material mass loading limits (with case name) for surface-only modes of transportation

Transport index based on nuclear criticality control	95% < enr. ≤ 100%	90% < enr. ≤95%	80% < enr. ≤90%	70% < enr. ≤80%	60% < enr. ≤70%	Enr. ≤60%
With can spacers						
CSI = 0.0	2,774-g ^{235}U hciabmt12_3_2_8_3	3,516-g ^{235}U hciabmt12_4_2_7_3	3,333-g ^{235}U hciabmt12_4_2_6_3	4,450-g ^{235}U hciabmt12_6_2_5_3	5,198-g ^{235}U nciabmt11_8_2_4_3	11,154-g U hciabmt12_12_2_3_3
CSI = 0.4	5,549-g ^{235}U ncf1bmt11_6_2_8_3	6,154-g ^{235}U ncf1bmt11_7_2_7_3	7,500-g ^{235}U ncf1bmt11_9_2_6_3	8,900-g ^{235}U ncf1bmt11_12_2_5_3	12,996-g ^{235}U ncf1bmt11_19_2_4_3	28,813-g U ncf1bmt11_29_2_3_3
CSI = 0.8	9,248-g ^{235}U ncf2bmt11_10_2_8_3	10,549-g ^{235}U ncf2bmt11_12_2_7_3	12,500-g ^{235}U ncf2bmt11_14_2_6_3	16,317-g ^{235}U ncf2bmt11_21_2_5_3	20,793-g ^{235}U ncf2bmt11_30_2_4_3	35,320-g U ncf2bmt11_36_2_3_3
CSI = 2.0	13,872-g ^{235}U ncf3bmt11_14_2_8_3	18,461-g ^{235}U ncf3bmt11_20_2_7_3	20,000-g ^{235}U ncf3bmt11_23_2_6_3	25,218-g ^{235}U ncf3bmt11_32_2_5_3	24,692-g ^{235}U ncf3bmt11_36_2_4_3	35,320-g U ncf3bmt11_36_2_3_3
CSI = 3.2	24,969-g ^{235}U ncf5bmt11_25_2_8_3	26,373-g ^{235}U ncf5bmt11_28_2_7_3	28,334-g ^{235}U [d] ncf5bmt11_35_2_6_3	28,184-g ^{235}U ncf5bmt11_36_2_5_3	24,692-g ^{235}U ncf5bmt11_36_2_4_3	35,320-g U ncf5bmt11_36_2_3_3

HEU metal turnings, fines, or powder [a, e, f]

Transport index based on nuclear criticality control	95% < enr. ≤ 100%	90% < enr. ≤95%	80% < enr. ≤90%	70% < enr. ≤80%	60% < enr. ≤70%	Enr. ≤60%
No can spacers						
CSI = 0.0	– [g]	– [g]	– [g]	2,967-g ^{235}U hciabmt12_4_1_5_3	3,249-g ^{235}U hciabmt12_5_1_4_3	5,576-g U nciabmt11_6_1_3_3
CSI = 0.4	– [g]	– [g]	– [g]	5,192-g ^{235}U ncf1bmt11_7_1_5_3	5,848-g ^{235}U ncf1bmt11_9_1_4_3	14,872-g U ncf1bmt11_15_1_3_3
CSI = 0.8	– [g]	– [g]	– [g]	8,900-g ^{235}U ncf2bmt11_12_1_5_3	13,646-g ^{235}U ncf2bmt11_20_1_4_3	28,814-g U ncf2bmt11_29_1_3_3
CSI = 2.0	– [g]	– [g]	– [g]	17,059-g ^{235}U ncf3bmt11_22_1_5_3	21,444-g ^{235}U ncf3bmt11_31_1_4_3	35,320-g U ncf3bmt11_36_1_3_3
CSI = 3.2	– [g]	– [g]	– [g]	19,284-g ^{235}U ncf5bmt11_35_1_5_3	24,692-g ^{235}U ncf5bmt11_36_1_4_3	35,320-g U ncf5bmt11_36_1_3_3

Table 6.2a. HEU fissile material mass loading limits (with case name) for surface-only modes of transportation

HEU oxide, UNX crystals, and unirradiated TRIGA fuel elements					
Transport index based on nuclear criticality control	**HEU product oxide, no can spacers**	**HEU skull oxide, no can spacers**	**UNX crystals, no can spacers**	**Unirradiated TRIGA fuel elements, no can spacers [h]**	
				20% enr.	**70% enr.**
CSI = 0.0	9,682-g ^{235}U hciapdoxt12_1_1_11_3	15,673-g ^{235}U and 921-g C [i] nciask_9_15	3,297-g ^{235}U nciapunhct11_7_3	921-g ^{235}U nciatriga_1_15_3	408-g ^{235}U nciatriga70_1_15_3
CSI = 0.4	12,323-g ^{235}U [j] 5ncf1pdoxt11_1_1_14_3	–	11,303-g ^{235}U ncf1punhct11_24_3	–	–

[a] Uranium alloys (uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) may be loaded to the appropriate mass limit as discussed in Appendix 6.9.11.

[b] When can spacers **are not** used, the mass limit = 17,374-g ^{235}U.

[c] When can spacers are used, a greater fissile mass limit is permissible based on enrichment. For CSI=0 and enrichments >80 wt %, the fissile mass must be reduced below the volumetric limit. For CSI=0.4, fissile mass is volumetrically limited by the size of the slugs. Note that within a fixed volume, the HEU mass increases slightly with decreasing enrichment.

[d] Case **ncf5bmt11_35_2_6_3** (with a mass of 30.8340 kg) establishes the CSI value of 3.2. The more restrictive mass of 28.334 kg is from Case **cvr3lha_32_1_6_15** (Table 6.1c).

[e] More restrictive mass limits for uranium metal as turnings, fines, or powder are obtained from Cases **cvr3cha_8_1_8_15**, **cvr3cha_12_1_7_15**, **cvr3cha_16_1_6_15**, and **cvr3cha_25_1_4_4_15** (Table 6.1d).

[f] Samples and small quantities (≤ 50 g) of HEU metal or alloy turnings, fines, or powder can be shipped under the parent form mass limits (e.g., broken metal, reactor fuel, etc.).

[g] Loading limit for HEU metal turnings, fines, or powder with enrichments >80% are provided in Appendix 6.9.11 and Table 6.9.11.53.

[h] For ground transport, TRIGA reactor fuel element content will be limited to three fuel sections (“meats”) per loaded convenience can and up to three loaded cans per package. The TRIGA fuel content may also be configured as clad fuel rods, each rod derived from a single TRIGA fuel element. A ~15-in.-long rod consists of the three fuel pellets and an exterior sheath of clad, where protruding clad at each end has been crimped in. Clad fuel rods will be packed into convenience cans, with a maximum of three fuel rods per loaded convenience can and one loaded can per containment vessel.

[i] Removal of the carbon limit (i.e., 921-g C) is addressed in Appendix 6.9.11.

[j] See Appendix 6.9.9.

Table 6.2b. HEU fissile material mass loading limits for air mode of transportation [a]

Solid HEU metal or alloy, unirradiated TRIGA fuel elements [b]					
Cylinders (3.24 ≤ d ≤ 4.25 in.)	**Bars**	**Slugs**	**Broken metal, unspecified geometric shape and characterized as broken metal, turnings, fines, or powder [c]**	**Unirradiated TRIGA [d]**	
				20% enr.	**70% enr.**
7,000-g ^{235}U	7,000-g ^{235}U	7,000-g ^{235}U	7,000-g ^{235}U	921-g ^{235}U	408-g ^{235}U

HEU oxide, UNX crystals		
HEU product oxide	**HEU skull oxide**	**UNX crystals**
5,281-g ^{235}U [e]	Not allowed	Not allowed

[a] The loading limit for mixed mode transportation is taken as the most restrictive limit for either the surface or the air mode of transportation, Tables 6.2a or 6.2b.
[b] For air transport, TRIGA reactor fuel element content will be limited to fuel sections or clad fuel rods as described for surface-only modes of transportation in footnote "c" of Table 6.2a and the fissile mass limit specified herein, whichever is more limiting.
[c] Research reactor related contents of uranium metal or U-Al alloy are packaged for air transport under these specified limits.
[d] Research reactor related contents of U_3O_8-Al, UO_2, or UO_2-Mg are packaged for air transport under limits specified for unirradiated TRIGA fuel elements. Per package limits for these items are a maximum of 921-g ^{235}U at enrichments not exceeding 20 wt % and a maximum of 408-g ^{235}U for content enrichments greater than 20 wt %.
[e] Appendix 6.9.10 details air transport evaluation of HEU product oxide.

Research reactor fuel elements or fuel components are composed of U-Al, U_3O_8-Al, UO_2, or UO_2-Mg. Related materials are broken uranium metal, U-Al alloy, or oxides of U_3O_8, U_3O_8-Al, or UO_2-Mg. With the exception of the oxide and compounds, research reactor related contents are packaged for air transport under limits specified in Table 6.2b for HEU broken metal, solid HEU metal of unspecified geometric shape and characterized as broken metal, turnings, fines, or powder. The oxide and compounds are packaged for air transport under limits specified in Table 6.2b for unirradiated TRIGA fuel elements. Per package limits for these items are a maximum of 921-g ^{235}U at enrichments not exceeding 20 wt % and a maximum of 408-g ^{235}U for content enrichments greater than 20 wt %.

Table 6.9.8.2 (Appendix 6.9.8) summarizes the fissile material load limits for the contents not covered in Table 6.2a. The loading limits from Tables 6.2a and 6.9.8.2 are consolidated in Tables 1.3 and 1.3a.

The criticality evaluation demonstrates that the ES-3100 packaging with the HEU content satisfies the requirements for single packages and for arrays of fissile material packages when the packages are load-limited as specified in Tables 6.2a, 6.2b, and 6.9.8.2 (reproduced in Tables 1.3, 1.3a, and 1.3b) under the conditions identified in Sect. 6.2.4.

6.1.4 Criticality Safety Index

A CSI is assigned to the Model ES-3100 package on the basis of an adequate margin of subcriticality for the single package and arrays of packages for both NCT and HAC. Values for the CSI given in Tables 6.2a and 6.2b are based on the uranium and the ^{235}U mass of the content and on the presence of 277-4 canned spacers as defined in Sect. 6.2.2.

The CSI is determined from bounding calculations using KENO V.a models of the containment vessel, the single package, and arrays of packages (NUREG/CR-0200, Rev. 6). It is a dimensionless number used to limit the number of packages in a conveyance for nuclear criticality safety control. The CSI is the larger of the CSI values for NCT and for HAC. For NCT, the CSI is equal to 50 divided by the allowable number of packages "N" that can be shipped, where the allowable number of packages is one-fifth of the maximum array size that is calculated to be subcritical. For HAC, the CSI is equal to 50 divided by the allowable number of packages "N" that can be shipped, where the allowable number of packages is one-half of the maximum array size that is calculated to be subcritical. The CSI is a calculated number rounded up to the nearest first decimal.

The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, 5×5×2, explicit triangular pitch (ETP) 27×3 for NCT, ETP 16×3 for HAC, and the degenerate single unit. For NCT, the "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: N = ∞, CSI = 0; N = 202, CSI = 0.3; N = 64, CSI = 0.8; N = 29, CSI = 1.8; N = 10, CSI = 5.0; and N = 16, CSI = 3.2. For HAC, the "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: N = ∞, CSI = 0; N = 507, CSI = 0.1; N =162, CSI = 0.4; N = 73, CSI = 0.7; N = 25, CSI = 2.0; and N = 24, CSI = 2.1. Absent an exact correspondence of CSI values for the NCT and HAC, the following arrays results were selected for rounded CSI values as indicated in Tables 6.1a–6.1f:

- infinite arrays evaluated for both NCT and HAC [designated as "(1,2)"], where N(1,2) = for a CSI = 0;
- 13×13×6 evaluated for NCT and 9×9×4 evaluated for HAC where N(1,2) = (202,162) for a CSI = 0.4;
- 9×9×4 evaluated for NCT and 7×7×3 evaluated for HAC where N(1,2) = (64,73) for a CSI = 0.8;

- 7×7×3 evaluated for NCT and 5×5×2 evaluated for HAC where N(1,2) = (29,25) for a CSI = 2.0; and
- 27×3 evaluated for NCT and 16×3 evaluated for HAC where N(1,2) = (16,24) for a CSI = 3.2.

6.2 PACKAGE CONTENTS

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

6.2.1 Fissile Material Contents

The per-package HEU mass loadings considered in the criticality evaluation range from 1000 to 36,000 g for uranium metal and from 1000 to 24,000 g for uranium oxide and UNX crystals. The HEU mass may include nonradioactive contaminants and trace elements or materials in the HEU.

The bounding types of HEU content evaluated in this criticality analysis are 4.25-in.- and 3.24-in.-diam cylinders; 2.29-in.-square bars; 1.5-in.-diam × 2-in.-tall slugs; cubes ranging from 0.25 to 1 in. on a side; broken metal pieces of unspecified geometric shapes; skull oxide; uranium oxide; UNX crystals; and unirradiated TRIGA reactor fuel elements.

The terms "broken metal" and "turnings, fines, or powder" are used to describe an HEU content without restrictions on shape or size other than a minimum size limit (spontaneous ignition), a maximum mass limit (criticality control), a minimum enrichment (the lower limit for HEU at 19 wt % ^{235}U in uranium), and the capacity limits of the convenience cans. The content geometry envelope encompasses regular, uniform shapes and sizes as well as irregular shapes and sizes. Broken metal pieces are distinguished from turnings, fines, or powder as having a surface-area-to-mass ratio of not greater than 1 cm^2/g or must not pass through a 3/8-in. mesh sieve (or equivalent size-grading method). By this definition, turnings, fines, or powder are packed in cans that are sealed and the cans' atmosphere is inerted for pyrophoric considerations.

The density of HEU metal ranges from 18.811 to 19.003 g/cm^3 for HEU metal, corresponding to enrichments ranging from 100 to 19 wt % ^{235}U. Theoretical (crystalline) densities for HEU oxide are 10.96 g/cm^3, 8.30 g/cm^3, and 7.29 g/cm^3 for UO_2, U_3O_8, and UO_3, respectively. However, bulk densities of product oxide are typically on the order of 2.0 to 6.54 g/cm^3. With increased moderation of fissile mass possible at these lower densities, only "less-than-theoretical" mass loadings would actually be achieved. Skull oxides are a mixture of U_3O_8 and graphite, having densities on the order of 2.44 g/cm^3 for poured material and 2.78 g/cm^3 for tamped (packed) material. Combined water saturation and crystallization of the HEU oxide is not expected in the HAC because UO_2 is non-hygroscopic, and both UO_3 and U_3O_8 are only mildly hygroscopic. The density of UNX crystals varies depending on the degree of hydration. The most reactive form of UNX crystals considered for shipment in the ES-3100 is $UO_2(NO_3)\cdot xH_2O$ with 6 molecules of hydration, having a density of 2.79 g/cm^3. UNX crystals are highly soluble in nitric acid and mildly soluble in water. Dissolution of UNX crystals in water is assumed in this criticality evaluation. The content geometry envelope encompasses both regular, uniform clumps and densities, and irregular clumps and densities.

The ~40 stock items of TRIGA fuel are cataloged as one of the four basic types: a standard element, an instrumented element, a fuel follower control rod, or a cluster assembly. The active region of TRIGA element consists of three 5-in long sections "fuel meats" of uranium zirconium hydride ($UZrH_x$). The "x" in $UZrH_x$ equals 1.6 in all cases except for two stock items where x = equals 1.0 and the fissile

content is < 40-g ^{235}U. The clad thickness is ~0.02 in. for a TRIGA fuel element with stainless steel cladding and ~0.03 in. for an element with aluminum cladding.

Solid form TRIGA fuel is either 20 or 70 wt % enriched in ^{235}U and has specific dimensional characteristics for its designed function. For the 20 wt % enriched TRIGA elements, the active fuel diameters are 1.44 in., 1.41 in., 1.40 in., 1.37 in., 1.34 in., or 1.31 in. The uranium weight fractions are 45 wt %, 30 wt %, 20 wt %, 12 wt %, and 8.5 wt %. The TRIGA element with a maximum fissile content of 307-g ^{235}U in 1,560-g U is 45 wt % U in $UZrH_x$ and has a computed density of ~8.6 g/cm^3 (Appendix 6.9.3.1). For the 70 wt % enriched TRIGA fuel, the active fuel diameter is 1.44 in. in the standard element and instrumented element, and 1.31 in. in the fuel follower control rod. Both the standard element and instrumented elements contain ~136-g ^{235}U in 194-g U while the fuel follower control rod contains ~113-g ^{235}U in 162-g U. The 70 wt % enriched TRIGA fuel is 8.5 wt % U in $UZrH_x$ and has a computed density of ~5.7 g/cm^3 (Appendix 6.9.3.1).

In preparation for shipment in the ES-3100, the unirradiated TRIGA fuel elements may be disassembled and the fuel sections removed from the thin-wall cladding. The TRIGA fuel may also be configured as clad fuel rods. Each clad fuel rod will be derived from a single TRIGA fuel element by removal of the stainless steel or aluminum clad beyond the plenum adjacent to the axial ends of the active fuel section. Each ~15-in.-long rod consists of the 3 fuel pellets and an exterior sheath of clad, where the protruding clad at each end has been crimped in.

The 0.02-in.-thick sheath of stainless steel clad adds ~179 g to the mass of the active fuel for the standard element or instrumented element with 1.48 in. overall diameter, and ~163 g to active fuel mass for the fuel follower control rod with 1.35 in. overall diameter. Allowance for 0.5 in. of residual stainless steel crimped on each end of the clad fuel rod adds ~11 to 12 g stainless steel to these amounts. Likewise, the 0.03-in.-thick sheath of aluminum clad adds ~90 g to the mass of the active fuel for the 1.47-in.-diam standard element or instrumented element. Allowance for 0.5 in. of residual aluminum crimped on each end of the clad fuel rod adds ~6 g aluminum.

Research reactor fuel elements or fuel components are composed of U-Al, U_3O_8-Al, UO_2, UO_2-Zr, UO_2-ZrO_2, or UO_2-Mg. Related materials include broken uranium metal, U-Al alloy, or oxides (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-ZrO_2, or UO_2-Mg). These items contain small quantities of fissile uranium typically ranging from 4.2-g ^{235}U to 2000-g ^{235}U. The maximum enrichment is ~93%. Components are of various solid shapes (rods, square bars, plates, or tubes).

Skull oxides, uranium alloys of aluminum, molybdenum, or zirconium and unirradiated TRIGA reactor fuel elements are evaluated where composition data is for material in the as-manufactured condition. A maximum enrichment of 100 wt % is used for HEU metal, oxide and UNX crystals in the criticality calculations strictly for the purpose of maximizing reactivity, even though HEU enrichment ranges from 19 to 97.7 wt % ^{235}U. Although mass loading limits for oxide and crystals are based on 100% enrichment, the actual enrichment is expected to be less than the stated maximum, with the remainder of the uranium being primarily ^{238}U. The HEU mass may also include nonradioactive contaminants and trace elements or materials in the HEU.

No intact weapon part or component will be shipped in this package. Weapon parts or components that have been reduced to "broken metal pieces" or processed into HEU oxide and meet the additional content requirements identified in Sect. 6.2.4 may be shipped in this package.

6.2.2 Convenience Cans, Teflon and Polyethylene Bottles, and 277-4 Canned Spacers

HEU fissile material to be shipped in the ES-3100 package will be placed in stainless steel, tin-plated carbon steel, aluminum, or nickel alloy convenience cans, polyethylene or Teflon bottles,

or polyethylene bagging. Can lids may be welded, press fit, slip lid, or crimp seal types; bottle lids are screw cap type. Convenience cans and bottles are used to hold the HEU 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. The HEU metal or oxide content may be wrapped or bagged in polyethylene, and the convenience cans may also be wrapped in polyethylene to further reduce the possibility of radioactive contamination of the packaging. Nylon straps may be used for handling the nickel alloy cans. Masses of the convenience cans and packing materials are in addition to the fissile material mass.

Three 4.25-in.-diam × 10.0-in.-tall or six 4.25-in.-diam × 4.88-in.-tall convenience cans, separated by can pads, may be placed inside the 31-in.-tall cavity of the ES-3100 containment vessel (Fig. 1.4). The convenience cans may have press-fit or crimp-seal lids. The size of solid content placed inside a convenience can is physically limited by both the can opening and the usable height of the convenience can. Other can arrangements fit inside the containment vessel, such as three 4.25-in.-diam × 8.75-in.-tall convenience cans or five 4.25-in.-diam × 4.88-in.-tall convenience cans. Both of these can arrangements include can pads and 277-4 canned spacers. Nickel alloy cans to be used exclusively for HEU oxide content are ~3-in. diam × 4.75-in. tall. Three Teflon bottles (4.69-in. diam × 9.4-in. tall) or three polyethylene bottles (4.94-in. diam × 8.76-in. tall) fit inside the containment vessel; however, 277-4 canned spacers are not used with these configurations.

A modified convenience can may be used to package the TRIGA and research reactor fuel element and fuel components that do not fit inside these containers. A 17.5 in. or 30 in.-tall convenience can is constructed from two 4.25-in.-diam × 8.75-in.-tall or three 10-in. cans brazed together. The research reactor fuel elements and fuel components that cannot be packaged in these convenience cans due to their overall dimensions will be bundled together and protected on each end with an open-ended convenience can having an outer diameter ≤ 5 in.

The can pad and 277-4 canned spacer have overall dimensions of 4.25-in. diam × 1.82-in. height (Drawing M2E801580A043, Appendix 1.3.7). A stainless-steel spacer can with a lid has a usable cavity with dimensions of 4.13-in. diam × 1.37-in. height, which nominally allows for ~510 g of neutron poison material. If closed convenience cans with an outer diameter >4.25 in. are used, at least 55 in.^{3} of free or void volume must exist inside the containment vessel to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC.

6.2.3 Packing Materials

Polyethylene bags may be used for contamination control to hold the HEU material that is packed into a convenience can. Realistically, the number of polyethylene bags used to bag content and wrap a convenience can would be six bags at most. Given that each bag weighs ~28 g, this results in a maximum of ~510 g of polyethylene per ES-3100 package. Possible additional sources of hydrogenous material inside the containment vessel include can pads and vinyl tape.

Polyethylene bottles (~85 g) may be used to pack HEU oxide; however, polyethylene bags are not used for packing HEU oxide. While polyethylene bags may be used to bag the 85 g polyethylene bottles, the amount of hydrogenous packing material inside the containment vessel is limited to an equivalent 500 g polyethylene. Non-metallic containers such as polyethylene or Teflon (~303 g) may be used to pack UNX crystals. Likewise, polyethylene bags are not used for packing the UNX crystals and the amount of hydrogenous packing material inside the containment vessel is limited to an equivalent 500 g polyethylene.

Normally, the H/X ratio inside the containment vessel is specified as an administrative control used to restrict both the amount of hydrogenous packing material normally used inside the containment vessel and other sources of moisture present in the fissile content. The total amount of hydrogen inside the containment vessel is used in the determination of package H/X ratio (i.e., the ratio of the number

of hydrogen atoms "H" to the number of fissile atoms "X," where the hydrogen atoms are those of the content, including absorbed moisture and of the packing material both inside and outside of the convenience cans). However, containment vessel flooding is assumed in calculations performed for the derivation of fissile material loading limits. This simulated condition produces fissile material content that is more reactive than actual.

The 7.1–10.1 kg quantity of evaluation water required in both the NCT and HAC criticality calculations bounds reasonable amounts of hydrogenous packing material present inside the ES-3100 containment vessel for solid HEU metal content (cylinders, bars, buttons, slugs, unirradiated TRIGA fuel, and research-related fuel components fissile material). The hydrogenous packing material encompasses the solid fissile material but is not interspersed within it.

However, the 7.1–10.1 kg quantity of evaluation water does not necessarily bound reasonable amounts of hydrogenous packing material present inside the containment vessel when the fissile material is in particulate form (primarily HEU oxides and UNX crystals) or must be evaluated in particulate form (broken metal). An administrative criticality control is used to restrict the amount of hydrogenous packing material normally present inside the containment vessel (see Item 7 in Sect. 6.2.4).

6.2.4 Package Content Loading Restrictions

Loading restrictions based upon the results of the criticality safety calculations presented in Sects. 6.4 and 6.5 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, aluminum, or nickel alloy convenience cans, polyethylene or Teflon bottles, or polyethylene bagging. Enriched uranium oxide in the form of UO_2-Mg will be shipped in glass bottles inside a metal convenience can. Any closure is allowed on the convenience can.

2. The content shall not exceed the "per package" fissile material mass loading limits specified in Tables 6.2a and 6.2b, and 277-4 canned spacers shall be used as indicated for criticality control. Research reactor related contents of uranium metal or U-Al alloy may be packaged for air transport under limits specified in Table 6.2b for HEU broken metal, solid HEU metal of unspecified geometric shape and characterized as broken metal, turnings, fines, or powder. Research reactor fuel elements and components may be packaged for air transport under limits specified in Table 6.2b for unirradiated TRIGA fuel elements. Per package limits for these items are a maximum of 921-g ^{235}U for content at enrichments not exceeding 20 wt % and a maximum of 408-g ^{235}U for content enrichments greater than 20 wt %.

3. Where 277-4 canned spacers are required, not greater than one-third of the permissible package content for that category indicated in Tables 6.2a or 6.2b shall be loaded in any vacancy between or adjacent to canned spacers inside the containment vessel. The content mass loading may be further restricted based on structural, mechanical, and practical considerations (see Sects. 1 and 2).

4. As shown in Fig. 1.4, the ES-3100 package may carry up to six loaded convenience cans. In situations where the plan for loading the containment vessel calls for the use of empty convenience cans to fill the containment vessel, empty cans and/or stainless-steel scrubbers may be used to fill the void space in 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. These empty cans may be placed above or below the loaded cans.

5. The presence of uranium isotopes is limited on a weight-percent basis as follows: $^{232}U \leq 40$ ppb U, $^{233}U \leq 0.6$ wt % U, $^{234}U \leq 2.0$ wt % U, $^{235}U \leq 100.0$ wt % U, and $^{236}U \leq 40.0$ wt % U.

6. With the exception of slug content, unirradiated TRIGA reactor fuel element content, and research reactor related content, solid HEU metal or alloy content of specified geometric shape shall be one item per loaded convenience can. HEU metal or alloy content not covered by the specified geometric shapes (cylinder, bar, button, billet, slug, or unirradiated TRIGA fuel element contents) will be in either the "HEU broken metal or solid HEU metal of unspecified geometric shape and characterized as broken metal" category or in the "HEU metal turnings, fines, or powder" category, and so limited (Table 6.2a). Broken metal is distinguished from turnings, fines, or powder as having a surface-area-to-mass ratio of not greater than 1 cm^2/g or must not pass through a 3/8-in. mesh sieve (or equivalent size-grading method).

7. The package content is defined as the HEU fissile material, bottles, the convenience cans, the can spacers, and the associated packing materials (plastic bags, pads, tape, etc.) inside the ES-3100 containment vessel. The amount of hydrogenous packing material inside the containment vessel shall not exceed an equivalent mass of 500 g polyethylene. The only hydrogenous packing materials that can be used in the containment vessel when shipping HEU broken metal content are those that have a hydrogen density less than or equal to water.

8. The mass of unidentified constituents of an HEU fissile material to be loaded into the ES-3100 will be counted against the fissile mass loading limit. The HEU fissile material will not contain unevaluated moderating materials.

9. Allowable HEU oxide bulk densities are 0.5–6.54 g/cm^3 for ground transport and 2.0–6.54 g/cm^3 for air transport.

10. For air transport, the total free water permitted in the ES-3100 packaging is limited to 12 lb (5,443.1 g).

6.3 GENERAL CONSIDERATIONS

The ES-3100 packaging configuration is shown on Drawing M2E801580A031 (Appendix 1.3.7). KENO V.a modeling of this configuration with the maximum allowable contents (Sect. 6.2) for a variety of array sizes and array conditions yields bounding calculations that determine the package's CSI (Tables 6.1a–6.1f). Can spacers are used as indicated in Table 6.2a and 6.2b for the purpose of reducing neutronic interaction between the contents of the package, aiding in maintaining the $k_{eff} + 2\sigma$ below the USL for the ES-3100 package. Key input listings are provided in Appendix 6.9.7.

The HEU content of a package is in one of the following forms: solid metal or alloy of a specified geometric shape; broken metal; turnings, fines, or powder; solid metal or alloy of unspecified geometric shape and characterized as broken metal; uranium or skull oxide; UNX crystals; or unirradiated TRIGA reactor fuel elements. The bounding types of HEU content evaluated in this criticality analysis are: 4.25-in.- and 3.24-in.-diam cylinders; 2.29-in.-square bars; 1.5-in.-diam × 2-in.-tall slugs; cubes ranging from 0.25 to 1 in. on a side; broken metal pieces of unspecified geometric shapes; product and skull oxide; Uranyl nitrate hexahydrate (UNH) crystals; and unirradiated TRIGA reactor fuel elements. UNH has a chemical formula of $UO_2(NO_3)_2 \cdot 6H_2O$. This most reactive form is used as the bounding composition for UNX crystals in the criticality evaluation. TRIGA fuel elements are 1.44-in.-diam × 15-in.-tall cylinders of $UZrH_x$ containing <310-g ^{235}U. Fuel elements are sectioned into three equal length pieces. Calculations demonstrate that these contents are bounded by 3.24-in.-diam HEU metal cylinders. Evaluation of the 3.93-in.-diam × 9.5-in.-tall U-Al cylinders is covered under the evaluation of the 4.25-in.-diam HEU metal cylinders. The evaluation of the U-Mo content is covered under the assessment of HEU contents at 95 wt % enrichment.

HEU metal shapes are distributed in an optimum arrangement in the flooded containment vessel. For the single package and the array calculations, the HEU broken metal is modeled as a homogeneous mixture of uranium metal and water filling the interior of a flooded containment vessel. This representation bounds the heterogeneous configuration of metal pieces interspersed with hydrogenous packing material inside of wrapped convenience cans (Appendix 6.9.3., Sect. 6.9.3.1). Water soluble UNH crystalline content is modeled as a homogeneous mixture of UN and water filling the interior of the containment vessel.

No credit is taken for the fissile material spacing, neutron absorption, or free volume reduction provided by the presence of can pads, spacer can steel, and convenience cans inside the containment vessel. Water is substituted for polyethylene bagging which may be in use as packing material for both the content placed inside the convenience can and the cans themselves. Pads of steel turnings rolled up into a disk-like shape may also be present in the ES-3100 package for use as cushioning and for reducing the free volume inside the convenience cans. This steel packing material acts as a neutron absorber and is excluded from the calculation model.

Criticality calculations are performed for the containment vessel under full water reflection whereby the water content inside the containment vessel is varied from dry to fully flooded conditions. These calculations demonstrate that the fully flooded condition is most reactive. The containment vessel is flooded in the single-unit calculation model and the infinite and finite array calculation models for both the NCT and HAC evaluations.

The KENO V.a models discussed in the following sections are the single-unit calculation model (Sect. 6.3.1.1), the infinite and finite array calculation models (Sect. 6.3.1.2), the HAC calculation models (Sect. 6.3.1.3), and the air transport models (Sect. 6.3.1.4). The single-unit calculation model is evaluated with a vacuum boundary condition and with full water reflection. The finite array calculation model is evaluated in arrays consisting of packages stacked in 13×13×6, 9×9×4, 7×7×3, 5×5×2, ETP 27×3 and ETP 16×3 arrangements with full water reflection at the array boundary. The ETP arrangements are used specifically for defining smaller array configurations with a high CSI value.

The geometry of the ES-3100 package is depicted in Drawing M2E801580A001 (Appendix 1.3.7). Calculation models of this geometry for evaluating NCT and HAC must be constructed for the single-unit, infinite array and finite arrays within the constraints and capabilities of KENO V.a. As shown in the drawing, the ES-3100 geometry is complex. Given KENO V.a's constraints and capabilities, two methods may be used to evaluate these complex geometries: simplify the geometries with conservative approximations or construct accurate geometries from simple components. Both methods yield valid results; however, the latter method is chosen for this analysis in order to maximize accuracy and to eliminate unnecessary conservatism.

6.3.1 Model Configuration

A detailed ES-3100 geometry model is accurately constructed using many simple geometric shapes. The selection of these components is governed by two of KENO V.a's geometry constraints: geometry regions must be composed of uniform and homogeneous materials and exterior regions must completely enclose interior regions. It is apparent from Drawing M2E801580A001 (Appendix 1.3.7) that these constraints could not be simultaneously applied to the entire ES-3100 package. However, these constraints could be applied to vertical segments of the package. Segments (i.e., simple components) are defined by starting at the bottom of the package and defining geometry regions radially outward until the drum surface is reached. A vertical segment is extended upward to the point where the KENO V.a constraints are violated. This vertical position is the termination point of a segment (i.e., the interface with the adjacent segment above it). The vertical segments are constructed accordingly, ignoring the minor variations in the ES-3100 geometry (i.e., radii of curvature, beveled edges, nuts and bolts). The KENO V.a geometry model for the ES-3100 is then assembled from the vertical segments. The resulting calculation model geometry

includes the HEU content, 277-4 canned spacers, the containment vessel, the stainless-steel liner, the inner-liner cavity filled with 277-4, the outer-liner cavity filled with Kaolite, the Kaolite top plug and steel shell, the silicon rubber spacers, and the stainless-steel drum.

6.3.1.1 Single-unit packaging calculation model

The single-unit packaging calculation model is comprised of the geometry model, material compositions, and boundary conditions. Figures 6.1–6.5 depict section views of the geometry model used to evaluate a single ES-3100 package. Excluding minor variations in the ES-3100 geometry (i.e., radii of curvature, beveled edges, nuts and bolts), the single-unit packaging calculation model is an accurate representation of the ES-3100 geometry.

Figure 6.1 depicts a vertical section view of an ES-3100 package with the content of three loaded convenience cans and 277-4 can spacers inside the containment vessel. The fissile material contents shown are HEU cylinders, but convenience cans are not modeled. As illustrated in Fig. 6.1, credit is not taken for fissile material spacing provided by convenience cans inside the containment vessel. Appendix 6.9.1 provides wire-frame schematic and isometric diagrams depicting other fissile material contents considered in this criticality calculation.

Figures 6.2–6.5 depict vertical section views at various elevations in the package. The dimensions and the material specifications of any element of the ES-3100 single-unit packaging model may be obtained directly from the KENO V.a input listings in Appendix 6.9.7. The vertical segments (KENO V.a geometry unit numbers) are denoted in parenthesis to the right of the dimensions. The dimensions are given in units of centimeters. Material specification data for the single-unit packaging calculation model are provided in Sect. 6.3.2.

The single-unit calculation model is evaluated as both a bare system (i.e., with a vacuum boundary condition) and as a reflected system with 30.48 cm (1 ft) of water surrounding the package for effectively infinite water reflection.

10 CFR 71.55(b) requires evaluation of water leakage into the containment system disregarding any performance capability demonstrated by physical testing per 10 CFR 71.71 and 71.73. In conjunction, 10 CFR 71.55(b)(3) also requires evaluation of the efficiency of the packaging as an external reflector to the containment vessel. The test case is defined as a flooded package. All regions within the water-reflected, single-unit packaging calculation model are flooded with water. The reference case is defined as a water-reflected flooded containment vessel. This calculation model is a modification of the water-reflected, single-unit packaging calculation model where all regions of the packaging external to the containment vessel are replaced with full density water.

6.3.1.2 Infinite and finite array packaging calculation models

Array packaging calculation models like the single-unit packaging calculation model are comprised of geometry, material compositions, and boundary conditions. Figures 6.6–6.10 depict section views of the geometry model used to evaluate an array of ES-3100 packages. The array geometry model incorporates a 7.0% reduction in the inside diameter of the ES-3100 drum. This reduction of the drum's inside diameter produces an array density equivalent to drums in a tightly packed, triangular pitch configuration (O'Dell). Since all array calculations in this evaluation use a square pitch package configuration, using the 7.0% reduction in diameter of uniform-shaped packages avoids the use of a nonconservative lattice arrangement in the array analysis.

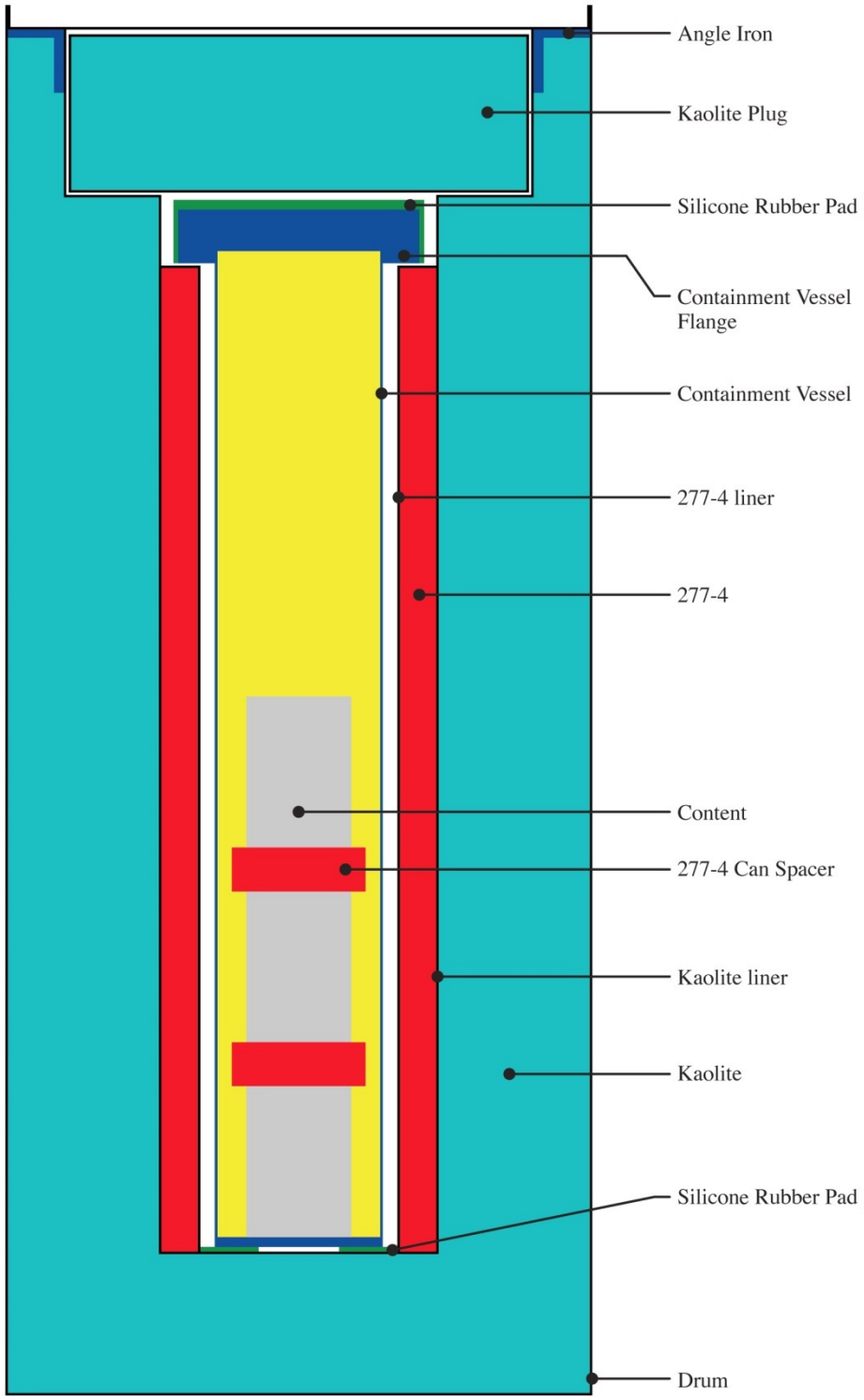
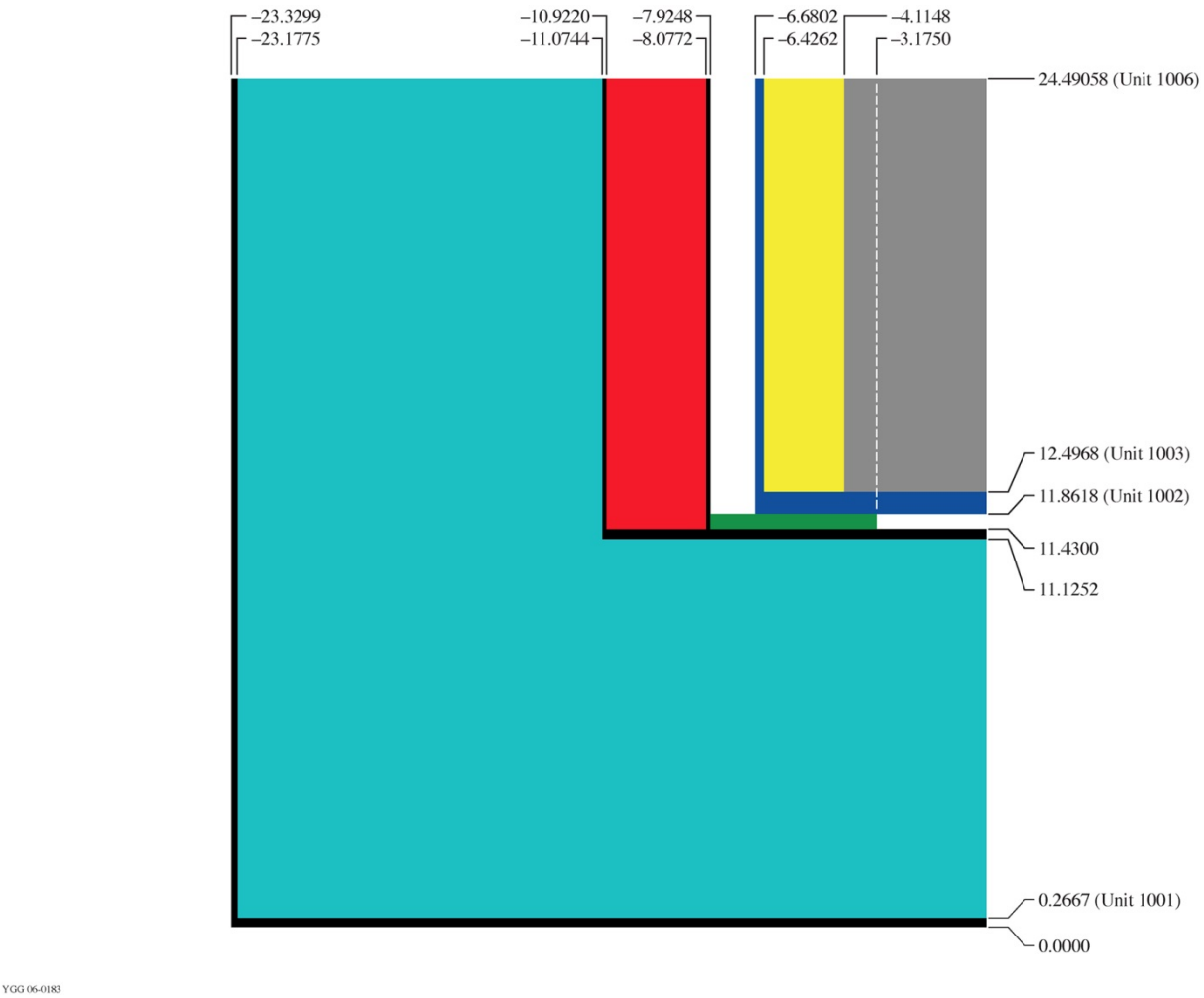
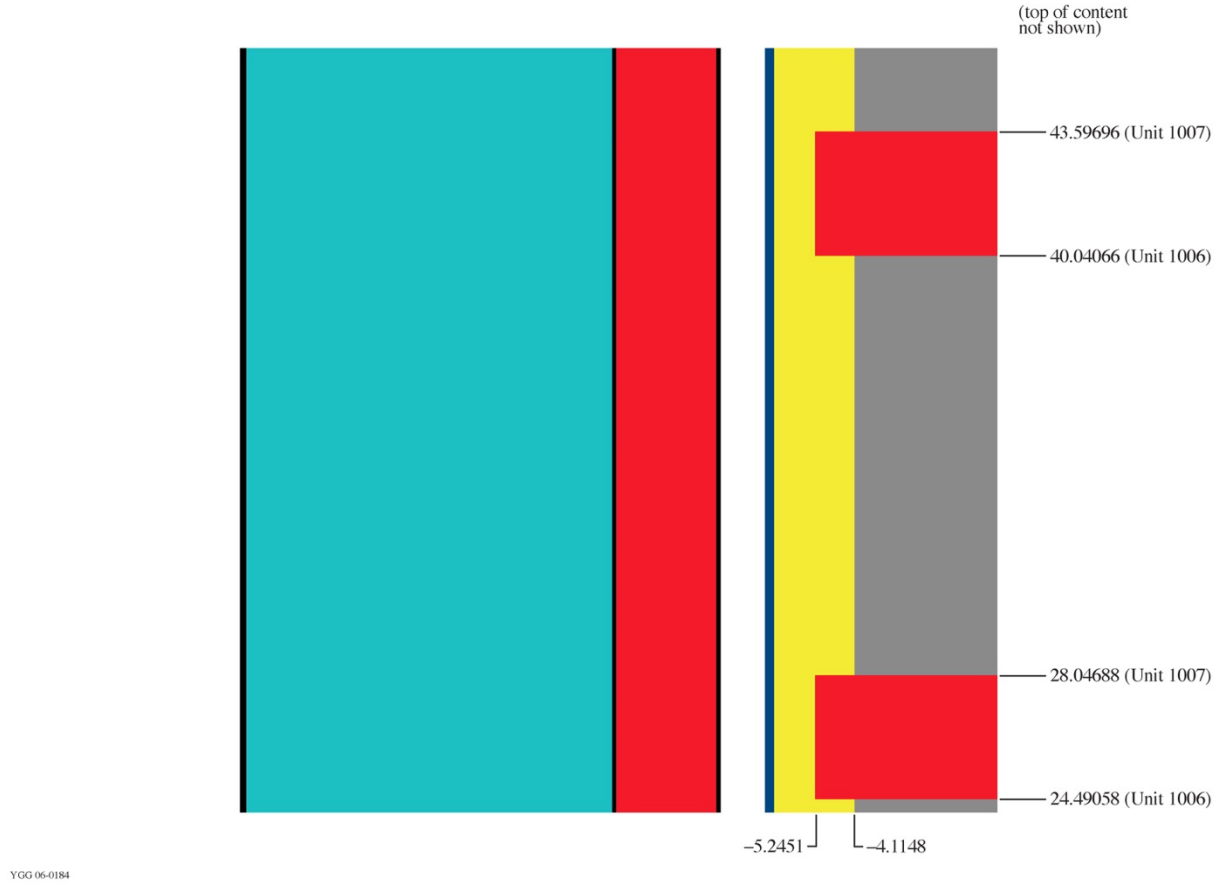


Fig. 6.1. R/Z section view of ES-3100 single-unit packaging model.



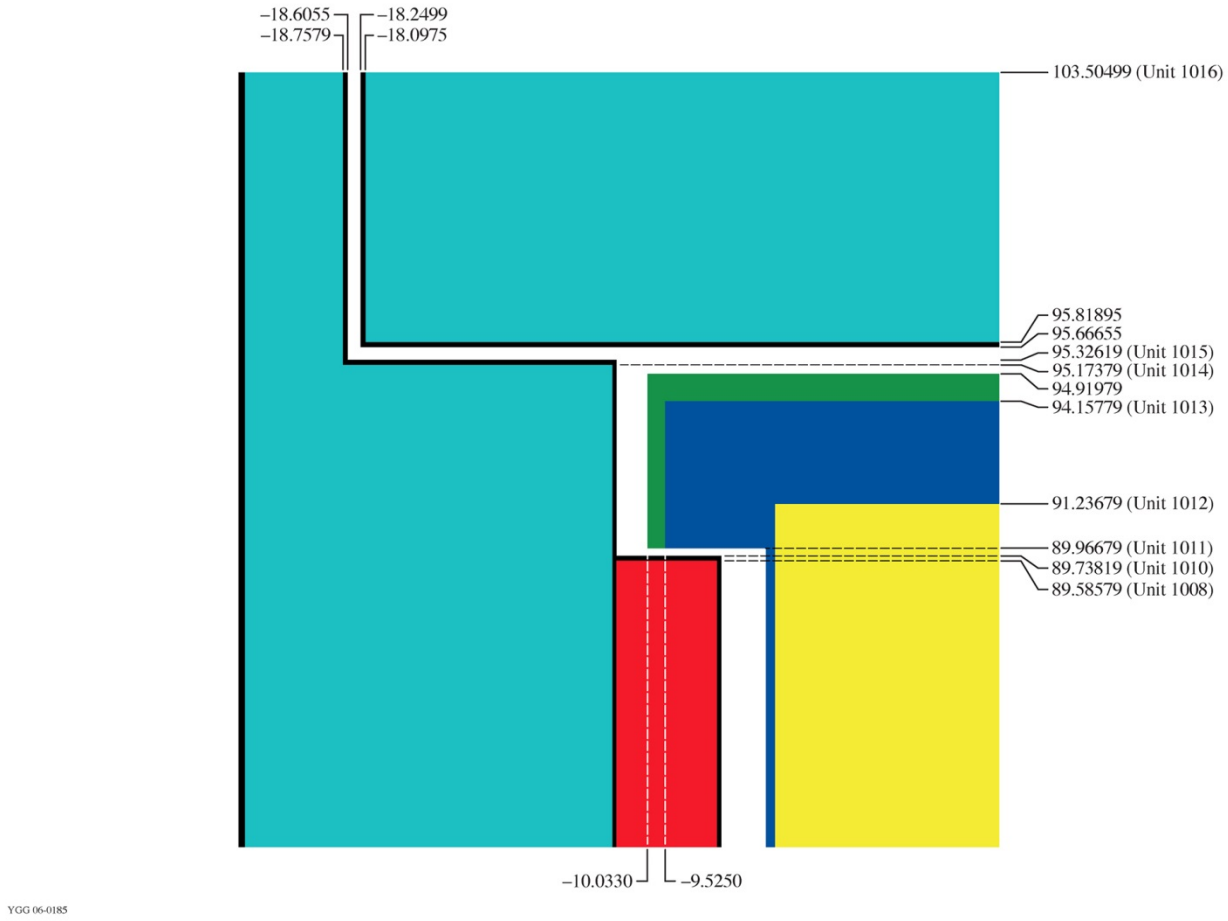
Note: Dimensions are in centimeters.

Fig. 6.2. R/Z section view at bottom of ES-3100 single-unit packaging showing KENO V.a geometry units 1001–1003, and 1006 (partial).



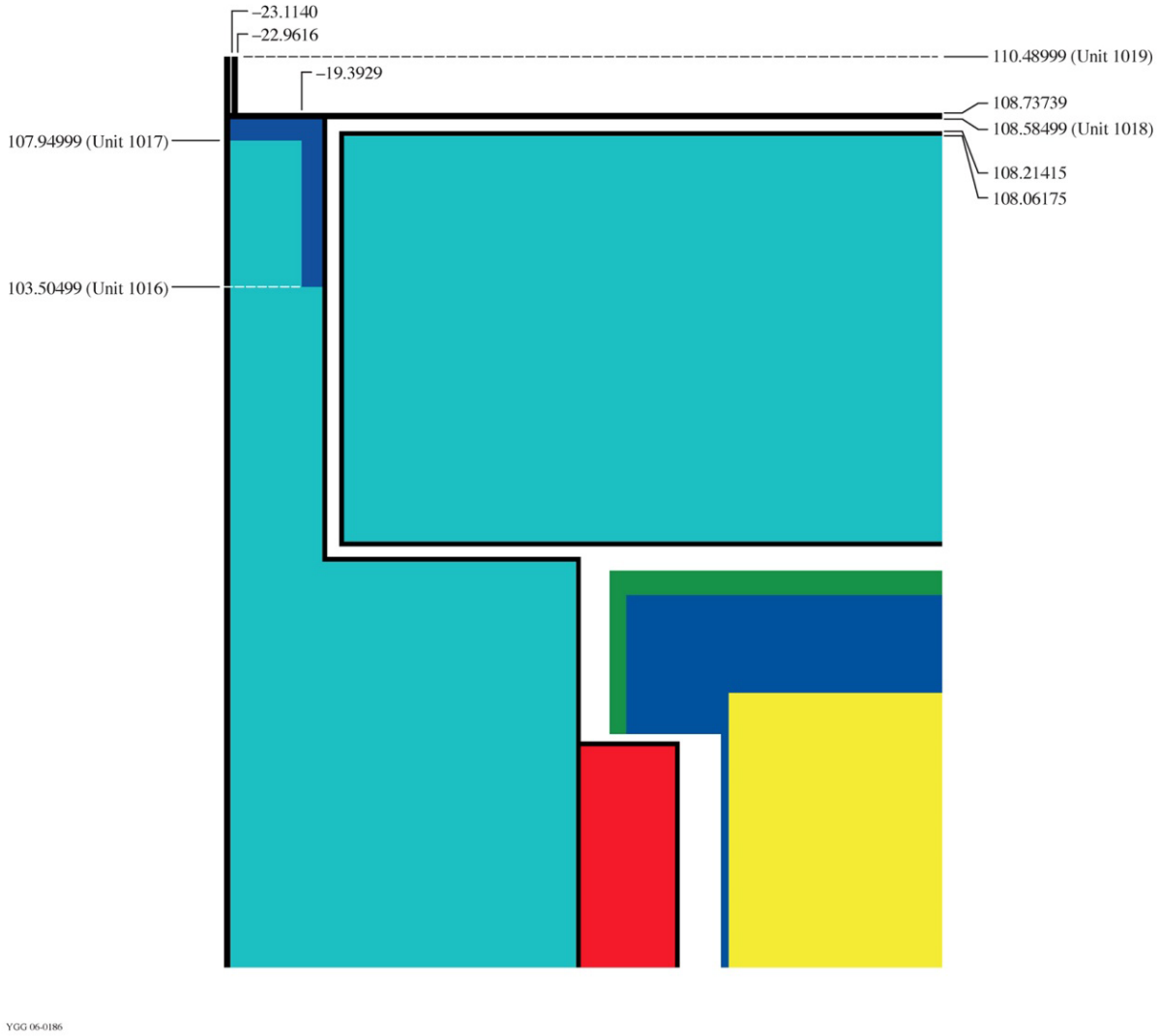
Note: Dimensions are in centimeters.

Fig. 6.3. R/Z section view at center of the ES-3100 single-unit packaging showing KENO V.a geometry units 1006 (partial), 1007, and 1008 (partial).



Note: Dimensions are in centimeters.

Fig. 6.4. R/Z section view of near top of the ES-3100 single-unit packaging showing KENO V.a geometry units 1008 (partial) and 1010–1016.



Note: Dimensions are in centimeters.

Fig. 6.5. R/Z section view at the top of the ES-3100 single-unit packaging showing KENO V.a geometry units 1016–1019.

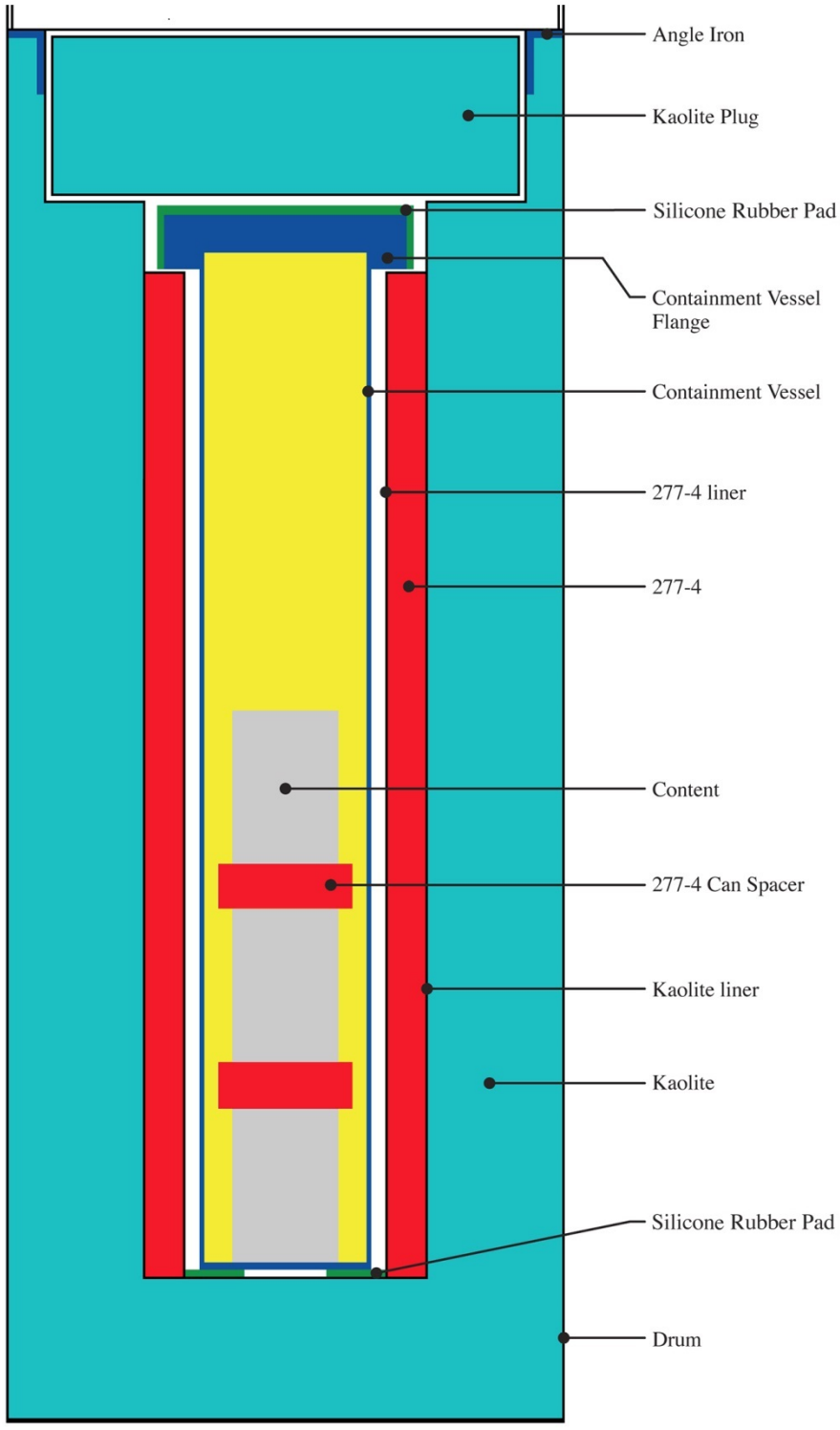
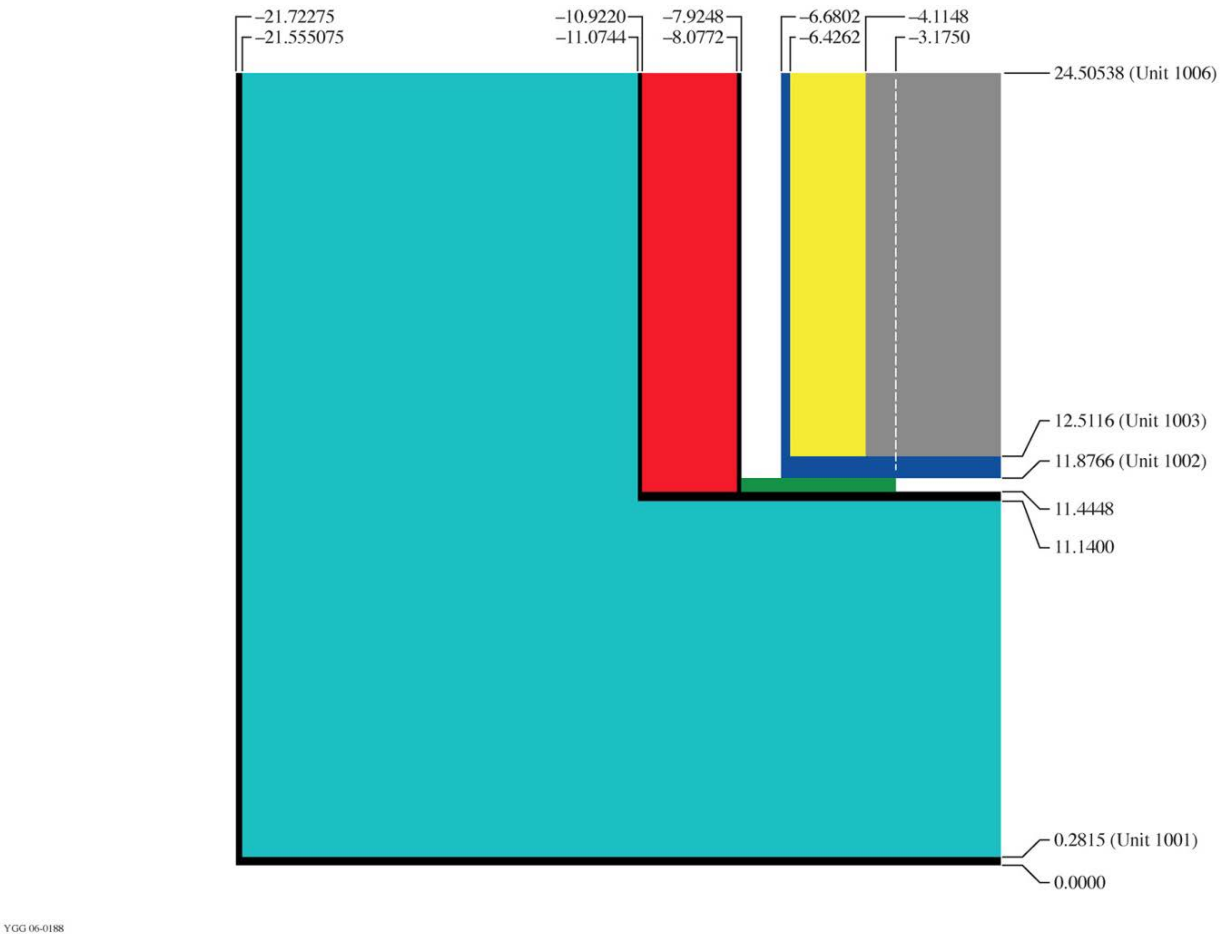
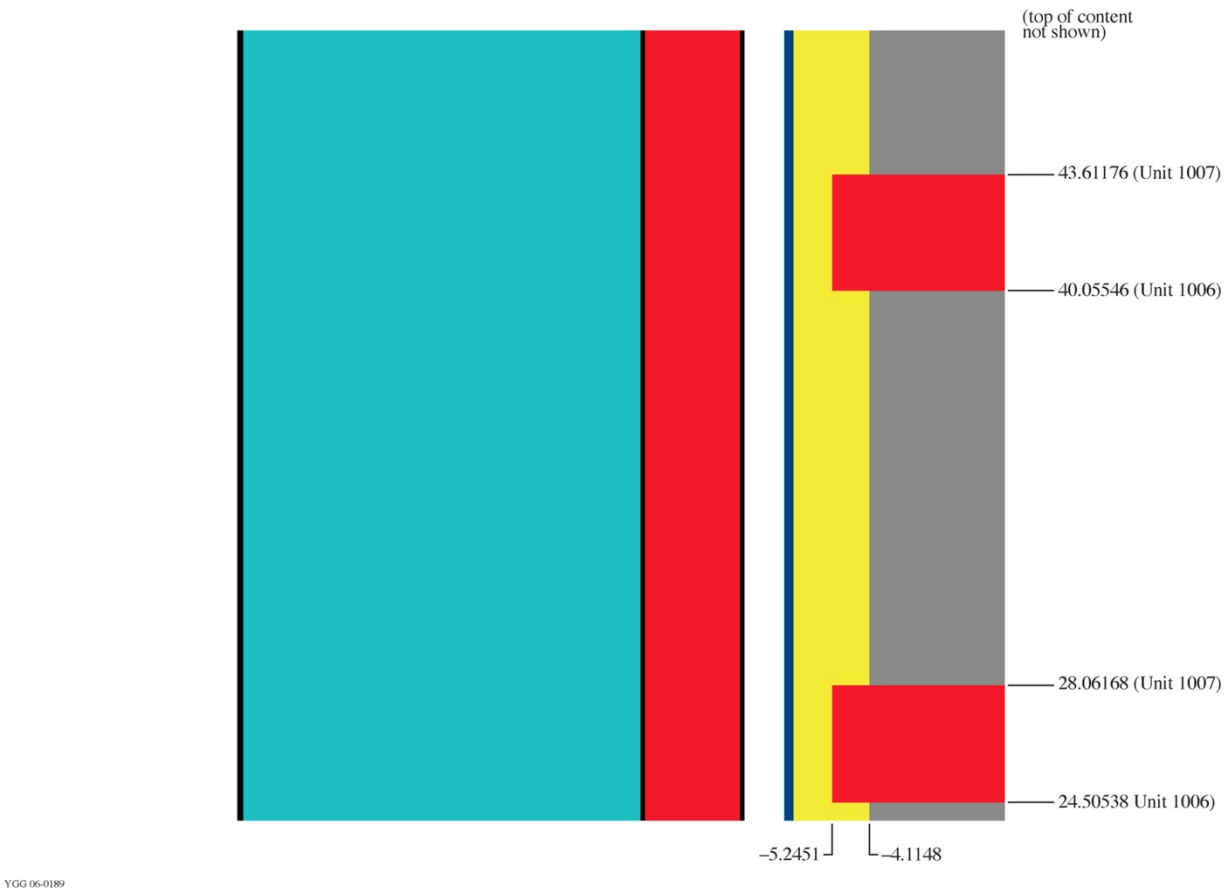


Fig. 6.6. R/Z section view of ES-3100 array packaging model with a 7% reduction in the drum's inner diameter.



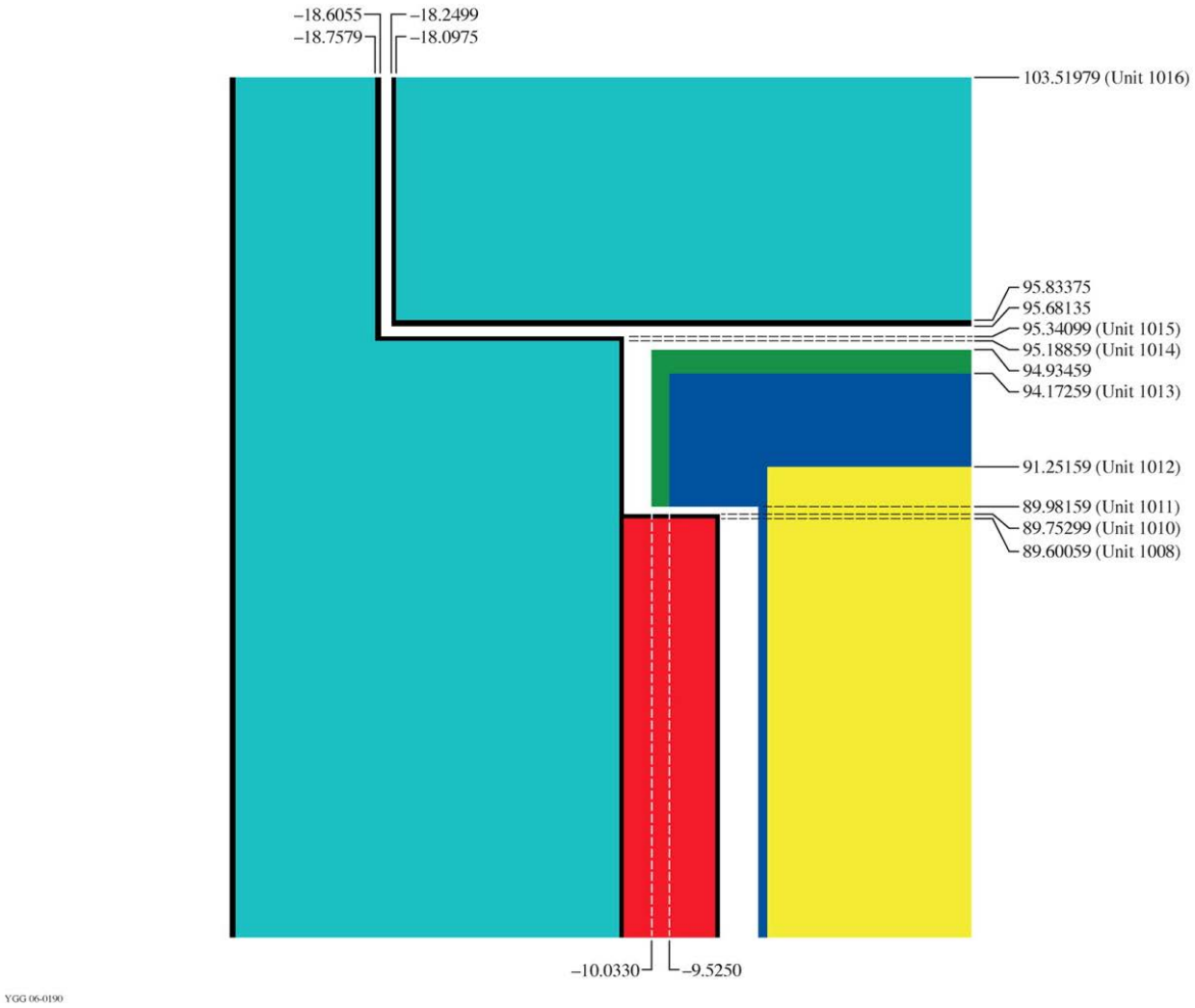
Note: Dimensions are in centimeters.

Fig. 6.7. R/Z section view at the bottom of the ES-3100 array packaging showing KENO V.a geometry units 1001–1003, and 1006 (partial).



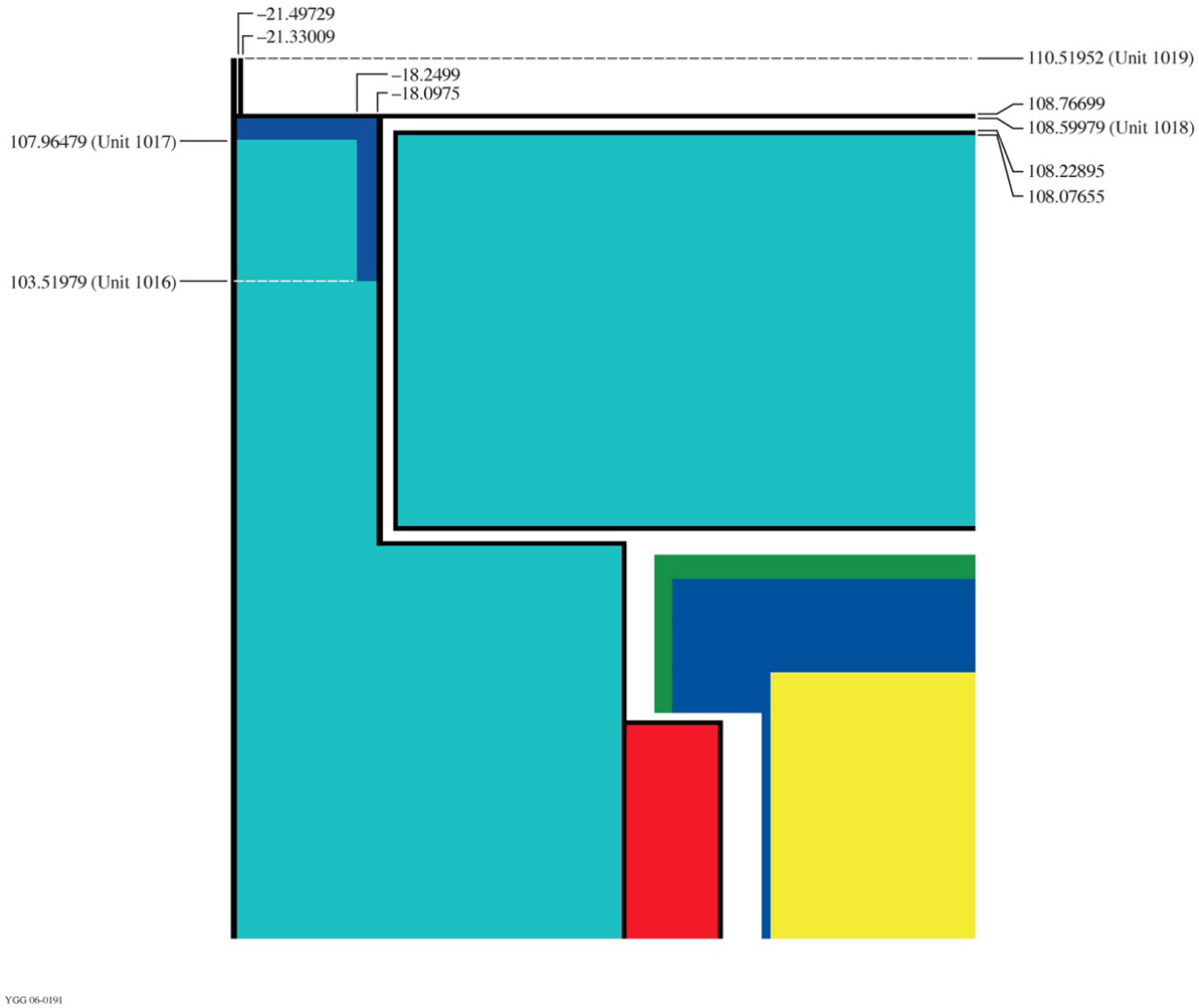
Note: Dimensions are in centimeters.

Fig. 6.8. R/Z section view at the center of the ES-3100 array packaging showing KENO V.a geometry units 1006 (partial), 1007, and 1008 (partial).



Note: Dimensions are in centimeters.

Fig. 6.9. R/Z section view of near top of the ES-3100 array packaging showing KENO V.a geometry units 1008 (partial) and 1010–1016.



Note: Dimensions are in centimeters.

Fig. 6.10. R/Z section view at the top of the ES-3100 array packaging showing KENO V.a geometry units 1016–1019.

As seen in Drawings M2E801580A002 and M2E801580A003 (Appendix 1.3.7), a 7.0% reduction of the inside diameter of the ES-3100 drum affects the masses of the drum, the modified 2 × 2 × ¼ in. angle (angle iron), and the Kaolite refractory material. Also, a 7.0% reduction in diameter affects the mass of interstitial water between the ES-3100 packages of a tightly packed array. To maintain the correct mass of these materials in the NCT array packaging calculation model, the drum's outside dimensions, the density of the steel in the angle iron, the density of Kaolite, and the density of interstitial water are modified. Excluding modifications required to simulate a triangular pitch and minor variations in the ES-3100 geometry (i.e., radii of curvature, beveled edges, nuts and bolts), the array geometry model is an accurate model of the ES-3100 geometry.

In the NCT array packaging calculation model, the drum outside diameter is 43.444550 cm (17.104154 in.) [21.722275-cm radius used as the input value], and the drum inside diameter is 43.11015 cm (16.972500 in.) [21.555075-cm radius]. This inside diameter corresponds to 93% of the inside diameter of the ES-3100 drum. The thicknesses of the drum wall, the drum bottom flat cover, and the drum lid are uniformly increased in order to maintain the region volume and to conserve drum mass while the stainless steel density and volume fraction remain unchanged in the KENO V.a input specification. However, the region volume for the drum steel in the NCT array packaging calculation model is not equal to the volume in the single-unit packaging calculation model due to internal round-off in KENO V.a. Therefore, the volume fraction is changed from 1.0 to 0.99981 in the NCT array packaging calculation model for normalization of the drum mass.

The angle iron outside diameter is identical to the drum inside diameter. To maintain mass, the angle iron steel, the liner outer-cavity Kaolite, and interstitial water densities are modified by factors of 1.25705, 1.22252, and 1.16235, respectively. Excluding the modifications to drum and angle iron dimensions, the dimensions of any element of the ES-3100 array geometry model may be obtained directly from Appendix 6.9.7. Material specification data from the array calculation models are provided in Sect. 6.3.2.

O'Dell and Schlesser equate modeling triangular arrays with square pitch arrays, provided that the outer dimension of the array is reduced by a factor of 0.9306 and that the mass of materials is maintained. The actual reduction factors (ratio of the reduced radii to the single unit radii) for the Kaolite of the body weldment and for the angle iron is slightly <0.9306. Given that the array packages are closer than required by O'Dell and Schlesser, the array models are conservative with respect to their reduced radii.

The finite array calculation model is evaluated with arrays of packages stacked in 13×13×6, 9×9×4, 7×7×3, and 5×5×2 arrangements where the arrays are surrounded with 30 cm (~1 ft) of water as a boundary condition representative of full water reflection. These arrays are nearly cubic in shape for optimum reactivity of the array, thus eliminating the need for placing limitations on array configurations in terms of stack height, width, and depth.

The KENO V.a users manual (NUREG/CR-0200, Rev. 6) describes the input statements for an ETP model of cylinders in a close-pack array. This technique is adapted for modeling the ES-3100 in small compact array configurations. The ETP geometry model is much more complicated than the reduced-diameter approximation model described previously, but it yields smaller package configurations with correspondingly higher CSI values than the 7×7×3 and 5×5×2 package arrangements. Use of the ETP geometry specification allows for constructing compact package arrangements of 27×3 (27 packages in the horizontal plane stacked 3 packages high) and 16×3 packages.

6.3.1.3 Calculation models for damaged packages

Sections 2, 3, and 4 of this report address the overall integrity of the Model ES-3100 package in tests for NCT and HAC (ORNL/NTRC-013). From a dimensional viewpoint, the only physical changes

of interest for criticality safety occurred as a result of the 9-m (30-ft) drop test, the crush test, and the 1-m (40-in.) puncture test. There was significant crushing of the drum rim at the point of impact from the 9-m (30-ft) drop test and an indentation on the drum side from the 1-m (40-in.) puncture test. Even though significant crushing of the drum mid-section and bottom occurs, the effective center-to-center spacing of the contents actually increases under HAC. Selective rearrangement of alternating packages would be required to achieve a more compact array; however, this event is not credible.

The deformation of the outer diameters of the drum as predicted by finite element analysis is presented in Table 6.3. These diameters measured along the 90–270° and 0–180° axes are specified at five node points located along the vertical axis of an upright package. These node points are designated in a downward direction from the top of the drum as "UR," "MUR," "MR," "MLR," and "LR." Equivalent circular diameters for representing the deformed drum in the calculation models for the HAC study (Appendix 6.9.2) are based on the assumption that the drum cross section at each deformation point is ellipsoidal.

Table 6.3. Deformation of 18.37-in.-diam ES-3100 drum projected by finite element analysis Case "3100 RUN1HL Lower Bound Kaolite May 2004"

Deformation point	FEA node	Diameter at 90° (in.)	Diameter at 180° (in.)	Equivalent circular diameter (in.)
UR	098194	20.02	15.60	17.67
MUR	100238	20.74	15.07	17.68
MR	101589	20.74	14.18	17.15
MLR	103012	22.00	13.44	17.20
LR	105786	20.92	12.92	16.44

The package water content in the void spaces external to the containment vessel and the interstitial spaces between drums is varied in the calculation model while maintaining the Kaolite in the dry condition. At a low moisture content where neutronic interaction between packages of an array is greatest, there is no statistically significant difference in the calculated neutron multiplication factor for package models based on the "MR," "MLR," and "LR" node points. At high moisture content where a statistically significant difference in the calculated neutron multiplication factor occurs, the packages of an array are nearly isolated. The slight increase in k_{eff} at the smaller diameters is not numerically significant. A calculation model based on the "MLR" node point is used to represent HAC.

As concluded in Sect. 6.9.2.3, the criticality analysis of an array of HAC packages based on the "MLR" package model (diameter = 17.20 in.) in rectangular pitch bounds the analysis of damaged packages (diameter = 17.26 in.) in close-pack array configurations. Considering both the irregular shape of the deformed drums and the fact that overall (maximum) dimensions rather than a mean or minimum dimension for a damaged package would establish array spacing—this assumption is a reasonable one, and the model is conservative.

A reduced-diameter version of the "MLR" package model used for modeling a close-pack array configuration of HAC packages is not created. Instead, "MLR," the single-unit packaging model, is evaluated in a rectangular-pitch array configuration using appropriate boundary conditions. Consequently, the dimensions of the HAC array packaging calculation model do not differ from those of the HAC single-unit packaging calculation model. Therefore, the region volume of the drum and the atomic densities for the elemental constituents for the drum stainless steel are the same in both of the HAC calculation models.

The neutron poison, Kaolite refractory material, and stainless-steel components of the ES-3100 package were not significantly damaged during thermal testing. The principal material change of consequence that occurred during the thermal test was the loss of volatile material (Sect. 2.7.4). No loss of volatile material other than steam from the Kaolite was experienced during prototype testing of the Model ES-3100 package.

Physical damage is significant in terms of criticality safety when the amount of volatile hydrogenous material available for interstitial moderation is reduced. Conversely, the package could be saturated with water during water immersion conditions. Both possibilities affect only the amount of interstitial moderation. The representation of the changes to material composition from temperature extremes and water intrusion is addressed in Sect. 6.3.2.

In the case of broken metal content, the ETP geometry specification using the "MLR" package model (diameter = 17.20 in.) produces a 16×3 package configuration having a correspondingly higher CSI value than a 5×5×2 package arrangement. This allows for a greater fissile payload.

6.3.1.4 Calculation models for catastrophically-damaged packages (air-transport)

It is possible for accidents to be substantially more severe in the air transport mode than in the surface transport mode. Thus, the performance requirements for packages designed to be transported by air are more stringent. U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 7.9 states that the criticality evaluation should evaluate a single package under the expanded accident conditions specific in 10 CFR 71.55(f).

For a fissile material package designed to be transported by air, 10 CFR 71.55(f)(1) requires the criticality evaluation demonstrate that the package be subcritical, assuming reflection by 20 cm (7.9 in.) of water but no water inleakage, when subjected to the sequential application of the HAC free drop and crush tests of 10 CFR 71.73(c)(1 and 2) and the modified puncture and thermal tests of 10 CFR 71.55(f)(1)(iii and iv). 10 CFR 71.55(f)(2) requires the criticality evaluation demonstrate that the package be subcritical, assuming reflection by 20 cm (7.9 in.) of water but no water inleakage, when subjected to an impact on an unyielding surface of 90 m/s normal to the surface.

The "no water inleakage" condition of 10 CFR 71.55(f)(1) and (f)(2) signifies that the hydrogenous material present in the package during air transport is limited to the amount present in the package when it is loaded on the aircraft for transport. Potential sources of hydrogen moderator are the hydrogenous packing materials present inside the containment vessel, moisture inside the containment vessel well, and the moisture inside the Kaolite region of the package. The use of hydrogenous packing material is limited to 500 g. Both the use of a drum covering and administrative controls (Sects. 7 and 7.1.3.1) will ensure dryness of the containment vessel well. Thus, the focus is on the Kaolite region of the ES-3100 package. The 53,420 g of dry-baked Kaolite in the drum body weldment and drum top plug consists of 51,214.9 g of vermiculite-cement constituents and 2,204.7 g of bound water. For establishing the loading limits for air transport, the total **free** water in wet Kaolite was conservatively evaluated up to 15 lb (6,803.8 g).

Physical testing of Type-B fissile material packages transported by air was not conducted for the ES-3100. In lieu of testing, criticality calculations are performed using calculation models that conform to the basic requirements of 10 CFR 71.55(f) regarding both the absence of water inleakage and reflection of the package by 20 cm of water. In addition, the air-transport calculation models incorporate features exhibiting the worst-case assumptions made regarding the geometric arrangement of the packaging and package contents. No credit is taken for the geometric form of the package content. Spherical geometry is used to represent the ultimate configuration of the ES-3100 package which undergoes catastrophic destruction.

The criticality analysis for air transport does not credit the ES-3100 for maintaining the geometry configuration of the packaged content. Fissile material is configured spherical in shape for optimization of neutron multiplication. Also, the criticality analysis does not credit the ES-3100 packaging for structural integrity of the containment and the confinement. The reactivity "enhancing" materials of the packaging may be interspersed with the fissile material content. However, selective removal of the neutron-absorbing material of the package (i.e., Kaolite and stainless steel) accompanied by retention of the moderating constituents of the neutron-absorbing material (i.e., bound water in the Kaolite) is not a credible condition. Moreover, a calculation model where the fissile material is homogenized with moderating material is only an appropriate representation when the fissile material content being shipped consists of numerous solid pieces uranium ("broken metal"), metal turnings, fines, powder, oxide, or crystals. Homogenization of fissile material with moderating material is not performed with exclusive preference given to specific constituents of the moderating material.

A set of six calculation models are constructed in order to determine the worst case or most reactive configuration with consideration given to the efficiency of moderators, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes, and temperature effects. The fissile material component is dry in each case.

Model 1 (Fig. 6.11) represents the fissile material content configured into a spherical core with a 20.0-cm thick water reflector. All ES-3100 packaging material (Kaolite, stainless steel, 277-4 neutron poison, etc.) is excluded from Model 1. The fissile material content considered in the calculation model consists of a specific material form: solid HEU metal (7–10 kg ^{235}U); TRIGA fuel (10 kg $UZrH_x$ having 921-g ^{235}U); or broken HEU metal ($\leq$ 7 kg ^{235}U). The presence of hydrogenous packing material inside the containment vessel is also addressed in this calculation model. Five hundred grams of polyethylene is used to represent a maximum amount of hydrogenous packing material in the ES-3100. For 7 kg ^{235}U HEU homogenized with 500 g of polyethylene, the radius of the core is 6.0238 cm. The parametric variation of both the ^{235}U mass and the enrichment in Model 1 is used to establish a reference point for the evaluation neutron reflection and absorption effects on k_{eff} provided by the stainless steel and Kaolite packaging materials, addressed separately in Models 2 and 3. Case names for Model 1 are designated with the prefix "atdmr" for the HEU solid and broken metal contents. Case names for TRIGA fuel at 19.7 and 70% enrichments are designated with the prefixes "atdzr" and "atdzr70," respectively.

Model 2 (Fig. 6.12) represents a spherical core of Model 1 blanketed by a variable-thickness shell of stainless steel, and a 20.0 cm thick water reflector external to the shell. The shell at maximum thickness corresponds to the 66,133 g stainless steel of the containment vessel and the liner and drum assembly. For 7 kg ^{235}U HEU metal homogenized with 500 g of polyethylene, the radius of the core is 6.0238 cm while the outer radius of the stainless steel shell is 13.0198 cm. Case names for Model 2 are designated with the prefix "atdmsr" for HEU solid and broken metal content. Case names for TRIGA fuel are designated "atdzsr" and "atdzsr70."

Model 3 (Fig. 6.13) is configured the same as Model 2 with the exception that instead of stainless steel, the variable-thickness shell is composed of wet Kaolite. Maximum shell thickness corresponds to 60,223.4 g of wet Kaolite (53,419.6 g of dry-baked Kaolite plus 6,803.8 g of free water). For 7 kg ^{235}U HEU metal homogenized with 500 g of polyethylene, the radius of the core is 6.0238 cm while the outer radius of the shell is 31.0802 cm. Case names for Model 3 are designated with the prefix "atdm15kr" for HEU solid and broken metal content. Case names for TRIGA fuel are designated "atdz15kr" and "atdz15kr70." The parametric variation of shell thickness in Models 2 and 3 is performed for the purpose of evaluating the effect on k_{eff} of neutron reflection and absorption provided by each packaging material.

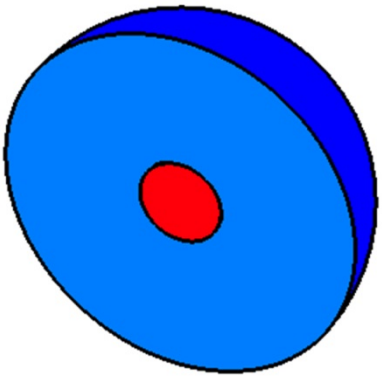


Fig. 6.11. Model 1.
7 kg ^{235}U (red) reflected by 20 cm of water (blue).

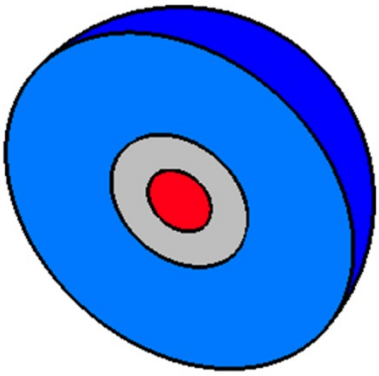


Fig. 6.12. Model 2.
7 kg ^{235}U (red) blanketed by a stainless-steel shell (gray), reflected by 20 cm of water (blue).

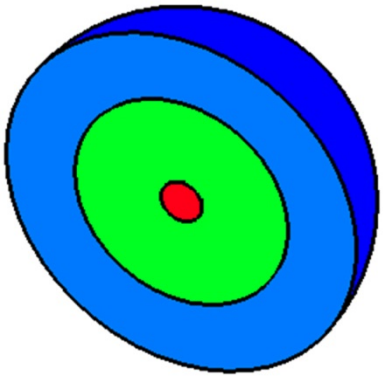


Fig. 6.13. Model 3.
7 kg ^{235}U (red) blanketed by a wet-Kaolite shell (green), reflected by 20 cm of water (blue).

Models 1–3 are applicable for establishing loading limits for air transport packages having a single piece or several pieces of solid HEU metal where the integrity of the content is demonstrated based on package tests or dynamic impact simulations per Type-C test criteria. Otherwise, the criticality evaluation of additional accident models is required for those situations where: (1) data is not available or is inadequate for discounting fragmentation of the fissile content in the air transport accident, or (2) the fissile material is in a physical form (crystals, oxide, or multiple pieces of solids) having the potential to blend with the other material of the package in the air transport accident.

Model 4 (Fig. 6.14) depicts a spherical core of broken metal homogenized with wet Kaolite and hydrogenous packing materials inside the containment vessel represented by 500 g of polyethylene. A 20-cm thick water reflector blankets the spherical core. All other ES-3100 packaging material (stainless steel, 277-4 neutron poison, etc.) is excluded from Model 4. For 7 kg of HEU (7 kg of ^{235}U), the radius of the homogenized core is 31.0803 cm with the amount of water in Kaolite ranging from 2,204.7 g in baked-dry Kaolite to 9,008.6 g in wet Kaolite. Model 4 also applies to TRIGA fuel content. Case names for Model 4 are designated with the prefix “athmp15kr” for the HEU solid and broken metal contents. Case names for TRIGA fuel at 19.7 and 70% enrichments are designated with the prefixes “athzp15kr” and “athzp15kr70,” respectively.

Model 5 (Fig. 6.15) is an extension of Model 3 applied to the case of TRIGA fuel and broken metal contents. Excess water from wet Kaolite is homogenized with the fissile material in the core. For 7 kg of HEU where 7 kg of ^{235}U is homogenized with 500 g of polyethylene and 0 g of free water from wet Kaolite, the radius of the spherical core is 6.0238 cm. The exterior Kaolite shell containing 9,008.5 g of water and the 51,214.9 g of vermiculite-cement constituents, has an outer radius of 31.0802 cm. At the extreme condition where the entire 6,803.8 g of water from wet Kaolite is homogenized with the core, the radius of the spherical core is 12.2667 cm. The exterior shell of dry Kaolite, containing 2204.72 g of bound water and 51,214.35 g of vermiculite cement constituents, has an outer radius of 31.6319 cm. Case names for Model 5 are designated with the prefix “athmpw15kr” for the HEU solid and broken metal contents. Case names for TRIGA fuel at 19.7 and 70% enrichments are designated with the prefixes “athzpw15kr” and “athzpw15kr70”, respectively.

Model 6 (Fig. 6.16) is configured similarly to Model 4 with the exception that only a partial amount of broken metal resides in the homogenized core. The remainder of the fissile material is modeled as a shell external to the spherical core and internal to the 20.0 cm thick water reflector. The amount of fissile material in the homogenized core is varied in 500 g increments from the full amount

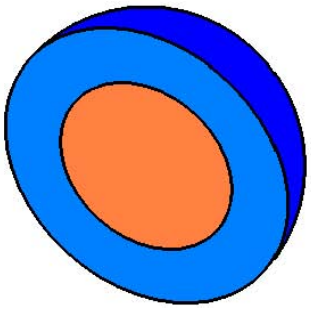


Fig. 6.14. Model 4. Homogenized sphere of 7 kg ^{235}U, polyethylene, and wet-Kaolite (orange), reflected by 20 cm of water (blue).

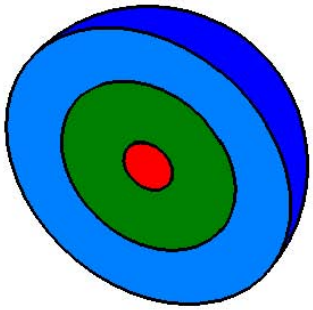


Fig. 6.15. Model 5. Homogenized sphere of 7 kg ^{235}U, polyethylene, and excess moisture from wet-Kaolite (red), blanketed by Kaolite shell (green), reflected by 20 cm of water (blue).

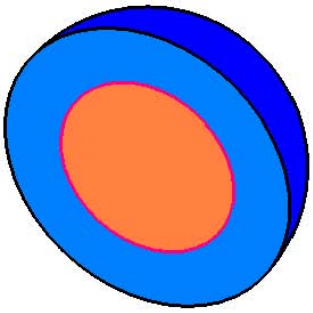


Fig. 6.16. Model 6. Homogenized sphere of 3.5 kg ^{235}U, polyethylene, and wet-Kaolite (orange); blanketed by shell of 3.5 kg ^{235}U, reflected by 20 cm of water (blue).

of Model 5 minus 500 g to a minimum amount of 500 g HEU. In the case of 7 kg of broken metal where 3.5 kg of ^{235}U is homogenized with 500 g of polyethylene and wet Kaolite, the radius of the core is 31.0649 cm while the outer radius of the exterior 3.5 kg shell of ^{235}U is 31.0804 cm. The same dimensions apply in the case of 7.0 kg of broken metal where 3.5 kg of ^{235}U is homogenized with 500 g of polyethylene and dry Kaolite. In the case where 0.5 kg of ^{235}U is homogenized with 500 g of polyethylene and wet Kaolite, the radius of core is 31.0518 cm while the outer radius of the exterior 6.5 kg shell of ^{235}U is 31.0804 cm. In the case where 6.5 kg of ^{235}U is homogenized with 500 g of polyethylene and wet Kaolite, the radius of core is 31.0781 cm while the outer radius of the exterior 0.5 kg shell of ^{235}U is 31.0804 cm. Case names for Model 6 are designated with the prefix "athmpw15kmr" for the HEU solid and broken metal contents. Case names for TRIGA fuel at 19.7 and 70% enrichments are designated with the prefixes "athzpw15kmr" and "athzpw15kmr70," respectively. Model 6 addresses potential redistribution of fissile material consisting of multiple pieces, specifically the broken metal content. The parametric variation of shell thickness in Model 6 is performed for the purpose of evaluating the effect on k_{eff} of moderation efficiency of the core and enhanced neutron multiplication of the shell.

Models 1–6 are applicable to air transport of the ES-3100 package given that the physical integrity of the fissile content following the air transport accident cannot be established, or that the physical form of fissile material content may be multiple solid pieces, turnings, fines, powder, or oxide.

6.3.2 Material Properties

Criticality calculation models include the definition of material compositions in the geometry model for both NCT and HAC. The materials which affect nuclear criticality safety and may be present in the ES-3100 package during these conditions are fissile material content (HEU metal, aluminum, molybdenum, and zirconium alloys of uranium, HEU product or skull oxide, UNX crystals, or $UZrH_x$), stainless steel, 277-4 neutron poison, Kaolite, silicon rubber, Teflon or polyethylene, and various amounts of water. Other materials are present in the package (e.g., tin-coated steel convenience cans, nylon bagging, rubber O-rings, and trace impurities). However, these other materials are not present in amounts that will significantly affect the reactivity of the package. Detailed discussion of the package content and packaging materials is contained in Appendix 6.9.3. Specific topics are summarized in this section as required to support the discussion of the criticality calculations presented in Sects. 6.4–6.6.

Cat 277-4 neutron poison is designed to maximize the hydrogen content necessary for thermalizing fast neutrons for capture in the boron constituent. Cat 277-4 is a formulation of the vendor's Cat 277-0, a boron carbide additive, and water. This mixture is cast and dried. "Loss on drying" (LOD) tests are used to measure the amount of water in the as manufactured 277-4 casting. The as-manufactured neutron poison material at 100 lb/ft^3 and 31.8% LOD has a hydrogen concentration of 3.56 wt % and a natural boron concentration of 4.359 wt % (DAC-PKG-801624-A001, Table 5).

The testing of 277-4 reveals that the material will dehydrate at elevated temperatures. Test specimens were dried at 250°F for 168 hours to reach the NCT state, and weight measurements were taken. These specimens were subsequently heated to 320°F for 4 hours to reach the HAC state, and weight measurements were again taken. The compositions of 277-4 at NCT and HAC states were derived by adjustment of the formulation specification for measured losses taking into account the statistical variations in the data. Conservation of mass for non-volatiles was observed in the derivation of material specifications based upon testing. Given that hydrogen presence is key to the effectiveness of the neutron poison, conservative material specifications were derived for minimum hydrogen content and minimum material density.

The NCT material specification for 277-4 at minimum density (95.39 lb/ft^3) and minimum hydrogen (25.15% LOD) is given in Table 11 of DAC-PKG-801624-A001. The average density of 277-4 in the ES-3100 package used for NCT calculations in KENO V.a is 1.52797 g/cm^3; the boron constituent is 7.31015E-2 g/cm^3; the residual base is 1.07070 g/cm^3; and the water component is 3.84169E-01 g/cm^3 (Appendix 6.9.3, Table 6.9.3.3-2). The HAC material specification at minimum density (95.32 lb/ft^3) and minimum hydrogen (25.09% LOD) is given in Table 12 of DAC-PKG-801624-A001. The average density of 277-4 used for HAC calculations in KENO V.a is 1.52680 g/cm^3; the boron constituent is 7.31015E-2 g/cm^3; the residual base is 1.07071 g/cm^3; and the water component is 3.82995E-1 g/cm^3 (Appendix 6.9.3, Table 6.9.3.3-3).

A set of 20 canned spacer assemblies as-manufactured has an average weight of 591.55 g. On average, the weight of an empty can with a lid is 86.05 g, and the 277-4 is 505.5 g. On the basis of volumetric measurements, the neutron poison is ~10.075 oz or 297.95 cm^3. The resultant 277-4 density is 1.6966 g/cm^3. The corresponding minimum mass is 473.84 g (given that the 277-4 material inside the spacer can is ≥4.07-in. diam and 1.31-in. thickness). Based on model dimensions of 4.13-in. diam × 1.37-in. height and use of composition data from Table 11 of DAC-PKG-801624-A001 (as-manufactured material at minimum density and hydrogen), the mass of neutron poison in the calculation model of the canned spacer is conservatively modeled as 457.15 g.

The density of 277-4 in the liner inner cavity is further reduced by a factor of 0.966893 because the actual volume of neutron poison is 12,831.4 cm^3 in the package, but 13,270.8 cm^3 is used in the calculation model. Also, guidance in Sect. 6.5.3.2 of NUREG-1609 requires that 75% of elemental boron be used in the material specification. Consequently, the minimum weight of 277-4 in the liner inner cavity of the calculation models is 19.37 kg (42.71 lb) for NCT and 19.36 kg (42.67 lb) for HAC, determined from the input density and the volume of the 277-4 region calculated by KENO V.a.

Kaolite is a lightweight, low thermal conductivity, refractory material that is used in the ES-3100 package between the drum and the inner liner. Kaolite is formed by mixing a dry constituent powder with water, pouring the mixture into a casting form, and curing and baking the cast. For NCT, the average density of Kaolite in the Model ES-3100 package is 0.34438 g/cm^3, and the residual water is 0.01493 g/cm^3 (Appendix 6.9.3, Sect. 6.9.3.4). The nominal weights of Kaolite in the liner outer cavity and in the top plug as determined from the input density and the region volumes calculated by KENO V.a are 49.04 kg (108.1 lb) and 4.37 kg (9.63 lb), respectively.

Kaolite is a nonvolatile refractory material, not significantly damaged by thermal excursions associated with HAC. It is assumed that upon immersion, a cured and dried casting will absorb a quantity of water equal to that required during preparation. This assumption is valid because the casting is fully saturated with water prior to curing and baking, and the casting does not change volume significantly during baking. The maximum water content of Kaolite refractory material is the water content of manufacture (1.5 g water per gram dry Kaolite) equivalent to a density of 0.51655 g/cm^3. For the single package, water saturation in the Kaolite region maximizes the effect of self-reflection in the surrounding package. This condition is assumed in the NCT single package calculations. For an array of packages, neutronic interaction between packages is maximized when the minimum amount of water is present in the Kaolite, which occurs in the as-manufactured condition. A volume fraction of 1.0 in the material specification corresponds to the water-saturated condition, while a volume fraction of 0.0289 corresponds to the dry condition.

The fissile material content packed into the containment vessel is ordinarily dry. Given that a flooded containment vessel is assumed for both NCT and HAC, the concurrent condition where the water-saturated Kaolite is baked dry beyond the as-manufactured condition while the containment vessel remains flooded is considered not credible. Therefore, the as-manufactured condition is assumed for the Kaolite water content in the HAC array analysis.

As stated in Sect. 6.3.1.2, the drum thicknesses of the NCT single-unit packaging model is increased for producing the NCT array packaging calculation model. The intent is to maintain the drum region volume thereby conserving drum mass. However, the both the region volume of the drum and the atomic densities for the elemental constituents of stainless steel in the resulting NCT array packaging calculation model are not identical to corresponding values for the single-unit packaging calculation model. This is due to internal round-off in KENO V.a. (Even though the volume fraction is changed from 1.0 to 0.99981 in the KENO V.a input specification of the NCT array packaging calculation model for normalization of the drum's region volume, the atomic densities still differ by 0.019% due to round-off.)

The material compositions for the NCT array calculation models are identical to compositions for the NCT single-unit calculation models except as noted in Table 6.4. In the NCT array calculation model, the adjusted model densities for the Kaolite in the body weldment liner inner cavity (Mix. No. 12), the stainless steel of the angle iron (Mix. No. 18), and the drum steel (Mix. No. 19) compensate for the dimensional changes of the reduced-diameter model (93% ID of drum). A difference between the NCT specifications for Kaolite (Mix. Nos. 12 and 13) in the array and the single-unit models occurs in the water component. The dry state is represented in the array model for maximizing neutronic interaction between packages of an array, while the flooded state is represented in the single-unit model for maximizing reflection.

The material compositions for the HAC single-unit calculation model are identical to those for the NCT single-unit calculation models except as noted in Table 6.4. The adjusted model densities for 277-4 neutron poison in both the canned spacers (Mix. No. 2) and the inner-liner cavity (Mix. No. 11) represent the HAC discussed earlier in this section. In the HAC single-unit calculation model, the adjusted model densities for the Kaolite in the body weldment liner inner cavity (Mix. No. 12), the stainless steel of the angle iron (Mix. No. 18), and the drum steel (Mix. No. 19) correspond to dimensional changes resulting from damage. While the atomic densities for the HAC model differ from those for the NCT model, the component masses do not change because mass is conserved.

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
Fissile material contents							
Uranium (solid metal)	1	18.81109	1.0	^{235}U	235.0441	1.00	4.81970E-02
				^{238}U	238.0510	0.00	0.0000E+00
Uranium (solid metal)	1	18.82298	1.0	^{235}U	235.0441	0.95	4.58156E-02
				^{238}U	238.0510	0.05	2.38089E-03
Uranium (solid metal)	1	18.83488	1.0	^{235}U	235.0441	0.90	4.34317E-02
				^{238}U	238.0510	0.10	4.76479E-03
Uranium (solid metal)	1	18.85873	1.0	^{235}U	235.0441	0.80	3.86548E-02
				^{238}U	238.0510	0.20	9.54164E-03
Uranium (solid metal)	1	18.88264	1.0	^{235}U	235.0441	0.70	3.38659E-02
				^{238}U	238.0510	0.30	1.43306E-02
Uranium (solid metal)	1	18.90661	1.0	^{235}U	235.0441	0.60	2.90647E-02
				^{238}U	238.0510	0.40	1.91317E-02
Uranium (solid metal)	1	18.95474	1.0	^{235}U	235.0441	0.40	1.94258E-02
				^{238}U	238.0510	0.60	2.87707E-02
Uranium (solid metal)	1	19.00554	1.0	^{235}U	235.0441	0.19	9.25199E-03
				^{238}U	238.0510	0.81	3.89445E-02
Uranium oxide (UO_2)	1	6.94256	1.0	H	1.0077	0.6490	2.69208E-02
				O	15.9904	16.4340	4.29699E-02
				^{235}U	235.0441	82.9170	1.47490E-02
Uranium oxide (U_3O_8)	1	6.75167	1.0	H	1.0077	0.3510	1.41552E-02
				O	15.9904	17.6620	4.49101E-02
				^{235}U	235.0441	81.9870	1.41826E-02
Uranium oxide (UO_3)	1	6.64270	1.0	H	1.0077	0.1730	6.86795E-03
				O	15.9904	18.0650	4.51925E-02
				^{235}U	235.0441	81.7620	1.39155E-02
Skull oxide (UO_3+graphite)	1	3.34850	1.0	H	1.0077	1.9000	3.80225E-02
				C	12.0001	11.9173	2.00261E-02
				O	15.9904	25.9923	3.27786E-02
				^{235}U	235.0441	56.0976	4.81282E-03
				^{238}U	238.0510	4.0929	3.46713E-04
UNH crystals (24000.0 g) $[UO_2(NO_3)_2+6H_2O]$	1	2.50804	1.0	H	1.0077	2.9770	4.46274E-02
				N	14.0033	5.2570	5.66985E-03
				O	15.9904	47.6480	4.50055E-02
				^{235}U	235.0441	44.1180	2.83495E-03
UNH crystals (9000.0 g) $[UO_2(NO_3)_2+6H_2O]$	1	1.56439	1.0	H	1.0077	6.2525	5.84562E-02
				N	14.0033	3.1604	2.12620E-03
				O	15.9904	64.0630	3.77431E-02
				^{235}U	235.0441	26.5240	1.06311E-03

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
UNH crystals	1	1.50149	1.0	H	1.0077	6.6172	5.93782E-02
(8000.0 g)				N	14.0033	2.9270	1.89000E-03
$[UO_2(NO_3)_2+6H_2O]$				O	15.9904	65.8907	3.72591E-02
				^{235}U	235.0441	24.5651	9.45006E-04
UNH crystals	1	1.06111	1.0	H	1.0077	10.3811	6.58313E-02
(1000.1 g)				N	14.0033	0.5178	2.36275E-04
$[UO_2(NO_3)_2+6H_2O]$				O	15.9904	84.7556	3.38697E-02
				^{235}U	235.0441	4.3455	9.45006E-04
~20% enriched UZrH	1	8.65974	1.0	H	1.0078	0.9554	4.94386E-02
(3466.7 g)				Zr	91.2196	54.0447	3.08972E-02
				^{235}U	235.0441	8.8558	1.96487E-03
				^{238}U	238.0510	36.1441	7.91816E-03
~70% enriched UZrH	1	5.70132	1.0	H	1.0078	1.5894	5.41480E-02
(2282.4 g)				Zr	91.2196	89.9107	3.38410E-02
				^{235}U	235.0441	5.9588	8.67175E-04
				^{238}U	238.0510	2.5413	3.69825E-04
~20% enr. U_3O_8-Al	1	3.52015	1.0	O	15.9904	5.2477	6.95687E-03
(12254.7 g)				Al	26.9818	65.5398	5.14922E-02
				^{235}U	235.0441	5.8425	5.26934E-04
				^{238}U	238.0510	23.3700	2.08111E-03
~70% enr. U_3O_8-Al	1	3.52095	1.0	O	15.9904	5.2800	7.00127E-03
(1995.7 g)				Al	26.9818	65.5141	5.14837E-02
				^{235}U	235.0441	20.4441	1.84427E-03
				^{238}U	238.0510	8.7618	7.80418E-04
~93% enr. U_3O_8-Al	1	3.52132	1.0	O	15.9904	5.2950	7.02187E-03
(1505.0 g)				Al	26.9818	65.5022	5.14798E-02
				^{235}U	235.0441	27.2170	2.45552E-03
				^{238}U	238.0510	1.9858	1.76895E-04
~9.9% enr. UO_2-Mg	1	3.95984	1.0	O	15.9904	6.4032	9.54899E-03
in Al clad				Mg	24.3048	7.6175	7.47379E-03
(15231.1 g)				Al	26.9818	38.3916	3.39305E-02
				^{235}U	235.0441	4.7062	4.77464E-04
				^{238}U	238.0510	42.8815	4.29560E-03
20% enr. UO_2-Mg	1	3.96017	1.0	O	15.9904	6.4110	9.56133E-03
in Al clad				Mg	24.3048	7.6169	7.47379E-03
(7523.6 g)				Al	26.9818	38.3885	3.39305E-02
				^{235}U	235.0441	9.5167	9.65604E-04
				^{238}U	238.0510	38.0670	3.81363E-03

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
~93% enr. UO_2-Mg	1	3.96254	1.0	O	15.9904	6.4670	6.34806E-03
in Al clad				Mg	24.3048	7.6123	4.91617E-03
(1472.1 g)				Al	26.9818	38.3655	2.23190E-02
				^{235}U	235.0441	44.3215	2.95985E-03
				^{238}U	238.0510	3.2338	2.13227E-04
Single-unit calculation models (NCT)							
277-4	2	1.50970	1.0	H	1.0077	2.84745	2.56909E-02
canned spacer				^{10}B	10.0130	0.65907	5.98418E-04
Table 11 data: [b]				^{11}B	11.0096	2.97264	2.45475E-03
as-manufactured,				C	12.0001	1.36094	1.03107E-03
minimum density and				N	14.0033	0.01000	6.49252E-06
hydrogen				O	15.9904	53.39650	3.03592E-02
				Na	22.9895	0.08326	3.29274E-05
				Mg	24.3048	0.23957	8.96150E-05
				Al	26.9818	27.69370	9.33137E-03
				Si	28.0853	1.74979	5.66427E-04
				S	32.0634	0.21865	6.19983E-05
				Ca	40.0803	8.39267	1.90373E-03
				Fe	55.8447	0.37575	6.11714E-05
Water-flooded containment vessel (CV)	3	0.9982	1.0	H	1.0077	11.1909	6.67536E-02
				O	15.9904	88.8091	3.33856E-02
SS304	8	7.9400	1.0	C	12.0001	0.0800	3.18772E-04
CV body				Si	28.0853	1.0000	1.70252E-03
16.60 lb				P	30.9741	0.0450	6.94680E-05
but 15.74 lb used				Cr	51.9957	19.0000	1.74726E-02
				Mn	54.9379	2.0000	1.74071E-03
				Fe	55.8447	68.3750	5.85446E-02
				Ni	58.6872	9.5000	7.74020E-03
SS304	9	7.9400	0.97267	C	12.0001	0.0800	3.10060E-04
CV lower flange				Si	28.0853	1.0000	1.65599E-03
used 3.36 lb				P	30.9741	0.0450	6.75695E-05
				Cr	51.9957	19.0000	1.69951E-02
				Mn	54.9379	2.0000	1.69314E-03
				Fe	55.8447	68.3750	5.69445E-02
				Ni	58.6872	9.5000	7.52866E-03

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
SS304	10	7.9400	0.94348	C	12.0001	0.0800	3.00755E-04
CV upper flange				Si	28.0853	1.0000	1.60629E-03
used 13.75 lb				P	30.9741	0.0450	6.55417E-05
				Cr	51.9957	19.0000	1.64850E-02
				Mn	54.9379	2.0000	1.64233E-03
				Fe	55.8447	68.3750	5.52356E-02
				Ni	58.6872	9.5000	7.30272E-03
277-4	11	1.45971	1.0	H	1.0077	2.84746	2.48404E-02
filling CV				^{10}B	10.0130	0.65907	5.78606E-04
inner-liner cavity				^{11}B	11.0096	2.97265	2.37348E-03
Table 11 data: [b]				C	12.0001	1.36094	9.96935E-04
as-manufactured,				N	14.0033	0.01000	6.27756E-06
minimum density and				O	15.9904	53.39660	2.93541E-02
hydrogen				Na	22.9895	0.08326	3.18372E-05
				Mg	24.3048	0.23957	8.66479E-05
				Al	26.9818	27.69360	9.02241E-03
				Si	28.0853	1.74979	5.47673E-04
				S	32.0634	0.21865	5.99456E-05
				Ca	40.0803	8.39266	1.84069E-03
				Fe	55.8447	0.37575	5.91461E-05
Kaolite	12	(body weldment)					
Al_2O_3		0.34864	0.096	Al	26.9818	52.9390	3.95461E-04
				O	15.9904	47.0610	—
SiO_2		0.34864	0.367	Si	28.0853	46.7570	1.28281E-03
				O	15.9904	53.2430	—
Fe_2O_3		0.34864	0.067	Fe	55.8447	69.9540	1.76211E-04
				O	15.9904	30.0460	—
TiO_2		0.34864	0.012	Ti	47.8793	59.9530	3.15486E-05
				O	15.9904	40.0470	—
CaO		0.34864	0.307	Ca	40.0803	71.4810	1.14955E-03
				O	15.9904	28.5180	—
MgO		0.34864	0.131	Mg	24.3048	60.3170	6.82560E-04
				O	15.9904	39.6830	—
Na_2O		0.34864	0.020	Na	22.9895	74.1960	1.35522E-04
				O	15.9904	25.8040	—
Total O		—	—	—	15.9904	—	5.39065E-03
Water	12	0.52294	1.0	H	1.0077	11.1909	3.49711E-02
				O	15.9904	88.8091	1.74856E-02

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
Kaolite	13	(top plug)					
Al_2O_3		0.33241	0.096	Al	26.9818	52.9390	3.77052E-04
				O	15.9904	47.0610	—
SiO_2		0.33241	0.367	Si	28.0853	46.7570	1.22309E-03
				O	15.9904	53.2430	—
Fe_2O_3		0.33241	0.067	Fe	55.8447	69.9540	1.68008E-04
				O	15.9904	30.0460	—
TiO_2		0.33241	0.012	Ti	47.8793	59.9530	3.00799E-05
				O	15.9904	40.0470	—
CaO		0.33241	0.307	Ca	40.0803	71.4810	1.09604E-03
				O	15.9904	28.5180	—
MgO		0.33241	0.131	Mg	24.3048	60.3170	6.50785E-04
				O	15.9904	39.6830	—
Na_2O		0.33241	0.020	Na	22.9895	74.1960	1.29213E-04
				O	15.9904	25.8040	—
Total O		—	—	—	15.9904	—	5.13975E-03
Water	13	0.49860	1.0	H	1.0077	11.1909	3.33433E-02
				O	15.9904	88.8091	1.66717E-02
Silicon rubber pads	14	1.21791	1.0	H	1.0077	8.1562	5.93660E-02
				C	12.0001	32.3774	1.97887E-02
				O	15.9904	21.5782	9.89729E-03
				Si	28.0853	37.8882	9.89432E-03
Water—CV well	15	0.9982	variable	H	1.0077	11.1909	variable
				O	15.9904	88.8091	variable
SS304 liner	16	7.94	1.0	C	12.0001	0.0800	3.18772E-04
				Si	28.0853	1.0000	1.70252E-03
				P	30.9741	0.0450	6.94680E-05
				Cr	51.9957	19.0000	1.74726E-02
				Mn	54.9379	2.0000	1.74071E-03
				Fe	55.8447	68.3750	5.85446E-02
				Ni	58.6872	9.5000	7.74020E-03
SS304 plug cover used 9.907 lb	17	7.94	1.06388	C	12.0001	0.0800	3.39135E-04
				Si	28.0853	1.0000	1.81128E-03
				P	30.9741	0.0450	7.39056E-05
				Cr	51.9957	19.0000	1.85887E-02
				Mn	54.9379	2.0000	1.85191E-03
				Fe	55.8447	68.3750	6.22844E-02
				Ni	58.6872	9.5000	8.23464E-03

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
SS304 angle iron	18	7.94	1.0	C	12.0001	0.0800	3.18772E-04
				Si	28.0853	1.0000	1.70252E-03
				P	30.9741	0.0450	6.94680E-05
				Cr	51.9957	19.0000	1.74726E-02
				Mn	54.9379	2.0000	1.74071E-03
				Fe	55.8447	68.3750	5.85446E-02
				Ni	58.6872	9.5000	7.74020E-03
SS304 steel drum	19	7.94	1.0	C	12.0001	0.0800	3.18772E-04
				Si	28.0853	1.0000	1.70252E-03
				P	30.9741	0.0450	6.94680E-05
				Cr	51.9957	19.0000	1.74726E-02
				Mn	54.9379	2.0000	1.74071E-03
				Fe	55.8447	68.3750	5.85446E-02
				Ni	58.6872	9.5000	7.74020E-03
Water—interstitial	20	0.9982	variable	H	1.0077	11.1909	variable
				O	15.9904	88.8091	variable
Water—reflector	21	0.9982	1.0	H	1.0077	11.1909	6.67536E-02
				O	15.9904	88.8091	3.33856E-02
Array calculation models (NCT) same as single-unit calculation models NCT except as follows:							
Kaolite	12	(body weldment)					
Al_2O_3		0.42622	0.096	Al	26.9818	52.9390	4.83460E-04
				O	15.9904	47.0610	—
SiO_2		0.42622	0.367	Si	28.0853	46.7570	1.56821E-03
				O	15.9904	53.2430	—
Fe_2O_3		0.42622	0.067	Fe	55.8447	69.9540	2.15422E-04
				O	15.9904	30.0460	—
TiO_2		0.42622	0.012	Ti	47.8793	59.9530	3.85688E-05
				O	15.9904	40.0470	—
CaO		0.42622	0.307	Ca	40.0803	71.4810	1.40535E-03
				O	15.9904	28.5180	—
MgO		0.42622	0.131	Mg	24.3048	60.3170	8.34444E-04
				O	15.9904	39.6830	—
Na_2O		0.42622	0.020	Na	22.9895	74.1960	1.65678E-04
				O	15.9904	25.8040	—
Total O		—	—	—	15.9904	—	6.58477E-03
Water	12	0.63931	0.0287	H	1.0077	11.1909	1.22702E-03
				O	15.9904	88.8091	6.13510E-04
Kaolite	13	(top plug)					
Al_2O_3		0.33241	0.096	Al	26.9818	52.9390	3.77052E-04
				O	15.9904	47.0610	—

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
SiO_2		0.33241	0.367	Si	28.0853	46.7570	1.22309E-03
				O	15.9904	53.2430	—
Fe_2O_3		0.33241	0.067	Fe	55.8447	69.9540	1.68008E-04
				O	15.9904	30.0460	—
TiO_2		0.33241	0.012	Ti	47.8793	59.9530	3.00799E-05
				O	15.9904	40.0470	—
CaO		0.33241	0.307	Ca	40.0803	71.4810	1.09604E-03
				O	15.9904	28.5180	—
MgO		0.33241	0.131	Mg	24.3048	60.3170	6.50785E-04
				O	15.9904	39.6830	—
Na_2O		0.33241	0.020	Na	22.9895	74.1960	1.29213E-04
				O	15.9904	25.8040	—
Total O		—	—	—	15.9904	—	5.13548E-03
Water	13	0.49860	0.0287	H	1.0077	11.1909	9.56954E-04
				O	15.9904	88.8091	4.78477E-04
SS304 angle iron	18	7.94	1.25705	C	12.0001	0.0800	4.00712E-04
				Si	28.0853	1.0000	2.14015E-03
				P	30.9741	0.0450	8.73248E-05
				Cr	51.9957	19.0000	2.19639E-02
				Mn	54.9379	2.0000	2.18816E-03
				Fe	55.8447	68.3750	7.35934E-02
				Ni	58.6872	9.5000	9.72982E-03
SS304 steel drum	19	7.94	0.99981	C	12.0001	0.0800	3.18711E-04
				Si	28.0853	1.0000	1.70220E-03
				P	30.9741	0.0450	6.94548E-05
				Cr	51.9957	19.0000	1.74693E-02
				Mn	54.9379	2.0000	1.74038E-03
				Fe	55.8447	68.3750	5.85334E-02
				Ni	58.6872	9.5000	7.73873E-03
Water—reflector	21	1.16235	1.0	H	1.0077	11.1909	7.75911E-06
				O	15.9904	88.8091	3.88058E-06

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
Single-unit calculation models (HAC) same as single-unit calculation models NCT except as follows:							
277-4	2	1.50853	1.0	H	1.0077	2.84094	2.56124E-02
canned spacer				^{10}B	10.0130	0.65958	5.98418E-04
Table 12 data: [b]				^{11}B	11.0096	2.97494	2.45475E-03
as-manufactured,				C	12.0001	1.36193	1.03103E-03
minimum density and				N	14.0033	0.01001	6.49258E-06
hydrogen				O	15.9904	53.36920	3.03202E-02
				Na	22.9895	0.08333	3.29277E-05
				Mg	24.3048	0.23976	8.96158E-05
				Al	26.9818	27.71520	9.33140E-03
				Si	28.0853	1.75109	5.66409E-04
				S	32.0634	0.21882	6.19989E-05
				Ca	40.0803	8.39916	1.90373E-03
				Fe	55.8447	0.37604	6.11720E-05
277-4	11	1.45858	1.0	H	1.0077	2.84097	2.47645E-02
filling CV				^{10}B	10.0130	0.65959	5.78606E-04
inner-liner cavity				^{11}B	11.0096	2.97496	2.37348E-03
Table 12 data: [b]				C	12.0001	1.36193	9.96883E-04
as-manufactured,				N	14.0033	0.01001	6.27756E-06
minimum density and				O	15.9904	53.36930	2.93162E-02
hydrogen				Na	22.9895	0.08333	3.18372E-05
				Mg	24.3048	0.23976	8.66479E-05
				Al	26.9818	27.71510	9.02236E-03
				Si	28.0853	1.75109	5.47651E-04
				S	32.0634	0.21882	5.99456E-05
				Ca	40.0803	8.39913	1.84068E-03
				Fe	55.8447	0.37604	5.91461E-05
Kaolite	12	(body weldment)					
Al_2O_3		0.41898	0.096	Al	26.9818	52.9390	4.75248E-04
				O	15.9904	47.0610	—
SiO_2		0.41898	0.367	Si	28.0853	46.7570	1.54162E-03
				O	15.9904	53.2430	—
Fe_2O_3		0.41898	0.067	Fe	55.8447	69.9540	2.11763E-04
				O	15.9904	30.0460	—
TiO_2		0.41898	0.012	Ti	47.8793	59.9530	3.79136E-05
				O	15.9904	40.0470	—
CaO		0.41898	0.307	Ca	40.0803	71.4810	1.38148E-03
				O	15.9904	28.5180	—
MgO		0.41898	0.131	Mg	24.3048	60.3170	8.20270E-04
				O	15.9904	39.6830	—

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
Na_2O		0.41898	0.020	Na	22.9895	74.1960	1.62864E-04
				O	15.9904	25.8040	—
Total O		—	—	—	15.9904	—	6.47830E-03
Water	12	0.62843	1.0	H	1.0077	11.1909	4.20256E-02
				O	15.9904	88.8091	2.10128E-02
SS304 angle iron	18	7.94	1.23239	C	12.0001	0.0800	3.92851E-04
				Si	28.0853	1.0000	2.09817E-03
				P	30.9741	0.0450	8.56117E-05
				Cr	51.9957	19.0000	2.15330E-02
				Mn	54.9379	2.0000	2.14524E-03
				Fe	55.8447	68.3750	7.21497E-02
				Ni	58.6872	9.5000	9.53894E-03
SS304 steel drum	19	7.94	1.08401	C	12.0001	0.0800	3.45552E-04
				Si	28.0853	1.0000	1.84555E-03
				P	30.9741	0.0450	7.53040E-05
				Cr	51.9957	19.0000	1.89405E-02
				Mn	54.9379	2.0000	1.88695E-03
				Fe	55.8447	68.3750	6.34629E-02
				Ni	58.6872	9.5000	8.39045E-03
Array calculation models (HAC) same as single-unit calculation models HAC except as follows:							
Kaolite	12	(body weldment)					
Al_2O_3		0.41898	0.096	Al	26.9818	52.9390	4.75248E-04
				O	15.9904	47.0610	—
SiO_2		0.41898	0.367	Si	28.0853	46.7570	1.54162E-03
				O	15.9904	53.2430	—
Fe_2O_3		0.41898	0.067	Fe	55.8447	69.9540	2.11763E-04
				O	15.9904	30.0460	—
TiO_2		0.41898	0.012	Ti	47.8793	59.9530	3.79136E-05
				O	15.9904	40.0470	—
CaO		0.41898	0.307	Ca	40.0803	71.4810	1.38148E-03
				O	15.9904	28.5180	—
MgO		0.41898	0.131	Mg	24.3048	60.3170	8.20270E-04
				O	15.9904	39.6830	—
Na_2O		0.41898	0.020	Na	22.9895	74.1960	1.62864E-04
				O	15.9904	25.8040	—
Total O		—	—	—	15.9904	—	6.47293E-03
Water	12	0.62843	0.287	H	1.0077	11.1909	1.20613E-03
				O	15.9904	88.8091	6.03065E-04

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
Kaolite	13	(top plug)					
Al_2O_3		0.33241	0.096	Al	26.9818	52.9390	3.77052E-04
				O	15.9904	47.0610	—
SiO_2		0.33241	0.367	Si	28.0853	46.7570	1.22309E-03
				O	15.9904	53.2430	—
Fe_2O_3		0.33241	0.067	Fe	55.8447	69.9540	1.68008E-04
				O	15.9904	30.0460	—
TiO_2		0.33241	0.012	Ti	47.8793	59.9530	3.00799E-05
				O	15.9904	40.0470	—
CaO		0.33241	0.307	Ca	40.0803	71.4810	1.09604E-03
				O	15.9904	28.5180	—
MgO		0.33241	0.131	Mg	24.3048	60.3170	6.50785E-04
				O	15.9904	39.6830	—
Na_2O		0.33241	0.020	Na	22.9895	74.1960	1.29213E-04
				O	15.9904	25.8040	—
Total O		—	—	—	15.9904	—	5.13548E-03
Water	13	0.49860	0.0287	H	1.0077	11.1909	9.56954E-04
				O	15.9904	88.8091	4.78477E-04
Water—reflector	21	1.16235	1.0	H	1.0077	11.1909	7.75911E-06
				O	15.9904	88.8091	3.88058E-06

[a] The theoretical density input parameter is specified for each material such that the required (or desired) mass of material is represented in the KENO V.a calculation model. The mass of material is computed by KENO V.a as the product of the theoretical density input parameter times the volume fraction times the volume of the geometry region in which the material resides in the calculation model.

[b] DAC-PKG-801624-A001.

The material compositions for the HAC array calculation model are identical to those for the NCT single-unit calculation models except as noted in Table 6.4. Also, the dimensions of the HAC array packaging calculation model do not differ from those of the HAC single-unit packaging calculation model. Therefore, both the region volumes and the atomic densities for the elemental constituents for Kaolite in the body weldment liner inner cavity are the same in both of the HAC calculation models. A difference between the HAC specifications for Kaolite (Mix. Nos. 12 and 13) in the array and the single-unit models occurs in the water component. The dry state is represented in the array model for maximizing neutronic interaction between packages of an array, while the flooded state is represented in the single-unit model for maximizing reflection.

The material composition used in the calculation model for the containment vessel, the drum liner, and the drum is Type 304 stainless steel at a density of 7.94 g/cm^3. The density and composition of the Type 304 stainless steel for the drum is taken from the Standard Composition Library of the Standardized Computer Analysis for Licensing Evaluation (SCALE) code system. The nominal weights of these components, as determined by input density and volume calculated by KENO V.a, are 14.9 kg (32.85 lb) for the containment vessel, 15.67 kg (34.55 lb) for the drum liner, and 25.44 kg (56.1 lb) for the drum.

Both the type and amount of hydrogenous packaging material used for packing the content in the containment vessel is unknown. Polyethylene with a density of 0.92 g/cm^3 and a molecular formula of CH_2 has the greatest hydrogen density of potential packing materials. Although polyethylene bags are generally used in packing for contamination control, the exact mass of the polyethylene bags used is unknown. Multiple bags may be used to package the contents and to enclose the convenience cans, or bags may be omitted altogether. Realistically, the number of polyethylene bags used to bag the contents and wrap a convenience can would be six bags at most. Given that each bag weighs ~28 g, this results in a maximum of ~510 g of polyethylene per ES-3100 package. For consistency with other sections of this document, a maximum of 500 g of polyethylene per ES-3100 is used in the criticality evaluation. Possible additional sources of hydrogenous material inside the containment vessel include can pads, vinyl tape, and polyethylene (~85 g) or Teflon (~303 g) bottles.

For the criticality calculations, the sources of hydrogen contained in packing materials are not distinguished from other sources of hydrogen inherent in the fissile material content. Therefore, packing material mass is defined as all sources of hydrogenous packing materials inside the containment vessel plus the actual moisture in the content as constituent (the bonded hydrogen in UNX crystals or impurities in the oxide). Given content moisture is not to exceed 6 wt %, the amount of hydrogenous material inside the containment vessel is not expected to exceed 2,400 g.

Containment vessel flooding is assumed in calculations performed for the derivation of fissile material loading limits. Even though both the NCT tests under 10 CFR 71.71 and the HAC tests under 10 CFR 71.73 demonstrate that containment is not breached, this simulated condition produces package configurations in the criticality calculations that are more reactive than the actual package configurations. The 7.1–10.1 kg quantities of evaluation water required in both the NCT and HAC criticality calculations bound reasonable amounts of hydrogenous material and inherent moisture of fissile material (primarily HEU oxides) present inside the containment vessel (2,400 g).

HAC alter only the amount of volatile hydrogenous material contained in the package external to the containment vessel (Sect. 2.7.3). High temperatures may reduce the hydrogenous material content of the Kaolite. Conversely, water intrusion may increase the hydrogenous material content in the package. Thus, the package's range of possible volatile hydrogenous material content varies from none, caused by high temperatures, to the maximum possible value caused by water intrusion.

Table 6.4 lists the material, density, atomic or isotopic constituent, and atomic or isotopic weight percent as basic data for materials used in the single-unit packaging and array calculation models in this criticality safety evaluation for NCT and HAC, respectively. Appendix 6.9.3 provides the rationale, justification, or both for using the basic data for computing atomic densities listed in Table 6.4.

6.3.3 Computer Codes and Cross-Section Libraries

The Criticality Safety Analysis Sequences within the SCALE modular code system provide automated, problem-dependent, cross-section processing followed by calculation of the neutron multiplication factor (k_{eff}) for the system being modeled (NUREG/CR-0200, Rev. 6). Initiated by "=csas25" appearing on the first line in the user input, the CSAS module runs the CSAS25 control sequence. The cross-section processing functional modules BONAMI (NUREG/CR-0200, Rev. 6) and NITAWL-II (NUREG/CR-0200, Rev. 6) are activated, providing resonance-corrected cross sections to the multigroup Monte Carlo functional module, KENO V.a (NUREG/CR-0200, Rev. 6). Using the processed cross sections, KENO V.a calculates the k_{eff} of three-dimensional system models. The geometric modeling capabilities available in KENO V.a, coupled with the automated cross-section processing, allow complex, three-dimensional systems to be easily analyzed.

The CSAS25 control sequence and the 238-group ENDF/B-V cross-section library in SCALE are used for all calculations. The control sequence, functional modules, and cross-section library are summarized in the following paragraphs.

The CSAS25 control sequence reads user-specified input data, which include the required cross-section library, specifications for mixtures, information for resonance processing of nuclides (size, geometry, and temperature), and a detailed geometry model for KENO V.a. Physical and neutronic information not specified but required by the functional modules (such as theoretical density, molecular weights, and average resonance region background cross sections) is supplied by the Standard Composition Library or calculated by the Materials Information Processor. The Standard Composition Library (NUREG/CR-0200, Rev. 6) consists of a standard composition directory and table, an isotopic distribution directory and table, and a nuclide information table. The Materials Information Processor (NUREG/CR-0200, Rev. 6) checks the input data pertaining to cross-section preparation and prepares binary input files for the applicable functional modules BONAMI and NITAWL-II.

The standardized automated procedures process SCALE cross sections using the Bondarenko method (via BONAMI) and the Nordheim integral method (via NITAWL-II) to provide a resonance-corrected cross-section library based on the physical characteristics of the problem being analyzed.

BONAMI performs resonance shielding through the application of the Bondarenko shielding factor method. BONAMI reads the master format library and applies the Bondarenko correction to all nuclides that have Bondarenko data. BONAMI produces a Bondarenko-corrected master format library which is read by NITAWL-II.

NITAWL-II applies the Nordheim Integral Treatment to perform neutron cross-section processing in the resonance energy range for nuclides that have ENDF/B resonance parameter data. This technique involves the numerical integration of ENDF/B resonance parameters using a calculated flux distribution, which is based on the calculated collision density across each resonance and subsequent weighing of the reaction cross section to the desired broad group structure. In the CSAS sequence, NITAWL-II assembles the group-to-group transfer arrays from the elastic and inelastic scattering components and performs other tasks to produce a problem-dependent, working cross-section library which can be used by KENO.

KENO V.a, a multigroup Monte Carlo computer code, is used to determine k_{eff} for multidimensional systems. The basic geometrical bodies allowed in KENO V.a for defining models are cuboids, spheres, cylinders, hemispheres, and hemicylinders. KENO V.a has the following major characteristics:

- enhanced geometry package that allows arrays to be defined and positioned throughout the model;
- P_n scattering treatment;
- extended use of differential albedo reflection;
- printer plots for checking the input model;
- energy-dependent data supergrouping;
- restart capability; and
- origin specifications for cuboids, spheres, cylinders, hemicylinders, and hemispheres.

The 238-group ENDF/B-V master cross-section library in SCALE is activated in the CSAS25 control sequence by specifying 238GROUPNDF5 (238GR) as the cross-section library name. The 238-GROUP ENDF/B-V [neutron cross-section] library is a general-purpose criticality analysis library and the most complete library available in SCALE 4.4a. The library contains data for all nuclides (more than 300) available in ENDF/B-V processed by the AMPX-77 systems. It also contains data for ENDF/B-VI evaluations of ^{14}N, ^{15}N, ^{16}O, ^{154}Eu, and ^{155}Eu. The library has 148 fast groups and 90 thermal groups (below 3 eV). Most resonance nuclides in the 238 group have resonance data (to be processed by NITAWL-II in the resolved resonance range) and Bondarenko factors (to be processed by BONAMI) for the unresolved range. The 238-group library contains resolved resonance data for s-wave, p-wave, and d-wave resonances **R** = 0, **R** = 1, and **R** = 2, respectively. These data can have a significant effect on results for under-moderated, intermediate-energy problems. Resonance structures in several light-to-intermediate mass "nonresonance" ENDF nuclides (i.e., ^{7}Li, ^{19}F, ^{27}Al, ^{28}Si) are accounted for using Bondarenko shielding factors. These structures can also be important in intermediate energy problems.

All nuclides in the 238-group library use the same weighting spectrum, consisting of:

- Maxwellian spectrum (peak at 300 K) from 10^{-5} to 0.125 eV,
- a 1/E spectrum from 0.125 eV to 67.4 keV,
- a fission spectrum (effective temperature at 1.273 MeV) from 67.4 keV to 10 MeV, and
- a 1/E spectrum from 10 to 20 MeV.

The k_{eff} values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data. The convergence of the KENO V.a calculation is related to trends in the average calculated k_{eff}. In general, the KENO V.a output table of k_{eff} by Generation Skipped is reviewed for trends. If no trends are observed, the calculation is accepted, and the reported value of k_{eff} is the one with the most neutron histories. Usually there is no statistically significant difference between this result and the one with the smallest standard deviation.

No manual cross-section adjustment is performed for the criticality safety evaluation. The cross-section processing is performed automatically in the CSAS25 code sequence making use of the available cross-section treatment options, as appropriate.

The CSAS control module, the associated functional modules, cross sections, and databases used in this evaluation reside in the verified configuration control area designated **/vcc/scale4.4a** on a Hewlett Packard Series 9000 J Class workstation at the Y-12 Safety Analysis Engineering (SAE) organization in Oak Ridge, Tennessee. The detailed input and computer output for the criticality safety evaluation of the ES-3100 shipping container with HEU reside in a configuration control area **/archive/ylf717_Rv2** on the workstation. Input listings of the key cases indicated in Tables 6.1a–6.1f are provided in Appendix 6.9.7.

6.3.4 Demonstration of Maximum Reactivity

Liquid HEU is not being shipped in the ES-3100. Only the uranyl nitrate crystal content being shipped in the ES-3100 is soluble in water. The hypothetical occurrence of uranyl nitrate solution is evaluated as a consequence of evaluating the presence of water inside the containment vessel.

As stated in Sect. 6.1.2, 10 CFR 71.55(b) requires the evaluation of water leakage into the containment vessel or leakage of liquid contents out of the containment vessel and other conditions that produce maximum reactivity in the single package. For solid uranium contents, water leakage conditions are simulated by flooding all regions outside and inside of the containment vessel, including the sealed convenience cans. For liquid uranium "contents", water leakage conditions are simulated by flooding all regions outside the containment vessel except the containment vessel well. Uranyl nitrate solution resides inside both the containment vessel, including the Teflon bottles, and the well external to the containment vessel. According to the 10 CFR 71.55(b) requirement, a flooded containment vessel under full water reflection is also evaluated.

While the loss of containment is deemed incredible by merit of the results of the physical tests performed under 10 CFR 71.71 and 10 CFR 71.73, credit for the high-integrity, watertight containment is not taken in the single package analysis [10 CFR 71.55(d) and (e)]. Only partial credit is taken in the package array analysis (10 CFR 71.59). In both the single package and package array analyses, the containment vessel is flooded with water. This fictitious "evaluation" water provides moderation to such an extent as to cause maximum reactivity of the content consistent with the chemical and physical form of the material present. Uranyl nitrate crystals are soluble in water. In both the evaluation of undamaged packages under 10 CFR 71.59(a)(1) and damaged packages under 10 CFR 71.59(a)(2), the leakage out of the containment vessel of content moderated to such an extent as to cause maximum reactivity consistent with the physical and chemical form of material is not considered credible during NCT or HAC, based on results for tests specified in 10 CFR 71.71 and 10 CFR 71.73.

Contents are generally dry, and only small quantities of hydrogenous packing materials are used. However, credit for the high-integrity, watertight containment is not taken in this criticality evaluation (Docket 71-9315). Fissile material loading is restricted such that if a containment vessel were flooded, it would be adequately subcritical under full water reflection. But instead of loading limits being established in accordance with conditions of confinement and containment as demonstrated under the NCT and HAC tests, these single-unit fissile material loading limits are severely reduced on the basis of the array calculations where all of the containment vessels of the packages in an array are assumed to be flooded, but each packaging is dry. This has the effect of maximizing both the neutron source and neutronic interaction between packages. Because credit for the high-integrity, watertight containment is not fully taken in this criticality evaluation, the fissile material mass loading limits developed as a result are very conservative.

Section 6.3.1 provides dimensional data for content and package models, and Sect. 6.3.2 provides material composition data used in the calculation models. Appendix 6.9.3 provides justification for the composition data used in the evaluation. These sections and this appendix describe how the packaging dimensions and materials are optimized to produce a conservative model by reducing neutron-absorbing materials and maximizing the reactivity of the fissile material content through the inclusion of water in the containment vessel.

As described in Sect. 6.3.1.1, a geometry region is defined by dimensions and the type of material contained therein. The amount of material within a region is quantified in terms of the density, material volume fraction, and the volume of the region (Sect. 6.3.2). The term "water fraction" means the fraction of the maximum specific gravity of water possible for any geometry region in the ES-3100 package. Therefore, the water content is the fraction of the maximum specific gravity of water possible in a material in the ES-3100 package when flooded.

The maximum value for the void regions (spaces external to the containment vessel) is 1.0 for both single-unit and array geometries. For the geometry regions containing Kaolite, the maximum values are 0.51655 for the single unit and 0.63931 for the array. For the geometry regions containing 277-4, the maximum value is 0.6942 for both the single-unit and array geometries. The same single-unit values are used in the array calculation models because the 277-4–bearing regions do not require adjustment for the close-pack approximation (Sect. 6.3.1.2).

In general, boundary condition specifications are not required in KENO V.a, so calculation models analyzed using KENO V.a require no special boundary conditions. However, in this evaluation, the infinite array cases use a single package with a reduced radius modeled with specular reflection on all faces of a surrounding cuboid. The energies and angular dependence of the neutrons are treated such that an infinite system with no neutron leakage is simulated.

For simplicity, the NCT and HAC sets of calculations were performed for selected ES-3100 array sizes by varying the water content of the ES-3100 package external to the containment vessel from zero to its maximum value. This technique bounds all NCT and HAC; however, only the relevant calculation results are used in determination of the CSI for criticality purposes.

Although four decimal places are shown for k_{eff} values in result tables, the actual accuracy of the code, for a particular calculation, may be on the order of ± 0.02–0.03 based on the spread in results for benchmark calculations (Y/DD-896/R1 and Y/DD-972R1). Also, the standard deviation of the mean for a particular calculation is on the order of 0.001 for benchmark cases and somewhat higher for the package calculations. Therefore, numerical values are considered physically meaningful or significant to the third decimal place. The primary reason for reporting four (or five) decimal places for a calculation result is to confirm that the result reported actually originated from a given output file. A value of 0.925 is the USL used for this safety analysis report for packaging (Sect. 6.8.3).

6.4 SINGLE PACKAGE EVALUATION

The HEU content of a package is in one of the following forms: metal of a specified geometric shape; metal of an unspecified shape and characterized as broken metal; uranium oxide; or UNX crystals. The bounding types of HEU content evaluated in this criticality analysis are 3.24-in. and 4.25-in.-diam cylinders; 2.29-in.-square bars; 1.5-in.-diam × 2-in.-tall slugs; cubes ranging from 0.25 to 1 in. on a side; broken metal; metal turnings, fines, or powder; solid HEU metal of unspecified geometric shape and characterized as broken metal; product oxide; skull oxide; UNH crystals; and unirradiated TRIGA reactor fuel elements.

Dimensions for bounding calculation models of a TRIGA fuel section are 1.44 in. in diameter × 5 in. tall. The 20% enrichment fuel contains more fissile mass than the 70% enrichment fuel on account of a higher uranium weight fraction and associated material density. A 20 wt % enriched TRIGA fuel element with 45 wt % U contains ≤ 307-g ^{235}U; whereas, a 70 wt % enriched TRIGA fuel with 8.5 wt % U contains ≤ 136-g ^{235}U. The physical parameters which characterize the TRIGA fuel are enrichment, uranium weight fraction, and the fuel diameter (Appendix 6.9.3.1). These parameters are addressed in this section demonstrating that the calculation models are bounding in the criticality evaluation.

Alloys of uranium may include aluminum, molybdenum, or zirconium. Uranium-aluminum (U-Al) alloy is typically 70 to 95 wt % aluminum. Uranium-molybdenum (U-Mo) alloys are typically 1.5 to 12 wt % molybdenum. U-Mo alloys may be plated with, clad with, or contain traces of aluminum, gold, stainless steel, nickel, and/or chromium. The enrichment of U-Al, U-Mo, and U-Zr alloys range from 92.65 to 93.21 wt % ^{235}U.

Where scattering media (aluminum, molybdenum, or zirconium) is counted as multiplying media (^{235}U), the alloy is conservatively assessed. Consider a canned content of U-Al which contains 940 g of uranium, 600 g of ^{235}U, and 4070 g of aluminum. In determining compliance with a loading limit, the loading of this content would be on the basis that the material contains 4670-g ^{235}U rather than 600-g ^{235}U.

6.4.1 Solid HEU Metal of Specified Geometric Shapes

For bare and reflected single packages with HEU metal content, the neutron multiplication factor increases as a function of the ^{235}U mass and the moisture fraction of the package external to the containment vessel (MOIFR). For example, consider the ES-3100 package loaded with three convenience cans for a total of 36,000-g ^{235}U. Each press-fit lid type can contains a single 3.24-in.-diam, 12,000-g cylinder of ^{235}U. The $k_{eff} + 2\sigma$ values in the bare package increase from 0.911 to 0.955 with increasing moisture fraction of the package external to the containment vessel (MOIFR), Cases **ncsbcyt11_36_1_1** through **ncsbcyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-2). The $k_{eff} + 2\sigma$ values increase from 0.918 to 0.955 with increasing MOIFR in the water-reflected package, Cases **ncsrcyt11_36_1_1** through **ncsrcyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-2). The addition of water to the package reduces the neutron leakage fraction (NLF), thereby increasing k_{eff}. Water reflection external to a flooded package is inconsequential to package reactivity as a comparison of results for Cases **ncsbcyt11_36_1_15** and **ncsrcyt11_36_1_15** indicates.

In this series of calculations using the ES-3100 package model with NCT geometry (Cases **ncsrcyt11_36_1_1** through **ncsrcyt11_36_1_15)**, the MOIFR is varied uniformly over the package model with the exception of the neutron poison of the body weldment liner inner cavity and the flooded containment vessel. The single-unit case with a MOIFR = 1.0 pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(b). This pseudo-HAC condition is more reactive than either the true NCT where both the containment vessel and Kaolite are dry [10 CFR 71.55(d)] or this evaluation for NCT where the containment vessel is flooded and the Kaolite is dry (in the as-manufactured condition, MOIFR ~ 0.0289). At MOIFR = 1.0, external water reflection of the package is inconsequential to package reactivity. Moisture in the Kaolite and in the recesses of the package acts as a close reflector that decreases neutron leakage away from the package.

The single-unit case with a MOIFR = 1E-20 pertains specifically to a package under pseudo-HAC where both the Kaolite and the recesses of the package do not contain **any** water or bound hydrogen. This configuration is less reactive than the cases for Kaolite in the as-manufactured condition or water-saturated Kaolite because water in the Kaolite will provide some neutron moderation and reflection of neutrons back into the content.

Single package reactivity changes slightly between the bare and reflected conditions, while NLF changes considerably over the range of water fractions. This behavior illustrates the dependence of package reactivity on internal conditions of the package. Bare packages with low MOIFR values manifest low reactivity (k_{eff} = 0.911) and high neutron leakage (NLF = 0.47). These parameters indicate that fast neutrons scattered in the packaging do not slow down significantly but escape the package. Consequently, neutron interaction between these packages when they are configured into an array is high. Bare packages with MOIFR values >1E-2 manifest increasing k_{eff} values (from 0.911 to 0.955) and reduced NLF values (from 0.47 to 0.18). The increase in k_{eff} occurs due to water present in the regions of the package external to the content which reflects neutrons back into the HEU content that would otherwise escape the package.

A series of calculations are performed using the calculation model of a water-reflected containment vessel loaded with 3.24-in.–diam cylinders. The three cylinders are aligned as depicted in Fig. 6.9.1-1 (Appendix 6.9.1) but in very close proximity due to the omission of can spacers. A parametric variation of water density from zero to 1.0 sp gr inside the containment vessel is performed for establishing moderation by water to the most credible extent. The calculated $k_{eff} + 2\sigma$ values for Cases **cvcrcyt11_36_1_1** through **cvcrcyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-1) increase monotonically from 0.907 to 0.974 with increasing moisture fraction inside the containment vessel (MOCFR). Maximum reactivity of the fissile material occurs in the flooded containment vessel.

10 CFR 71.55(b)(3) requires evaluation of the efficiency of the packaging as an external reflector to the containment vessel. Comparison of the calculated $k_{eff} + 2\sigma$ value for Case **cvcrcyt11_36_1_15** to the value for Case **ncsrcyt11_36_1_15** reveals that the flooded containment vessel under full water reflection is a more reactive configuration than the containment vessel inside a flooded ES-3100 packaging. The ES-3100 package is not as efficient a reflector as full water reflection provided to the flooded containment vessel. For this reason, calculation results for the flooded containment vessel rather than a flooded package are reported in Tables 6.1a (and Tables 6.1b–6.1f) for the evaluation of 10 CFR 71.55(b) requirements.

Examination of the results for Cases **cvcrcyt11_36_1** through **cvcrcyt11_18_1** indicates that an adequately subcritical loading is achieved when the mass loading is limited to 21,000-g ^{235}U (Case **cvcrcyt11_21_1**). Case **cvcrcyt11_36_2** reveals that the 277-4 canned spacers are adequate for mass loading >18,000-g ^{235}U but ≤ 36,000-g ^{235}U. These potential fissile (^{235}U) mass loading limits derived through the evaluation of 10 CFR 71.55(b) are listed in Table 6.1a in the information block where a description of the content appears for fissile material, "the most reactive credible configuration consistent with the chemical and physical form of the content." The finalized mass loading limit is derived at the conclusion of the array analysis for these content configurations.

The NCT tests under 10 CFR 71.71 and the HAC tests under 10 CFR 71.73 demonstrate that containment is not breached. Nevertheless, containment vessel flooding is assumed in the criticality calculations performed for the derivation of fissile material loading limits. The 7.1–10.1 kg quantities of evaluation water in both the NCT and HAC criticality calculations are not actually present in the containment vessel. Simulation of this condition in the criticality calculations produces fissile material content that is more reactive than actual. The evaluation water required in both the NCT and HAC criticality calculations bounds reasonable amounts of hydrogenous material present inside the containment vessel for solid HEU shapes.

Consider Case **cvcrcyt11_21_1** as the reference case where the calculated $k_{eff} + 2\sigma = 0.923$ (Table 6.9.6-1). The fissile material content is 21,000 g HEU metal at 100% enrichment and a density of 18.81109 g/cm^3. Three HEU cylinders (3.24-in. diam and 2.75425-in. tall) are stacked end-to-end starting at 0.0005 cm above the bottom of the containment vessel. The stack height is 20.98987 cm where each cylinder is separated by a 0.0001-cm–thick 277-4 canned spacer and 0.0012 cm of moderating material. Effectively, this configuration does not have 277-4 canned spacers, and no polyethylene is used in this calculation model. The water-filled cavity above the content is 57.74963 cm in height. As the input listing for Case **cvcrcyt11_21_1** (Appendix 6.9.7) indicates, ~9083 g of **evaluation** water fills the flooded containment vessel and the calculated H/X ratio is ~11.29. The calculated H/X ratio for the HEU content wrapped in 500 g polyethylene (hydrogenous packing material) inside a dry containment vessel is ~0.80.

Case **cvcrpcyt11_21_1** is the same as reference Case **cvcrcyt11_21_1,** except that 500-g polyethylene wraps three HEU cylinders with a uniform thickness of 0.54956 cm. The three wrapped HEU cylinders are stacked end-to-end starting at 0.0005 cm above the bottom of the containment vessel. Each wrapped cylinder is separated by a 0.0001-cm–thick 277-4 canned spacer and 0.0012 cm of moderating

material resulting in a stack height of 24.28733 cm. The water-filled cavity above the content is 57.74963 cm in height. At a density of 0.9200 g/cm^3, 500 g polyethylene adds 543.47826 cm^3 to the volume of the content and reduces the free volume of the containment vessel by an equal amount. As indicated in the case title card, 8540.1 g of **evaluation** water fills the flooded containment vessel. The 500 g polyethylene increases the overall H/X ratio inside the flooded containment vessel to 11.41. The calculated $k_{eff} + 2\sigma$ is 0.908 for this configuration (Table 6.9.6-1). While polyethylene having a greater hydrogen density than water is a slightly better moderating material than water, the presence of polyethylene in the calculation model provides separation between the fissile material resulting in a slight reduction in the calculated $k_{eff} + 2\sigma$ value. Case **cvdcrpcyt11_21_1** is the same as Case **cvcrpcyt11_21_1**, except that the containment vessel is dry. The calculated $k_{eff} + 2\sigma$ is 0.847 for Case **cvdcrpcyt11_21_1** (Table 6.9.6-1). The calculated $k_{eff} + 2\sigma$ value of 0.923 for reference Case **cvcrcyt11_21_1** without polyethylene is greater than the values for Cases **cvcrpcyt11_21_1** and **cvdcrpcyt11_21_1** with polyethylene. In the case of solid HEU shapes, the 7.1–10.1 kg quantities of evaluation water required in both the NCT and HAC criticality calculations bound reasonable amounts of hydrogenous material present inside the containment vessel.

Because convenience cans are not credited for providing configuration control in the containment vessel, it is possible for the fissile material to be spaced farther apart than shown in Fig. 6.9.1-1. A series of cases was run to evaluate the axial spacing of content inside the containment vessel. As shown in Table 6.9.6-3b, the separation distances between adjacent cylinders range from 0.0 to 8.75 in. (12.225 cm). Zero separation occurs when the base surfaces of adjacent cylinders are flush with the 277-4 canned spacer between them. Figure 6.9.1-1b depicts a section view of the containment vessel with 3.24-in.-diam cylinders at 4.826 and 0.254 cm separation. The calculated $k_{eff}+2\sigma$ values for Cases **ncsrcyat11_1_2_15** through **ncsrcyat11_12_2_15** (Table 6.9.6-3c) decrease with increasing separation distance. Loading configurations where solid HEU of specified geometric shape is axially positioned in contact with the can spacers are the most reactive ones.

Case **hcsrcyt12_36_1_15** (Appendix 6.9.6, Table 6.9.6-3) represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded with the exception of the neutron poison of the body weldment liner inner cavity. The containment vessel well is flooded with water, and the Kaolite contains maximum water content. This single-unit case with a MOIFR = 1.0 pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(e). The $k_{eff} + 2\sigma = 0.955$ for this HAC. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.002 change in the neutron multiplication factor.

Repeated for 4.25-in.-diam cylinders (Appendix 6.9.6, Tables 6.9.6-6 and 6.9.6-7); 2.29-in.-square bars (Tables 6.9.6-4 and 6.9.6-5); and 1.5-in.-diam × 2-in.-tall slugs (Tables 6.9.6-8 and 6.9.6-9), this type of analysis for the 3.24-in.-diam cylinders demonstrates that single packages with restricted fissile material (^{235}U) loading remain subcritical over the entire range of water content or MOIFR. HEU metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited.

Each TRIGA fuel element for shipment in the ES-3100 is to be disassembled. The active fuel consisting of three 5-in.-tall cylinders of $UZrH_{1.6}$ is to be packed into a metal-type convenience can (Sect. 6.2.1). The use of three loaded convenience cans in the ES-3100 is assumed in the criticality calculation models for ground transport. However, credit is only taken for vertical spacing provided by canned spacers when present. For configurations where canned spacers are not used, the TRIGA content is assumed stacked end-to-end. The three cylinders of the active fuel are modeled in triangular-pitch configuration within the radial boundary of the convenience can(s). The pitch used in the criticality calculation models for the NCT and HAC ground transport is 4.9809 cm (1.96 in.).

As shown in Table 6.9.6-19b, a set of parametric cases were run where the triangular pitch for the fuel content is varied from 1.44 in. (fuel sections touching) to 2.413 in. (fuel sections at maximum separation and touching the inner boundary of the convenience can). As shown in Fig. 6.17, the calculated k_{eff} + 2σ values increase slightly from 0.48 to an asymptotic value of ~ 0.53 at a pitch of 2.121 in. or a foci of 3.1106 cm (Table 6.9.6-19b). The foci of 2.8757 cm. for the TRIGA fuel sections used in the criticality calculation models, corresponds to a 1.96-in. pitch. The calculated k_{eff} + 2σ value is 0.527 for Case **cvcrtriga_1_15** (Table 6.9.6-19a) indicating that the configuration is in the range of optimum moderation. Moreover, the calculated k_{eff} + 2σ value is substantially below the USL. The foci is the distance perpendicular from the containment vessel's vertical axis to the center of each fuel section. The value is obtained from the computer input listing on the comment line for geometry unit 1006 which reads: " -2.875700 minus-y location lower cylinder."

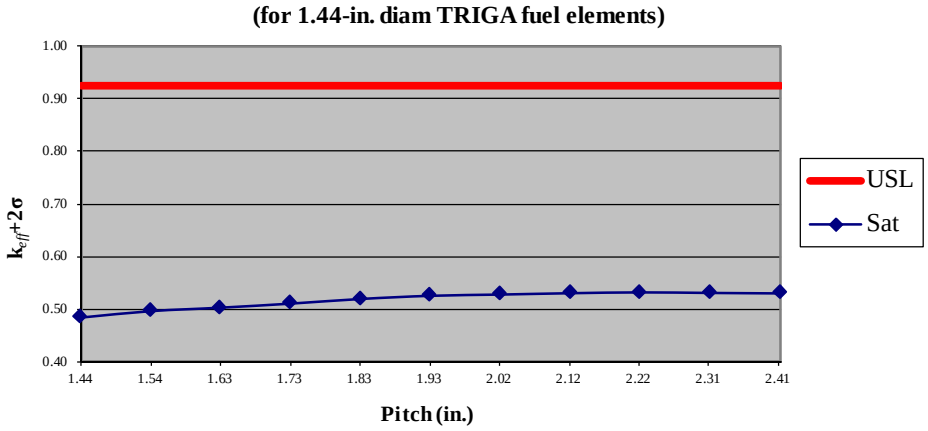


Fig. 6.17. k_{eff} + 2σ versus pitch for triangular arrangement of content in the containment vessel.

Parametric cases were also run as a function of the moisture fraction ("mocfr") in the containment vessel. As shown in Fig. 6.18, the k_{eff} + 2σ values decrease with decreasing water content in the containment vessel; and content spacing has less of an effect on k_{eff} at lower at the lower fractions.

The first of the three physical parameters which characterize the TRIGA fuel is enrichment. Table 6.9.6-19a presents results for 20 % enriched and 70 % enriched TRIGA fuel where the diameter of the active fuel is 1.44 in. The calculated k_{eff} + 2σ values for TRIGA fuel content at the lower enrichment is greater than for the fuel with the higher enrichment due to the greater quantity of fissile isotope present. The 20% enriched TRIGA fuel is considered the bounding content.

The second physical parameter which characterizes the TRIGA fuel is the uranium weight fraction. For a TRIGA fuel enriched to 20 wt % ^{235}U in U, the uranium weight fractions for the $UZrH_{1.6}$ fuel are: 45 wt %; 30 wt %; 20 wt %; 12 wt %; and 8.5 wt % U. A set of parametric cases were run where the uranium weight fraction is varied from the minimum value of 8.5 wt % to the maximum value of 45 wt %. Additionally, moderation in the containment vessel is varied from the dry to the flooded condition. As shown in Fig. 6.19, the k_{eff} + 2σ values decrease with both decreasing uranium weight fraction and decreasing water content in the containment vessel. Details are provided in Table 6.9.6-19c.

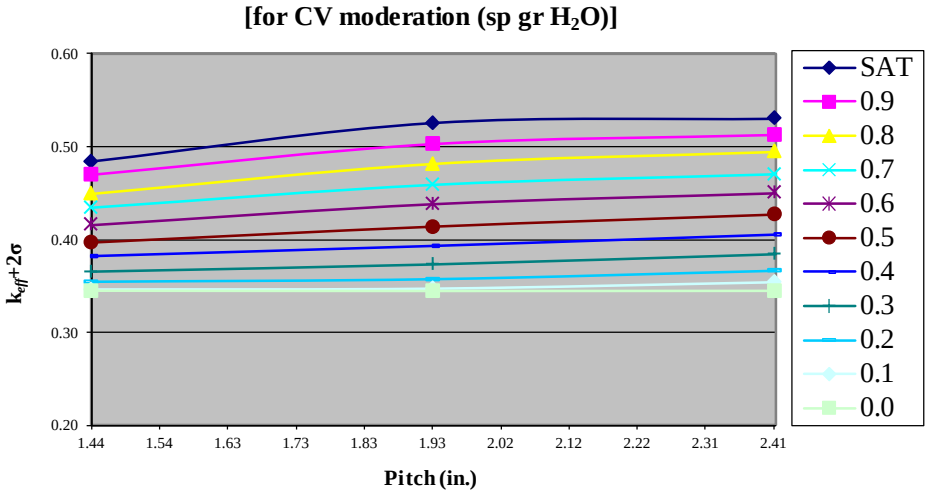


Fig. 6.18. $k_{eff} + 2\sigma$ versus triangular pitch over range of containment vessel moderation.

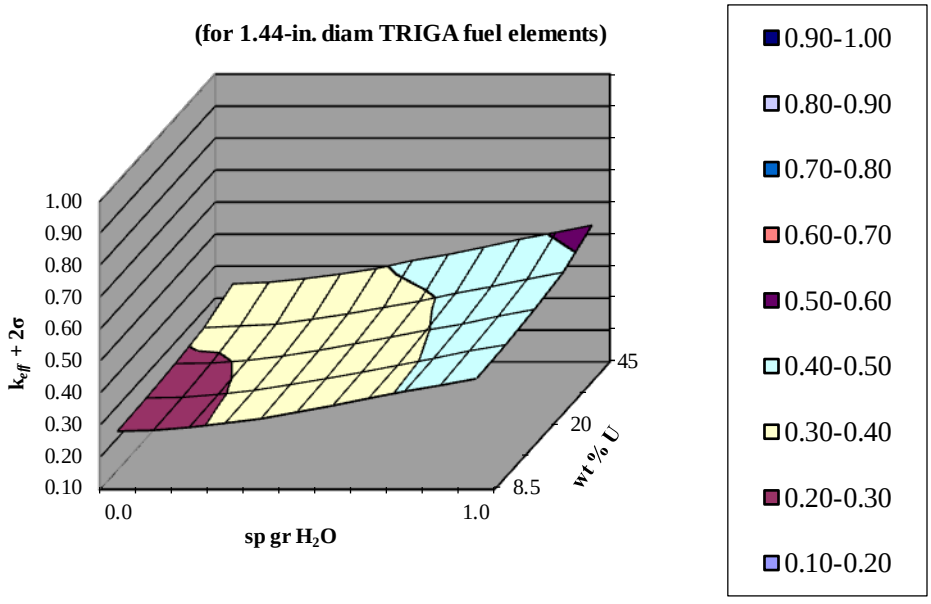


Fig. 6.19. $k_{eff} + 2\sigma$ as a function of uranium weight fraction and moderation.

Third physical parameter which characterizes the TRIGA fuel is active fuel diameter. The active fuel diameters are: 1.44 in.; 1.41 in.; 1.40 in.; 1.37 in.; 1.34in.; and 1.31 in. The smaller the diameter, the less the amount of ^{235}U is present resulting in lower $k_{eff} + 2\sigma$ values, as demonstrated later in this section.

Cases **cvcrtriga_1_1** through **cvcrtriga_1_15** (Appendix 6.9.6, Table 6.9.6-19a) represent the TRIGA fuel content in a flooded containment vessel, reflected by 30.48 cm of water. The flooded containment vessel under full water reflection is a more reactive configuration than the containment vessel inside of flooded ES-3100 packaging, Case **ncsrtriga_1_15_15** (Appendix 6.9.6, Table 6.9.6-20a). Further examination of the results in Table 6.9.6-20a indicates the content loading is adequately subcritical loading and that 277-4 canned spacers are not required for criticality control. Comparison of results for the NCT Case **ncsrtriga_1_15_15** and the HAC **hcsrtriga_1_15_15**, both with $k_{eff} + 2\sigma = 0.495$, reveal that changes to the packaging external to the containment vessel due to the HAC do not result in an appreciable change in the neutron multiplication factor for the single package.

Cases **ncsrtriga70_1_1_1** through **ncsrtriga70_1_15_15** (Appendix 6.9.6, Table 6.9.6-20b) represent the 70 % enriched TRIGA fuel content in a flooded ES-3100 package, reflected by 30.48 cm of water. Comparison of results for these cases with results for the 20 % enriched TRIGA fuel (Cases **ncsrtriga_1_1_1** through **ncsrtriga_1_15_15**) confirm that the 20 % enriched TRIGA fuel is the bounding content.

Cases **ncsrT70_131_1_1_15** through **ncsrT70_131_1_15_15** (Appendix 6.9.6, Table 6.9.6-20c) represent the 1.31-in.-diam TRIGA fuel content in a flooded ES-3100 package, reflected by 30.48 cm of water. Comparison of results for these cases with results for the larger 1.44-in.-diam TRIGA fuel content (Cases **ncsrtriga70_1_1_1** through ncsrtriga70_1_15_15) confirm that the 1.44-in.-diam TRIGA fuel is the bounding content.

10 CFR 71.55(d)(2) requires the geometric form of a package's content not be substantially altered under the NCT. Also, 10 CFR 7155(e)(1) requires that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration. However, conclusions about damage to the fuel content cannot be extrapolated from test data because a mock (test weight) content rather than actual TRIGA content is evaluated in the NCT and HAC tests of 10 CFR 71.71 and 10 CFR 71.73. Consequently, one way for addressing these requirements is to model the content in an extremely damaged condition and make a determination of subcriticality through a series of criticality calculations. Cases **ncsrt55d2_ 1_1_1**5 through **ncsrt55d2_1_15_15** (Appendix 6.9.6, Table 6.9.6-20d) represent TRIGA fuel content homogenized with variable density water over the free volume of the containment vessel, where the ES-3100 packaging is flooded and reflected by 30.48 cm of water. The variable density water ranges from the dry containment condition to the fully flooded condition. Credit for physical integrity of the content is not taken in this set of cases which model the substantially altered content. The calculation results in Table 6.9.6-20d indicate extremely damaged content (Case **ncsrt55d2_1_15_15** with $k_{eff} + 2\sigma = 0.611$) is more reactive than the unaltered configuration (Case **ncsrtriga_1_15_15** with $k_{eff} + 2\sigma = 0.403$). Nevertheless, both cases are adequately below the USL of 0.925 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to the HAC do not result in an appreciable change in the neutron multiplication for the single package, similar results are expected for the cases demonstrating compliance with 10 CFR 7155(e)(1).

The shipping configuration for disassembled TRIGA fuel addressed in this subsection is not the only permissible shipping configuration for TRIGA fuel in the ES-3100. TRIGA fuel may also be configured as clad fuel rods (Appendix 6.9.3.1). Each 15-in.-long rod is derived from a single TRIGA fuel element. The clad fuel rod consists of the 3 fuel pellets and the exterior sheath of stainless steel or aluminum clad. Clad fuel rods are packed into stainless steel or tin-plated carbon steel convenience cans

with a maximum of three fuel rods per loaded convenience can. This shipping configuration requires that only one convenience can is loaded with clad fuel rods.

Except for a 0.02-in.-thick sheath of stainless steel clad added to the exterior surface of the $UZrH_{1.6}$, a calculation model for the clad fuel rod configuration is essentially the same as the NCT shipping configuration model for disassembled TRIGA fuel. A 0.02-in. thickness of stainless steel is insignificant for an external reflection. As illustrated in Fig. 6.24 (Sect. 6.7.2), stainless steel up to several cm in thickness acts as a neutron absorber. Several inches in thickness are required for neutron multiplication to increase from neutron reflection by the stainless steel. The NCT shipping configuration model for disassembled TRIGA fuel is bounding. The same applies for TRIGA fuel with aluminum clad.

A clad fuel rod with 1.44-in.-diam fuel pellets contains 2,282.4-g $UZrH_x$ (Appendix 6.9.3.1) and ~179 to 191 g of stainless steel. Stainless steel tends to act as a neutron absorber; moreover, its presence as clad in the TRIGA fuel content replaces water moderator otherwise present in the geometry configuration of TRIGA fuel meats. When stainless steel is homogenized with the $UZrH_{1.6}$ as in the calculation model for package content in the extremely damaged condition [10 CFR 71.55(d)(2) and 10 CFR 7155(e)(1)], the stainless steel acts more effectively as a neutron absorber. However, the amount of stainless steel added and water displaced is not expected to have a statistically significant affect on neutron multiplication. Thus, the HAC shipping configuration model for disassembled TRIGA fuel (bare fuel meats) is bounding.

A clad fuel rod with 1.41-in.-diam fuel pellets contains ~2,188-g $UZrH_x$ and ~90 to 96 g of aluminum. While aluminum tends to act as a neutron scatter, its presence in the TRIGA fuel content replaces water moderator otherwise present in the geometry configuration of TRIGA fuel meats. The amount of aluminum added and water displaced is not sufficient to have a statistically significant affect on neutron multiplication. Thus, the HAC shipping configuration model for disassembled TRIGA fuel is also bounding for aluminum clad TRIGA fuel content.

The TRIGA content is to be transported by air; consequently, additional discussion is included in Sect. 6.7.

The 1.5-in.–diam × 2-in.–tall slugs may be packed up to ten items per press-fit lid type convenience can and up to twelve items per crimp-lid type convenience can. With nominal dimensions, each slug weighs ~1,090 g. With +1/16-in. tolerance on both the diameter and height, each slug in the calculation model weighs ~1218 g. As described in Appendix 6.9.1, different arrangements of slugs in the convenience cans are possible. A configuration of slugs in a flooded reflected containment vessel must be shown to be adequately subcritical and so limited either by the use of 277-4 canned spacers, by limitation of fissile mass, or by both.

Several slug arrangements depicted in Fig. 6.9.1-4b are evaluated for demonstrating that the most conservative arrangement of slugs is being analyzed. The blue marker shown in Fig. 6.9.1-4c depicts the 4.13-in. diam of the canned spacer. Content within a configuration radius of 2.125 in. (5.4 cm) are within the boundary of the convenience can wall. The convenience cans are not modeled and contents are allowed to project beyond the convenience can wall boundary. The slugs are modeled only as 100 wt % ^{235}U for this portion of the criticality evaluation. Cases **cvcr5st11_1_1**, **cvcr5est11_1_1**, **cvcr50st11_1**, **cvcr5e0st11_1**, **cvcr5u0st11_1**, and **cvcr5l0st11_1** depict very different spacing arrangements with five slugs per convenience can, three cans per package. The statistical difference in the calculated "$k_{eff} + 2\sigma$" values is insignificant. Cases **cvcr6e0st11_1** and **cvcr6st11_1_1** depict arrangements with six slugs per convenience can, and Case **cvcr70st11_1** depicts seven slugs per convenience can. (Considerable deformation of the 4.25-in.–diam convenience can wall is required to achieve all but the simple pentagonal-ring arrangement of slugs.) Calculation results reveal the primary dependence of the "$k_{eff} + 2\sigma$" value is on the fissile mass loading and the secondary dependence is on the arrangement and spacing of slugs. The calculation results

presented in Table 6.9.6-8 (Appendix 6.9.6) for a flooded containment vessel indicate that only five slugs per convenience can (18,277-g ^{235}U per package) may be loaded without the use of 277-4 canned spacers (Cases **cvcr5st11_1_1** and **cvcr5est11_1_1**). Further evaluation of the single package and array configurations are required. Also, results highlighted in red indicate that 277-4 canned spacers are required for the slug content.

The sensitivity of k_{eff} to the space between slugs arranged in a pentagonal ring is evident in the calculation results for Cases **cvcr5st11_1_2** and **cvcr5est11_1_2,** which model content for three convenience cans, each location with two pentagonal rings (10 slugs) per can. These two configurations represent degrees of separation between adjacent neighbors in the pentagonal rings of 0.0 cm and 1.0 cm, respectively. The most reactive configuration occurs when the slugs are spaced 1.0 cm apart from direct contact with adjacent neighbors in the pentagonal rings. Because positioning devices are not used in the convenience cans to control spacing and prevent an optimal arrangement of contents from occurring, both calculation models for slug arrangement are the basis for additional calculations where 277-4 canned spacers may not be required.

Cases **cvcr5st11_2_1**, **cvcr5est11_2_1**, **cvcr50st11_2**, **cvcr5e0st11_2**, **cvcr5u0st11_2**, and **cvcr5l0st11_2** represent the different spacing arrangements with five slugs per convenience can, three cans per package, and cans separated by canned spacers. Likewise, Cases **cvcr6e0st11_2** and **cvcr6st11_2_1** represent arrangements with six slugs per convenience can, three can per package, and cans separated by can spacers. Case **cvcr70st11_2** represents seven slugs per convenience can. While the differences in the calculated "$k_{eff} + 2\sigma$" values for equal numbers of slugs per can are ≤ 0.006, the "$k_{eff} + 2\sigma$" values are significantly below the USL. Again, the calculation results presented in Table 6.9.6-8 (Appendix 6.9.6) for these cases reveal the primary dependence of the "$k_{eff} + 2\sigma$" value is on fissile mass loading, and the secondary dependence is on the arrangement and spacing of slugs.

Case **cvcr6e0st11_2** models three sets of slugs, six slugs in a pentagonal ring with one slug in the center, and each set of slugs separated by a 277-4 canned spacer. Cases **cv0r6e0st11_2** and **cvwr6e0st11_2** are variations of the reference case where the 1.4-in. spacer is replaced with void in the first case and is replaced with water in the second case. Comparison of the "$k_{eff} + 2\sigma$" values between Cases **cvcr6e0st11_2** and **cv0r6e0st11_2** reveals that the spacers reduce k_{eff} by ~ 0.03. Comparison of the "$k_{eff} + 2\sigma$" values for Cases **cvcr6e0st11_2** and **cvwr6e0st11_2** reveals that axial spacing of the content provided by the content cans inside the containment vessel serves to reduce k_{eff}.

The calculation results presented in Table 6.9.1-8 for a flooded containment vessel indicate that up to ten slugs per convenience can (36,555-g ^{235}U per package) *might* be loaded when 277-4 canned spacers are used. Conceivable arrangements are considered in Cases **cvcr5st11_2_2**, **cvcr5est11_2_2**, **cvcr6e4st11_2**, and **cvcr73st11_2** (Table 6.9.6-8). Suitability is contingent on the results of single package and array calculations.

Cases **ncsr5est11_2_1_1** through **ncsr5est11_2_1_15** (Appendix 6.9.6, Table 6.9.6-9) model a reflected package with one pentagonal ring of slugs per content location with 277-4 canned spacers between content locations and HEU content at 100 wt % ^{235}U. The $k_{eff} + 2\sigma$ values range from a low value of 0.688 to 0.736. These results show that the most reactive configuration is the flooded condition with MOIFR=1.0.

As shown by the cylindrical content calculation models, the ES-3100 package is not as an efficient reflector as full water reflection provided to the flooded containment vessel. This is also true for content loadings of one pentagonal ring of slugs per content location without 277-4 canned spacers between locations and HEU content at 100 wt % ^{235}U. For Cases **cvcr5est11_1_1** and **ncsr5est11_1_1_15**, the $k_{eff} + 2\sigma$ values are 0.910 and 0.871, respectively. Likewise, the $k_{eff} + 2\sigma$ values

are 0.901 and 0.867 for content loadings of two pentagonal rings of slugs per content location with 277-4 canned spacers between locations, Cases **cvcr5est11_2_2** and **ncsr5est11_2_2_15**, respectively.

For the flooded containment vessel under full water reflection and loaded with the slugs in a pentagonal arrangement and 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ value is 0.903, Case **cvcr5st11_2_2** [10 CFR 71.55(b)]. This value is below the USL value of 0.925. For packages with the required 1.4-in. spacers, the calculated $k_{eff} + 2\sigma$ value is 0.878 for the water-reflected package, Case **ncsr5st11_2_2_15** [10 CFR 71.55(d)]. Case **hcsr5st11_02_2_15** represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded except the neutron poison of the body weldment liner inner cavity. This single-unit case with a MOIFR = 1.0 pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(e). The $k_{eff} + 2\sigma$ value is 0.872 for this HAC. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.001 change in the neutron multiplication factor.

6.4.2 HEU Broken Metal; Solid HEU Metal with Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder

Broken metal pieces are distinguished from turnings, fines, or powder as having a surface-area-to-mass ratio of not greater than 1 cm^2/g or must not pass through a 3/8-in. mesh sieve (or equivalent size-grading method). In the containment vessel calculations, broken metal is evaluated using the "lha" content model (Fig. 6.9.1-5c). The "lha" approximation model is derived from the "sqa" model (Figs. 6.9.1-5b) where HEU metal is homogenized with the water inside the rectangular lattice formed by an array of discretely modeled items of uniform size and shape (Appendix 6.9.1). The overall volume (and shape) of the content "envelope" containing the HEU and the amount of interstitial moderator between the actual pieces of HEU is preserved in the "lha" content model. This representation of discrete solid HEU broken metal in the containment vessel calculation model as fissile material homogenized with moderator is bounding (Table 6.9.3.1-2). In the containment vessel calculations, turnings, fines, and powder are evaluated using the "cha" content model (Fig. 6.9.1-5d) where HEU metal and the water inside a flooded containment vessel are homogenized as a uranium "solution" and dispersed over the internal volume of the containment vessel.

Credit for the presence of convenience cans is not taken in either the "lha" or the "cha" model. Content spacing provided by the convenience cans is absent in the models such that the canned spacer, if present, is located above the rectangular lattice (content envelop) between the convenience can locations (Fig. 6.9.1-5c). Credit for the presence of canned spacers is taken for broken metal but not for fines, turnings, and powder where the fissile material form is not conducive to maintaining spacer separation nor prevent gravitation of the canned spacers to the bottom of the containment vessel. For conservatism, the "cha" model was used to represent HEU metal content in the single package calculations.

Like packages with solid HEU metal shapes, the neutron multiplication factor for reflected single packages with HEU broken metal, turnings, fines, or powder increases as a function of the ^{235}U mass and the MOIFR. For example, consider the ES-3100 package loaded with three convenience cans for a total of 35,142-g ^{235}U. The $k_{eff} + 2\sigma$ values range from 0.814 to 0.891 with increasing MOIFR in the water-reflected package [Cases **ncsrbmt11_36_1_1** through **ncsrbmt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-11)]. The addition of water to the package reduces the NLF, thereby increasing k_{eff}.

For the containment vessel loaded with the broken metal content (excluding turnings, fines, or powder) and without 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ values increase from 0.751 to 0.949 as the water content in the containment vessel increases [Cases **cvr3lha_36_1_8_1** through **cvr3lha_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-10)]. Cases **cvr3lha_36_1_8_15** through **cvr3lha_36_1_1_15** model the flooded containment vessel with 35 kg of broken HEU metal where the

enrichment ranges from 100 to 19 wt % ^{235}U. The $k_{eff} + 2\sigma$ values decrease from 0.949 to 0.657. The $k_{eff} + 2\sigma = 0.949$ for Case **cvr3lha_36_1_8_15** indicates that the 35,142-g ^{235}U mass loading at 100% enrichment with canned spacers absent must be reduced below 35,142-g ^{235}U for establishing a loading limit over the range of 95 to 100 wt % ^{235}U. The result for Case **cvr3lha_26_1_8_15** indicates that for an enrichment of 100 wt % ^{235}U, the mass loading over the range 95 < enr. ≤ 100 wt % ^{235}U cannot exceed 25,894-g ^{235}U in the absence of canned spacers. (The orange highlighted cases in Table 6.9.6-10 indicate potential fissile loading limits, or evaluation limits.)

The result for Case **cvr3lha_29_1_7_15** indicates that for an enrichment of 95 wt % ^{235}U, the mass loading limit conservatively applied over the range 90 < enr. ≤ 95 wt % ^{235}U cannot exceed 27,252-g ^{235}U in the absence of canned spacers. Application of this 27,252-g ^{235}U limit to higher enrichment material is non-conservative, as illustrated by the result for Case **cvr3lha_28_1_8_15** where $k_{eff} + 2\sigma = 0.933$ for 100 wt % ^{235}U. As the enrichment increases, the mass loading limit must decrease from 27,252-g to 25,894-g^{235}U in this example due to less ^{238}U present for neutron absorption. Potential fissile loading limits for the reduced enrichment ranges are derived in a similar manner. For enrichments ≤ 60 wt % ^{235}U, the containment vessel is load-limited to 35,320-g U. As enrichment drops from 60 to 19 wt % ^{235}U, the $k_{eff} + 2\sigma$ values decrease from 0.829 to 0.657. The ^{235}U (or U) evaluation limits conservatively applied over the indicated ranges of enrichment are listed in the column headings of Table 6.1c. These evaluation limits represent the maximum amount of ^{235}U (or U) permissible in a flooded, reflected containment vessel for maintaining an adequate margin of subcriticality.

For the containment vessel loaded with the HEU metal content in the form of turnings, fines, or powder and without 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ values increase from 0.613 to 0.983 as the water content in the containment vessel increases [Cases **cvr3cha_36_1_8_1** through **cvr3cha_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-10)]. Cases **cvr3cha_36_1_8_15** through **cvr3cha_36_1_1_15** model the flooded containment vessel with 35.32 kg of HEU metal turnings, fines, or powder having an enrichment ranging from 100 to 19 wt % ^{235}U. The $k_{eff} + 2\sigma$ values decrease from 0.983 to 0.791. The $k_{eff} + 2\sigma = 0.983$ for Case **cvr3cha_36_1_8_15** indicates that the 35,142-g ^{235}U mass loading at 100% enrichment without canned spacers must be reduced in order to be considered as a loading limit over the range of 95 to 100 wt % ^{235}U. The result for Case **cvr3cha_8_1_8_15** indicates that for an enrichment of 100 wt % ^{235}U, the mass loading conservatively applied over the range 95 < enr. ≤ 100 wt % ^{235}U cannot exceed 7,398-g ^{235}U in the absence of canned spacers.

The result for Case **cvr3cha_12_1_7_15** indicates that for an enrichment of 95 wt % ^{235}U, the mass loading conservatively applied over the range 90 < enr. ≤ 95 wt % ^{235}U cannot exceed 10,549-g ^{235}U in the absence of canned spacers. Similarly, the application of this 10,549-g ^{235}U limit for HEU metal turnings, fines, or powder in the range 90 < enr. ≤ 95 wt % ^{235}U to higher enrichment material in the range 95 < enr. ≤ 100 wt % ^{235}U is non-conservative. As the enrichment increases, the mass loading limit must decrease from 10,549-g to 7,398-g ^{235}U in this example due to less ^{238}U present for neutron absorption. The result for Case **cvr3cha_16_1_6_15** indicates that for an enrichment of 90 wt % ^{235}U, the mass loading conservatively applied over the range 80 < enr. ≤ 90 wt % ^{235}U cannot exceed 14,167-g ^{235}U in the absence of canned spacers. The result for Case **cvr3cha_25_1_5_15** indicates that for an enrichment of 80 wt % ^{235}U, the mass loading conservatively applied over the range 70 < enr. ≤ 80 wt % ^{235}U cannot exceed 19,284-g ^{235}U in the absence of canned spacers. The result for Case **cvr3cha_36_1_4_15** indicates that for an enrichment of 70 wt % ^{235}U, the mass loading conservatively applied over the range 60 < enr. ≤ 70 wt % ^{235}U cannot exceed 24,693-g ^{235}U in the absence of canned spacers. The result for Case **cvr3cha_36_1_3_15** indicates that for an enrichment of 60 wt % ^{235}U, the mass loading conservatively applied over the range 40 < enr. ≤ 60 wt % ^{235}U cannot exceed 21,192-g ^{235}U in the absence of canned spacers. As enrichment drops from 60 to 19 wt % ^{235}U, the $k_{eff} + 2\sigma$ values decrease from 0.900 to 0.791. However, the containment vessel is load-limited to 35,320-g U; therefore, the maximum permissible loadings shown for Cases **cvr3cha_36_1_2_15** and **cvr3cha_36_1_1_15** are not

achievable. For this reason, the uranium mass rather the fissile isotope mass (g ^{235}U) is indicated as the potential mass loading limit for ≤ 60 wt % ^{235}U. The ^{235}U (or U) evaluation limits conservatively applied over the indicated ranges of enrichment are listed in the column headings of Tables 6.1d. These evaluation limits represent the maximum amount of ^{235}U (or U) in the form of HEU metal turnings, fines, or powder permissible in a flooded, reflected containment vessel for maintaining an adequate margin of subcriticality.

The most reactive credible configuration consistent with the chemical and physical form of the material consists of the containment vessel under full water reflection but with 277-4 canned spacers absent between content locations. For the flooded containment vessel loaded with the HEU broken metal content (excluding turnings, fines, or powder), the $k_{eff} + 2\sigma = 0.918$ in Case **cvr3lha_26_1_8_15** [Table 6.1c, 10 CFR 71.55(b)]. For the flooded containment vessel loaded with HEU metal turnings, fines, or powder (excluding unspecified geometric shape and characterized as broken metal, or broken metal), the $k_{eff} + 2\sigma = 0.923$ in Case **cvr3cha_8_1_8_15** [Table 6.1d, 10 CFR 71.55(b)].

For single packages loaded with HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder), the calculated $k_{eff} + 2\sigma$ value for Case **ncsrbmt11_36_1_15** is 0.891 [Tables 6.1c and 6.1d, 10 CFR 71.55(d)]. Case **hcsrbmt12_36_1_15** (Appendix 6.9.6, Table 6.9.6-11) represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded except the neutron poison of the body weldment liner inner cavity. This single-unit case with a MOIFR = 1.0 pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(e) (Tables 6.1c and 6.1d). The $k_{eff} + 2\sigma = 0.891$ for this HAC condition. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC does not result in detectible change in the neutron multiplication factor.

The finalized mass loading limits documented in Table 6.2a are derived from Tables 6.1c and 6.1d at the conclusion of the array analyses after consideration of other packing arrangements (i.e., single package under NCT and HAC and the various package array configurations under NCT and HAC).

6.4.3 HEU Oxide

HEU product oxide content is non-hygroscopic or mildly hygroscopic. The bulk density of HEU oxides considered for shipment in the ES-3100 ranges from 0.5 to 6.54 g/cm^3. HEU product oxides with a low bulk density from 0.5 to 2.0 g/cm^3 are evaluated in Appendix 6.9.11. HEU skull oxide is a less dense form of U_3O_8 intermixed with graphite. Of interest are those compositions with carbon/fissile uranium (C/^{235}U) ratios up to 2.3×10^5 µg C/g^{235}U. The quantity of fissile uranium is extremely low where even higher C/^{235}U ratios are present. Removal of the carbon limit (i.e., 921-g C) is addressed in Appendix 6.9.11.

HEU product oxide content may be packed in polyethylene bottles or metal convenience cans; HEU skull oxide content is packed in metal convenience cans. Polyethylene bottles and hydrogenous packing material are represented by 500 g polyethylene. While both the size and shape of the polyethylene bottles prevents the use of 277-4 canned spacers with product oxide loadings, the 10-in. height of the metal convenience cans eliminates the use of 277-4 canned spacers for product or skull oxide content packaged in these size cans. However, the convenience cans are not modeled in this criticality evaluation and this analysis is performed from the standpoint that metal-type convenience cans may be used for both oxide types.

HEU oxide content is not considered a "rigid" content like solid or broken HEU metal. For the calculation models of HEU oxides, the polyethylene is homogenized with the saturated bulk oxide. At a density of 0.9200 g/cm^3, polyethylene adds 543.47826 cm^3 to the volume of the saturated bulk oxide and reduces the free volume of the containment vessel by an equal amount. The evaluation water in the void region of the containment vessel fills the volume of the containment vessel that not occupied by oxide content. (The void region of the containment vessel is defined as the containment vessel volume minus the oxide content volume.) Because of the differences in densities and compositions, product oxides are addressed separately from skull oxides.

Like packages with HEU metal or broken metal, the neutron multiplication factor for reflected single packages with HEU oxide increases as a function of increasing MOIFR and decreases with decreasing ^{235}U mass. For example, consider the ES-3100 package loaded with oxide at 6.54 g/cm^3 in three convenience cans for a total of 24,000-g UO_2 (21,125-g ^{235}U). The $k_{eff} + 2\sigma$ values range from 0.724 to 0.804 with increasing MOIFR in the reflected package [Cases **ncsrpoxt11_1_24_1** through **ncsrpoxt11_1_24_15** (Table 6.9.6-13)]. The addition of water to the package reduces the NLF, thereby increasing k_{eff}. The flooded, reflected package is the most reactive single package configuration; consequently, MOIFR is treated as a constant rather than a variable in subsequent "**pdox**" cases.

Parametric calculations are performed for oxide content loadings in a flooded, reflected package by varying the oxide bulk density from 6.54 g/cm^3 to a lower value limited by the capacity of the convenience cans. The maximum content capacity of the ES-3100 is ~6,975 cm^3, where each of three 4.25-in.-diam × 10.0-in.-tall convenience cans has a capacity of ~2,375 cm^3. As shown in Table 6.9.6-13a, calculations for a loading of 24,000-g UO_2 are performed at bulk densities of 6.54 g/cm^3, 5.0 g/cm^3, and 4.0 g/cm^3, but not 3.0 g/cm^3 because the capacity of the convenience cans is exceeded for this mass loading. Note that Case **ncsrpoxt11_1_24_15** (Table 6.9.6-13) is identical to Case **ncsrpdoxt11_1_5_24** (Table 6.9.6-13a). Results for the parametric Cases **ncsrpdoxt11_1_*n*_24**, **ncsrpdoxt11_1_*n*_20**, and **ncsrpdoxt11_1_*n*_15** reveal the consistent increase in the $k_{eff} + 2\sigma$ values as the bulk density decreases. This increase in neutron multiplication is due to the increased moderation of the HEU oxide.

Cases **ncsrpdoxt11_1_*n*_14** for UO_2 (12,323-g ^{235}U), **ncsrpdoxt11_2_*n*_14** for U_3O_8 (11,850-g ^{235}U), and **ncsrpdoxt11_3_*n*_14** for UO_3 (11,627-g ^{235}U) evaluate the ES-3100 package loaded with 14 kg oxide over the range of bulk density "*n*." The $k_{eff} + 2\sigma$ values reveal a consistent increase over the range of density. Results for Cases **ncsrpdoxt11_2_1_14** and **ncsrpdoxt11_3_1_14** indicate that both the U_3O_8 content ($k_{eff} + 2\sigma = 0.778$) and the UO_3 content ($k_{eff} + 2\sigma = 0.760$) are bounded by the UO_2 content ($k_{eff} + 2\sigma = 0.814$). Even though the capacity of the convenience cans is exceeded by 25 g, these cases are retained for the purpose of illustrating this point.

Results for a reflected containment vessel loaded with HEU oxide reveal the same trends in the $k_{eff} + 2\sigma$ values as do results for the reflected package; however, the $k_{eff} + 2\sigma$ values are ~0.1 greater in the containment vessel cases. For the flooded containment vessel loaded with UO_2, the $k_{eff} + 2\sigma$ values increase from 0.838 to 0.911 with decreasing bulk density [Cases **cvcrpdoxt11_1_5_14_15** through **cvcrpdoxt11_1_1_14_15** (Table 6.9.6-12 and Fig. 6.9.1-6)]. For the dry containment vessel, the $k_{eff} + 2\sigma$ values increase from 0.824 to 0.912 [Cases **cvcrpdoxt11_1_5_14_1** through **cvcrpdoxt11_1_1_14_1** (Table 6.9.6-12 and Fig. 6.9.1-6)]. Comparison of results for high density UO_2 oxide saturated with 862 g water reveals a small increase in $k_{eff} + 2\sigma$ from 0.824 to 0.838 due to flooding of the containment vessel. Comparison of results for low density UO_2 oxide saturated with 5,712 g water reveals an insignificant increase in $k_{eff} + 2\sigma$ due to flooding of the containment vessel, [Cases **cvcrpdoxt11_1_5_14_15** and **cvcrpdoxt11_1_5_14_1** (Table 6.9.6-12 and Fig. 6.9.1-6)].

Cases **cvcrpdoxt11_1_11_14_15** through **cvcrpdoxt11_1_1_14_15** demonstrate that the $k_{eff} + 2\sigma$ values decrease for decreased mass loadings of HEU oxide at constant bulk density.

For the flooded containment vessel under full water reflection containment, the $k_{eff} + 2\sigma$ value is 0.914, Case **cvcrpdoxt11_1_3_24_15** [10 CFR 71.55(b)]. The $k_{eff} + 2\sigma$ value is 0.817 for water-reflected package, Case **ncsrpdoxt11_1_3_24** [10 CFR 71.55(d)]. Case **hcsrpdoxt12_1_3_24** (Table 6.9.6-13a) represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded except the neutron poison of the body weldment liner inner cavity. This single-unit case pertains specifically to the flooded drum under conditions specified in 10 CFR 71.55(e). The $k_{eff} + 2\sigma$ value is 0.819 for this HAC condition. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.002 change in the neutron multiplication factor.

Cases **cvcrsk3cc_1_15_17** through **cvcrsk3cc_10_15_17** (Appendix 6.9.6, Table 6.9.6-17) evaluate the 10 skull oxide compositions identified Table 6.9.3.1-3b, where the containment vessel is loaded with 3 convenience cans. The fissile enrichment is ~70 wt % ^{235}U for contents "**sk3cc_1**" through "**sk3cc_5**" and ~38 wt % ^{235}U for contents "**sk3cc_6**" through "**sk3cc_8**." The observed maximums of 7.1 kg skull oxide and ~93.2 wt % ^{235}U enrichment present in 292 convenience cans are the basis for the hypothetical contents "**sk3cc_9**" and "**sk3cc_10**," where unidentified material is treated as ^{235}U and the carbon content is either maximized or minimized. Content "**sk3cc_10**" differs from "**sk3cc_9**" in that 921 g of graphite in the skull oxide is replaced with 921-g ^{235}U in the form of U_3O_8. Content "**sk3cc_10**" is more representative of high enrichment skull oxides where < 85 g of graphite is present. For each of the 10 content models, 513 g of the skull oxide content is modeled as polyethylene, representing the potential use of hydrogenous packing material. The U_3O_8 content ranges from 8 to 21 kg, while the ^{235}U content ranges from 3.7 to 16.4 kg. The graphite content ranges from 0 to 921-g C, and the C/^{235}U ratio ranges from 0 to 223,432 µg C/g ^{235}U. For Cases **cvcrsk3cc_1_15_17** through **cvcrsk3cc_10_15_17** at both saturation moisture and full graphite content, the $k_{eff} + 2\sigma$ values range from 0.759 to 0.855 in the flooded, water-reflected containment vessel. Cases **cvcrsk3cc_9_15_17** and **cvcrsk3cc_10_15_17** reveal that $k_{eff} + 2\sigma$ increases slightly when the 921 g of carbon in the skull oxide is replaced with 726-g ^{235}U in the form of U_3O_8.

Cases **cvcrsk3cc_4_1_1** through **cvcrsk3cc_4_*m*_*g*** evaluate the effects of moisture and skull oxide graphite content on reactivity. The case designator "***m***" ranges from 1 to 15, signifying the variation in moisture; "***g***" ranges from 1 to 17, signifying the variation in graphite. Examination of results indicates that moisture content has a predominate effect on the neutron multiplication factor, while variation in graphite content has a minor effect. The peak $k_{eff} + 2\sigma$ value occurs at saturated moisture and full graphite content.

Cases **ncsrsk_1_15** through **ncsrsk_10_15** (Appendix 6.9.6, Table 6.9.6-18a) model the 10 skull oxide compositions in a flooded containment vessel in a water reflected package. The $k_{eff} + 2\sigma$ values range from 0.641 to 0.745. Likewise, Cases **hcsrsk_1_15** through **hcsrsk_10_15** (Appendix 6.9.6, Table 6.9.6-18b) evaluate infinite arrays damage packages. The $k_{eff} + 2\sigma$ values ranging from 0.658 to 0.767 are not statistically significantly different from the NCT case results.

Cases **ncsrsk_9_1** through **ncsrsk_9_15** evaluate the bounding skull oxide content containing ~19.9 kg U_3O_8 and 921 g graphite, where the saturation moisture is varied from 0 to 3801 g water. Likewise, Cases **ncsrsk_10_1** through **ncsrsk_10_15** evaluate the skull oxide content containing ~20.8 kg U_3O_8 where the 921 g of graphite in the skull oxide is replaced with 726-g ^{235}U in the form of U_3O_8. The $k_{eff} + 2\sigma$ values range from 0.403 to 0.741 in the former set of cases and range from 0.404 to 0.746 in the latter set of cases. The $k_{eff} + 2\sigma$ values are well below the USL value of 0.925, indicating that canned spacers are not required for criticality control. Moreover, these results indicate that moisture content has a predominate effect on the neutron multiplication factor, while the graphite content has an insignificant effect.

6.4.4 UNH Crystals

UNH crystal content is to be packed in Teflon bottles, which may be placed in polyethylene bags. The Teflon bottles are not credited for containing the UNH crystal content. The 277-4 canned spacers are not used in this packing configuration. Teflon is polytetrafluoroethylene (or polyethylene tetrafluoride) having a monomer formula of C_2F_4 with a melting point of ~280°C (536°F). Teflon will not melt at the much lower containment vessel inner wall temperatures associated with NCT and HAC. The use of Teflon and polyethylene packing material is conservatively represented by 500 g of polyethylene in the calculation model. UNH crystal content is not considered a "rigid" content like solid or broken HEU metal. Like HEU oxide content, the UNH crystal content is homogenized with the polyethylene.

Unlike the other HEU contents, UNH crystals are soluble in water. The most reactive content condition occurs at an optimum solution concentration derived from the UNH crystal loading and the volume of water flooding the containment vessel. Both flooding of the containment vessel and a reduced loading of UNH crystals going into solution is required to achieve the most reactive configuration.

Consider a flooded containment vessel with the UNH crystals in solution and no polyethylene. For Cases **cvcrunhct11_24_1** through **cvcrunhct11_1_1** (Table 6.9.6-14), the $k_{eff} + 2\sigma$ values range from 0.823 to 0.609 and optimum concentration occurs at ~9,000-g UNH (Case **cvcrunhct11_9_1**, $k_{eff} + 2\sigma = 0.857$). Consider a flooded containment vessel with a solution of UNH crystals homogenized with 500 g polyethylene. For Cases **cvcrpunhct11_24_15** through **cvcrpunhct11_1_15** (Table 6.9.6-14), the $k_{eff} + 2\sigma$ values range from 0.827 to 0.613 and optimum concentration occurs at ~10,000-g UNH (Case **cvcrpunhct11_10_15**, $k_{eff} + 2\sigma = 0.863$). The replacement of water with 500 g of polyethylene in the latter set of cases results in changes to the neutron multiplication factor on the order of ~0.004 to 0.006. The concentration for a 24,000 g loading in both set of cases is 1,106-g ^{235}U per liter of flooded containment vessel. In the calculation of the uranium concentration, the solution volume is not reduced by the volume of polyethylene because polyethylene is homogenized with UNH in the solution.

For Cases **cvcrpunhct11_24_1** through **cvcrpunhct11_1_1** (Table 6.9.6-14), the homogenized UNH crystals and polyethylene are dispersed over a dry containment vessel. The $k_{eff} + 2\sigma$ values range from 0.769 to 0.251 as the mass loading decreases. Comparison with results for corresponding Cases **cvcrpunhct11_24_15** through **cvcrpunhct11_1_15** for a flooded containment vessel reveals that the most reactive content condition occurs for UNH in the solution state.

For Cases **cvcrbpunhct11_24_15** through **cvcrbpunhct11_1_15** (Table 6.9.6-14), homogenized UNH crystals and polyethylene are settled on the bottom of the containment vessel and the residual volume above it is flooded. The $k_{eff} + 2\sigma$ values range from 0.817 to 0.553 as the mass loading decreases. For Cases **cvcrbpunhct11_24_1** through **cvcrbpunhct11_1_1**, the residual volume above the content is dry. Likewise, the $k_{eff} + 2\sigma$ values range from 0.815 to 0.478 as the mass loading decreases.

Comparison of results for corresponding Cases **cvdrpunhct11_*n*_1** and **cvcrbpunhct11_*n*_15** reveal greater changes in the k_{eff} values occurring at the lower mass loadings when dispersed content is settled to the bottom of the containment vessel. Nevertheless, interspersed moderation has a dominant effect on k_{eff} occurring when settled content goes into solution (Case **cvcrbpunhct11_10_15** vs Case **cvcrpunhct11_10_15**).

Similar to packages loaded with HEU metal, broken metal, or oxide, the neutron multiplication factor for a reflected single package with UNH crystals increases as a function of MOIFR. Consider the ES-3100 package loaded with bottles for a total of 24,000-g UNH crystals (11,303-g ^{235}U). For Cases **ncsrunhct11_24_1_1** through **ncsrunhct11_24_1_15** (Table 6.9.6-15), the $k_{eff} + 2\sigma$ values range from 0.605 to 0.702 with increasing MOIFR in the water-reflected package. For Cases **ncsrpunhct11_24_1** and **ncsrpunhct11_24_15** (Table 6.9.6-15), the $k_{eff} + 2\sigma$ values range from 0.609 to 0.708 with increasing

MOIFR in the water-reflected package. These cases confirm that the replacement of water with 500 g of polyethylene results in changes to the neutron multiplication factor on the order of ~0.004 to 0.006.

For a flooded containment vessel with UNH crystals in solution, the $k_{eff} + 2\sigma$ values range from 0.702 to 0.646 [Cases **ncsrunhct11_24_1_15** through **ncsrunhct11_2_1_15** (Table 6.9.6-15)]. Similarly, for a flooded containment vessel with a solution of UNH crystals homogenized with 500 g of polyethylene, the $k_{eff} + 2\sigma$ values range from 0.708 to 0.545 [Cases **ncsrpunhct11_24_15** through **ncsrpunhct11_1_15** (Table 6.9.6-15)]. At optimal concentration (~8,000-g UNH), the calculated $k_{eff} + 2\sigma$ value is 0.863 for Case **cvcrpunhct11_10_15** and $k_{eff} + 2\sigma = 0.753$ for Case **ncsrpunhct11_8_15**. The water-reflected containment vessel is more reactive than the water-reflected package; therefore, the result for Case **cvcrpunhct11_10_15** is reported [10 CFR 71.55(b)]. The result for Case **ncsrpunhct11_8_15** having the maximum $k_{eff} + 2\sigma$ value is reported for the NCT water-reflected package [10 CFR 71.55(d)].

Unlike solid HEU metal and oxide content, which are confined to the containment vessel and only water leakage into the containment vessel need be considered, the evaluation of UNH crystal content for compliance with 10 CFR 71.55(b) also requires that the leakage of liquid HEU contents out of the containment be addressed. This is because UNH crystals are soluble in water and would dissolve in the water flooding the containment vessel and the containment vessel well. For a content loading of 24,000-g UNH, the uranium concentration inside the containment vessel drops from 1,106-g ^{235}U/L to 710-g ^{235}U/L. Optimum solution concentrations occurs for fissile mass loadings of ~15,000-g UNH. In the calculation of the uranium concentration, the solution volume is not reduced by the volume of polyethylene because polyethylene is homogenized with UNH in the solution.

Cases **hcsrpunhct12_8_15** (Table 6.9.6-15) and **icsrpunhct12_15_15** (Table 6.9.6-16) represent the HAC model of the damaged ES-3100 package where the outer dimensions of the package are reduced accordingly. For Case **hcsrpunhct12_8_15**, the dilution of the UNH crystals is confined to the containment vessel, and maximum reactivity occurs at ~8000-g UNH homogenized with 500 g polyethylene. For Case **icsrpunhct12_15_15**, UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. The fissile material is uniformly distributed over the volume of the containment vessel and the well, but the polyethylene is confined to the containment vessel. Maximum reactivity occurs at ~15,000-g UNH. These single-unit cases with a MOIFR = 1.0 pertain specifically to the flooded drum under conditions specified in 10 CFR 71.55(e), where the $k_{eff} + 2\sigma$ values are 0.752 and 0.814 for this HAC condition. The result for Case **icsrpunhct12_15_15** having the maximum $k_{eff} + 2\sigma$ value is reported for the HAC water-reflected package [10 CFR 71.55(e)].

6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT

For the NCT array evaluation of ES-3100 packages, the package content is confined within the containment vessel, consistent with the result of the tests specified in §71.71 (Normal Conditions of Transport). The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, 5×5×2, ETP 27×3, and the degenerate single unit. The "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: $N = \infty$, CSI = 0; N = 202, CSI = 0.3; N = 64, CSI = 0.8; N = 29, CSI = 1.7; and N = 16, CSI = 3.2. All arrays, except the infinite array, are reflected with 30 cm (1 ft) of water. These arrays are nearly cubic in shape for optimum array reactivity, thus eliminating the need for placing criticality controls on package arrangements in terms of stack height, width, and depth of an array. The array configurations and the range of water contents (Table 6.4) evaluated bound all possible packaging arrangements and moderation conditions for NCT.

6.5.1 Solid HEU Metal of Specified Geometric Shapes

For infinite and finite arrays of packages with HEU metal, the neutron multiplication factor increases as a function of the ^{235}U mass and decreases as a function of MOIFR. For example, consider the ES-3100 package loaded with three convenience cans for a total of 36,000-g ^{235}U where each can contains a 3.24-in.-diam cylinder. For package content without 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 1.027 to 0.963 with increasing MOIFR in the package [Cases **nciacyt11_36_1_1** through **nciacyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-3)]. For package content with 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.957 to 0.880 with increasing MOIFR in the package [Cases **nciacyt11_36_2_1** through **nciacyt11_36_2_15** (Appendix 6.9.6, Table 6.9.6-3)].

The effect of increasing the water content of the array is straightforward. As interspersed water is added to the packages of an array, two reactivity effects occur in series. The first effect is the tendency for reactivity to remain constant due to controlled neutron interaction between the packages of the array. For an infinite array where neutrons cannot escape from the system, neutrons are scattered about the array. In the MOIFR range of 1E-20 to 1E-02, both the interspersed moderator inside the packages of the dry array and the interstitial moderator between the package drums of the array are not sufficient for neutron thermalization and absorption to occur in the adjacent packaging materials. However, hydrogen in the 277-4 provides moderation, and neutrons are absorbed in the interspersed boron of this neutron poison. This results in a subcritical system with near constant neutron multiplication factors over the range of MOIFR. The second effect is the tendency for reactivity to decrease due to internal moderation in packages of the array. The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. The neutron multiplication factor approaches k_{eff} for the single, water-reflected unit at a full-content water fraction (MOIFR = 1.0).

The array case with a water fraction of MOIFR = 1E-04 pertains specifically to packages under NCT where the Kaolite and recesses of the package external to the containment vessel do not contain any residual moisture. This NCT case is more reactive than all other NCT cases where more moisture is present in the Kaolite and recesses of the package. Interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents because neutrons are absorbed in the hydrogen of the water. As more water is added, the packages of the array become isolated, and array reactivity ($k_{eff} + 2\sigma = 0.880$, Case **nciacyt11_36_2_1**5) approaches the reactivity of the single unit ($k_{eff} + 2\sigma = 0.873$, Case **ncsrcyt11_36_2_1**5).

Repeated for 4.25-in.-diam cylinders (Appendix 6.9.6, Table 6.9.6-7); 2.29-in. -square bars (Table 6.9.6-5); and 1.5-in.-diam × 2-in.-tall slugs (Table 6.9.6-9), this type of analysis for the 3.24-in.-diam cylinders demonstrates that arrays of packages with restricted fissile material (^{235}U) loading remain subcritical over the entire range of water content or MOIFR. HEU metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited.

Cases **nciatriga_1_1_3** through **nciatriga_1_15_3** (Appendix 6.9.6, Table 6.9.6-20a) represent infinite arrays of packages containing the bounding TRIGA fuel content (20 % enrichment with 45 wt % U containing 307-g ^{235}U), without 277-4 canned spacers. The MOIFR is set at 1.0E-04 such that neutronic interaction between packages is maximized. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.218 to 0.525 as MOIFR increases. The $k_{eff} + 2\sigma = 0.525$ for Case **nciatriga_1_15_3** is substantially below the USL value of 0.925, indicating that canned spacers are not required for criticality control.

As stated in Sect. 6.4.1, 10 CFR 71.55(d)(2) requires the geometric form of a package's content not be substantially altered under the NCT. Similarly, 10 CFR 71.55(e)(1) requires that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration.

Even though visible signs of damage to the metal convenience can have not been observed resulting from the regulatory tests, conclusions about damage to the TRIGA fuel content are not extrapolated from test data. The regulatory requirements are addressed by modeling the TRIGA fuel content in an extremely damaged condition. A series of criticality calculations is performed for making a determination of subcriticality. Cases **nciat55d2_1_1_3** through **ncia55d2_1_15_3** (Appendix 6.9.6, Table 6.9.6-20d) represent TRIGA fuel content homogenized with variable density water over the free volume of the containment vessel. The packaging is flooded in each ES-3100 package of the infinite array. The variable density water ranges from the dry containment condition to the fully flooded condition. Credit for physical integrity of the content is not taken in this set of cases which model the substantially altered content. The calculation results in Table 6.9.6-20d indicate extremely damaged content (Case **nciat55d2_1_15_3** with $k_{eff} + 2\sigma = 0.716$) is more reactive than the unaltered configuration (Case **nciatriga_1_15_3** with $k_{eff} + 2\sigma = 0.442$). Nevertheless, both cases are adequately below the USL of 0.925 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to the HAC do not result in an appreciable change in neutron multiplication for an array of packages, similar results are expected for the cases demonstrating compliance with 10 CFR 71.55(e)(1).

For TRIGA fuel content as clad fuel rods, the amount of cladding added (stainless steel as a neutron absorber or aluminum as a neutron scatter) and corresponding amount of water moderator displaced by the cladding is not expected to have a statistically significant affect on the calculated k_{eff}. Thus, the NCT shipping configuration model for disassembled TRIGA fuel (bare fuel meats) bounds shipping configuration model for TRIGA fuel configured as clad fuel rods (Appendix 6.9.3.1).

The array results for three slug configurations presented in Table 6.9.6-9 (Appendix 6.9.6) are for five or ten slugs touching or spaced apart in a pentagonal ring (Cases **ncia5st11** and **ncia5est11**) and for seven slugs formed by a hexagonal ring of slugs with one slug in the center of the ring **(ncia70st11**). These cases are used to establish the mass loading limitations, which in turn limit the number of slugs in the package to less than the number required to assemble a critical configuration.

Cases **ncia5est11_1_1_8_3** through **ncia5est11_1_1_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 18,277-g U without 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.550 to 0.924 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. The $k_{eff} + 2\sigma$ value is 0.924 for Case **ncia5est11_1_1_8_3**, which is below the USL of 0.925. Likewise, the $k_{eff} + 2\sigma$ values for Cases **ncia5st11_1_1_8_3** through **ncia5st11_1_1_1_3** increase from 0.521 to 0.929 as the enrichment is increased. However, the $k_{eff} + 2\sigma$ value is 0.929 for Case **ncia5st11_1_1_8_3**, which is slightly above the USL of 0.925. For simplification of the criticality evaluation, the maximum enrichment is limited to 95% and the corresponding fissile mass limit is 17,374-g ^{235}U. For Cases **ncia5st11_1_1_7_3** and **ncia5est11_1_1_7_3**, the $k_{eff} + 2\sigma$ values are below the USL. Moreover, the values are not statistically different.

Cases **ncia70st11_2_8_3** through **ncia70st11_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 25,588-g U with 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.473 to 0.915 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. The $k_{eff} + 2\sigma$ value of 0.894 for Case **ncia70st11_2_7_3** at the 95% enrichment limit is adequately below the USL of 0.925.

Cases **ncia5est11_2_2_8_3** through **ncia5est11_2_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 36,555-g ^{235}U with 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.583 to 0.983 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. At 80 wt % ^{235}U, the $k_{eff} + 2\sigma$ value (0.908) for Case **ncia5est11_2_2_5_3** with spaced-apart slugs is just below the USL. Similarly, Case **ncia5st11_2_2_5_3** with touching slugs has a calculated $k_{eff} + 2\sigma$ value of 0.902. Therefore, a restriction on mass and enrichment for slug content is

that for ≤ 80 wt % ^{235}U, the mass of ^{235}U in the package must not exceed 29,318 g as a prerequisite for the shipment of the package slug content and with 277-4 canned spacers under a CSI = 0.0.

Cases **ncf15est11_2_2_8_3** through **ncf15est11_2_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent a 13 × 13 × 6 array of packages containing 36,555-g ^{235}U with 277-4 canned spacers for which the corresponding rounded CSI = 0.4. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.548 to 0.938 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. Case **ncf15est11_2_2_7_3** at 95 wt % ^{235}U with $k_{eff} + 2\sigma = 0.920$ is below the USL of 0.925 to permit increasing the limit on enrichment for mass loadings of ≤ 34.7 kg uranium metal.

The CSI determinations provided in this section are contingent upon satisfactory results under the HAC evaluation (Sect. 6.6.1).

6.5.2 HEU Broken Metal; Solid HEU Metal of Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder

The ^{235}U (or U) evaluation limits listed in the column headings of Tables 6.1c and 6.1d represent the maximum amount of ^{235}U (or U) permissible in a flooded, reflected containment vessel for maintaining an adequate margin of subcriticality. These potential loading limits are taken into consideration for the determination of the fissile mass loading limit specified for a given CSI over a specified enrichment range. Under the subheading "Standards for arrays of fissile material packages (§ 71.59)," the fissile mass loading limits are identified for HEU broken metal in Table 6.1c and for HEU metal turnings, fines, or powder in Table 6.1d.

Consider the enrichment range >95 to 100 wt % ^{235}U. Comparison of results in Table 6.9.6-10 for Case **cvr3lha_26_1_8_15** (broken metal without canned spacers) and for Case **cvr3lha_36_2_8_15** (broken metal with canned spacers) reveals a considerable increase in the fissile mass loading from 25,894-g to 35,142-g ^{235}U is possible when 277-4 canned spacers are used. This result suggests the possibility of canned spacers not being required for certain packaging array configurations with broken metal. However, the comparison of results for Case **cvr3cha_8_1_8_15** without canned spacers and Case **cvr3cha_10_2_8_15** with canned spacers indicates only a minor increase from 7,398-g to 9,248-g ^{235}U in the fissile mass loading of metal turnings, fines, or powder might be possible if 277-4 canned spacers are used. The evaluation of the NCT and HAC array configuration for establishing the CSI = 0 for the ES-3100 package with broken metal (Table 6.9.6-11) reveals that 277-4 canned spacers are required in packages with enrichments >80% (Cases **nciabmt11_4_1_5_3** and **hciabmt12_4_1_5_3**).

Like arrays of packages with solid HEU metal shapes, the neutron multiplication factor for arrays of packages with HEU broken metal, turnings, fines, or powder decreases as a function of MOIFR and increases as a function of the ^{235}U mass. Consider the ES-3100 package loaded with three convenience cans for a total of 35,142-g ^{235}U and no canned spacers between content locations. The $k_{eff} + 2\sigma$ values range from 1.138 to 0.913 with increasing MOIFR [Cases **nciabmt11_36_1_8_1** through **nciabmt11_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-11)]. The introduction of water above MOIFR = 0.01 shows the effect of isolating the individual array units from each other. Array reactivity ($k_{eff} + 2\sigma = 0.913$) approaches the reactivity of the water-saturated, water-reflected single package Case **ncsrbmt11_36_1_15** ($k_{eff} + 2\sigma = 0.891$).

In the series of calculations using the ES-3100 package model with NCT geometry (Cases **nciabmt11_1_*n*_*m*_3** through **nciabmt11_36_*n*_*m*_3**), the enrichment of the content is varied from 19 wt % to 100 wt % ^{235}U. These array cases with a water fraction of MOIFR = 1E-04 pertain specifically to NCT packages where both the neutron poison of the body weldment liner inner cavity and the Kaolite are dry (in the as-manufactured condition) and both the recesses of the package external to the containment vessel and the interstitial space between the drums of the array do not contain any

residual moisture. As stated before, this NCT case is more reactive than all other NCT cases where more moisture is present in the Kaolite and recesses of the package. Increased interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents to a point where the packages of the array become isolated.

Evaluation of arrays of packages with HEU broken metal and canned spacers present. For enrichments <95 wt % ^{235}U, the maximum amount of ^{235}U permissible in a flooded ES-3100 package is 25,894-g ^{235}U of the broken metal. With 277-4 canned spacers present in the NCT package, the potential fissile mass loading limit for broken metal with enrichments >95% to 100 wt % ^{235}U and for a CSI = 0 must be limited to 2,774-g ^{235}U (Case **nciabmt11_3_2_8_3**) in order for the $k_{eff} + 2\sigma$ value (= 0.904) to be below the USL of 0.925. Suitability of this 2,774-g ^{235}U fissile mass loading limit for a CSI = 0, which is based on an infinite array of NCT packages, is contingent upon the infinite array of damaged packages also being adequately subcritical for HAC (Sect. 6.6.2).

The loading limits for solid HEU metal of unspecified geometric shape or for HEU broken metal are summarized in Table 6.2a based on array calculations performed using the uniform dispersal approximation "**cha**" model (Fig. 6.9.1-5d). The calculation results on which the determination of the loading limits is based are summarized in Table 6.1c.

As discussed in Appendix 6.9.1, the "**cha**" model is a first-order approximation model. The 500 g polyethylene representing the use of hydrogenous packing material is replaced with water in the flooded containment vessel. Broken metal and water is homogenized as a uranium "solution" and uniformly dispersed over the entire volume of the containment vessel. The vertical location of the 277-4 canned spacers inside the containment vessel is based on a fixed HEU packing fraction of ~0.59. The use of this large packing fraction results in minimum separation between canned spacers, which minimizes the size of the lower and middle content locations and maximizes the size of the upper content location. Reactivity of the containment vessel is driven by the oversized upper content location having a proportionately greater amount of fissile material. Conversely, the use of a small packing fraction (~0.2) in the "**cha**" model would result in greater separation between the canned spacers, which increases the size of the lower and middle content locations while reducing the size of the upper content location. Reactivity of the containment vessel would decrease as the proportions of fissile material in the content regions equalize. Calculations based on a packing fraction of ~0.59 bound similar cases based on lower packing fractions.

The "**cha**" model is characteristic of the situation where the dimensions of the broken metal pieces are sufficiently small to allow pieces of HEU to pass between the void spaces formed between the inner wall of the containment vessel and the exterior wall of the canned spacers.

As shown in Fig. 6.9.3.1-3, HEU broken metal content typically consists of irregular pieces, sufficiently large (0.5 in. to several inches on a side), that will not pass between the 277-4 canned spacer locations. The packing fraction calculation model "**fl**" and the dispersed content calculation model "**fd**" better represent broken metal content which does not pass between the canned spacer locations. Inside the containment vessel, the content locations between canned spacers are established based on a variable packing fraction for HEU broken metal ranging from 0.2 to 0.6. The 500 g polyethylene is included in the flooded containment vessel. HEU broken metal, polyethylene and water are homogenized as a uranium "solution" residing within the content locations (Figs. 6.9.1-5e and 6.9.1-5f) rather than distributed uniformly over the containment vessel (Fig. 6.9.1-5d). The "**fl**" model defines the upper content location based on packing fraction while the "**fd**" model defines the upper content location as the entire region above the upper canned spacer.

NCT cases for the "**fl**" and "**fd**" calculation models are documented in Table 6.9.6-11b. The reference case results based on the uniform dispersal approximation "**cha**" model are highlighted.

The corresponding cases for the packaging fraction ("**fl**") and for the dispersed content ("**fd**") calculation models are given in the rows below the reference case. Consider Case **nciabmt11_4_1_5_3** where the quantity of HEU content in the model is calculated based on a discrete number of 1-in. cubes. The HEU in corresponding Cases **nciapbmflt11_1_*n*_4_5** and **nciapbmfdt11_1_*n*_4_5** is not limited to fractional kilogram quantities based on whole cubes as in Case **nciabmt11_4_1_5_3**. Instead, the intended whole kilogram quantities of HEU are evaluated as a function of the packing fraction ("***n***") in the ". . . flt11_1_***n***_ . . ." and ". . . fdt11_1_***n***_ . . ." cases.

An increase of ~0.08 in the $k_{eff} + 2\sigma$ value is observed as the packing fraction is reduced and more water is homogenized with the fissile material, (i.e., Cases **nciapbmtfl11_1_6_4_5** through **nciapbmtfl11_1_2_4_5**, Table 6.9.6-11b). As the packing fraction is reduced and the volume of the content location increases accordingly, neutron multiplication increases due to increased moderation of the fissile material. A considerable increase of ~0.22 in the $k_{eff} + 2\sigma$ value is observed when fissile material in the upper can location is homogenized with water in the upper content location and dispersed over that region, (i.e., Case **nciapbmtfl11_1_6_4_5** vs Case **nciapbmtfd11_1_6_4_5**, Table 6.9.6-11b). Nevertheless, the $k_{eff} + 2\sigma$ values for the packaging fraction "**fl**" and dispersed content calculation "**fd**" models are lower than values for the corresponding uniform dispersal approximation "**cha**" model. The "**cha**" model evaluated without polyethylene bounds results for the more realistic "**fl**" and "**fd**" models evaluated with 500 g polyethylene and the HEU content of the package confined to the specific content locations.

Powder, particulate, or small pieces of HEU potentially present in broken metal are capable of passing between content locations. The quantity of this material, potentially present, represents a small fraction of the total HEU broken metal content. The placement of a limit on content size for criticality control is adopted as a package content loading restriction (Sect. 6.2.4, Item 6). Moreover, the loading limits for broken metal content established based on the "**cha**" model are retained, recognizing that the use of polyethylene is not addressed in "**cha**" model. Therefore, the only hydrogenous packing materials that can be used in the containment vessel when broken metal content is present are those that have a hydrogen density less than or equal to water (Sect. 6.2.4, Item 7).

Evaluation of arrays of packages with HEU broken metal, turnings, fines, or powder, and no canned spacers. For enrichments 70 to 80 wt % ^{235}U, the maximum amount of ^{235}U permissible in a flooded ES-3100 package is 27,443-g ^{235}U for broken metal or 19,284-g ^{235}U for metal turnings, fines, or powder. As discussed in Sect. 6.4.2, credit for the presence of 277-4 canned spacers for criticality safety cannot be taken when determining the loading limits for metal turnings, fines, and powder. Without 277-4 canned spacers present in the NCT package containing broken metal, turnings, fines, or powder, the potential fissile mass loading limit over the range 70 to 80 wt % ^{235}U and for a CSI = 0 must be 2,967-g ^{235}U (Case **nciabmt11_4_1_5_3**) in order for the $k_{eff} + 2\sigma$ value (0.921) to be below the USL of 0.925. Suitability of this 2,967-g ^{235}U fissile mass loading limit for a CSI = 0, which is based on an infinite array of NCT packages, is contingent upon an infinite array of damaged packages also being adequately subcritical for HAC (Sect. 6.6.2).

Repetitious use of the evaluation technique. This evaluation technique for determination of mass loading limits for enrichment intervals is repeated over the range of HEU enrichments identified in Tables 6.1c and 6.1d. At HEU enrichments ≤ 60 wt % ^{235}U, the evaluated package mass loading limit of 35.32-kg uranium is achieved, so further delineation of fissile mass loading limits by g ^{235}U is not required.

6.5.3 HEU Oxide

Like packages with HEU metal or broken metal, the neutron multiplication factor for an NCT array of packages with HEU product oxide decreases as a function of decreasing ^{235}U mass [parametric Cases **nciapdoxt11_1_*n*_24_3**, **nciapdoxt11_1_*n*_20_3**, **nciapdoxt11_1_*n*_15_3**, **nciapdoxt11_1_*n*_12_3**, **nciapdoxt11_1_*n*_11_3**, and **nciapdoxt11_1_1_10_3** through

nciapdoxt11_1_1_6_3 (Table 6.9.6-13b)]. For these NCT cases, the MOIFR is set at 1.0E-04 such that neutronic interaction between packages of an array is maximized. Results for the parametric cases reveal the same consistent increase in the $k_{eff} + 2\sigma$ values with decreasing bulk density as observed in the single package calculation results (Sect. 6.4.3). Results for Cases **nciapdoxt11_1_*n*_11_3** and **nciapdoxt11_1_1_10_3** through **nciapdoxt11_1_1_6_3** demonstrate that over the range of HEU oxide bulk densities from 6.54 to 2.0 g/cm^3, the $k_{eff} + 2\sigma$ values are below the USL of 0.925.

Cases **nciask_1_15** through **nciask_10_15** (Appendix 6.9.6, Table 6.9.6-18) evaluate infinite arrays of packages having the 10 skull oxide compositions described in Sect. 6.4.3. The MOIFR is set at 1.0E-04 such that neutronic interaction between packages is maximized. The $k_{eff} + 2\sigma$ values, ranging from 0.656 to 0.764, are substantially below the below the USL value of 0.925, indicating that canned spacers are not required for criticality control.

The CSI is 0.0 for an infinite array of packages having product oxide content with a bulk density ≥2.0 g/cm^3 and with a maximum of 9,682-g ^{235}U or having skull oxide content with a maximum of 16,399-g ^{235}U and 921 g graphite. The suitability of this determination is contingent upon satisfactory results under the HAC evaluation (Sect. 6.6.3).

6.5.4 UNH Crystals

Unlike the HEU metal, broken metal, or oxide content, UNH crystals are soluble in water (Sect. 6.4.4). The most reactive content condition occurs at an optimum solution concentration derived from the UNH crystal loading and the volume of water flooding the containment vessel. Both flooding of the containment vessel and a reduced loading of UNH crystals going into solution is required to achieve the most reactive configuration.

Similar to packages with HEU metal, broken metal, or oxide, the neutron multiplication factor for an array of packages with UNH crystals decreases as a function of increasing MOIFR. Cases **nciaunhct11_8_24_1_1** through **nciaunhct11_8_24_1_15** for content without polyethylene and Cases **nciapunhct11_24_1** and **nciapunhct11_24_15** for content with 500 g polyethylene (Table 6.9.6-15) reveal the effect of isolating the individual array units from each other with the introduction of water above ~0.01 MOIFR. Array reactivity ($k_{eff} + 2\sigma = 0.721$ without polyethylene and 0.729 with polyethylene) approaches the reactivity of the water-saturated, water-reflected single-unit package ($k_{eff} + 2\sigma = 0.702$ without polyethylene and 0.708 with polyethylene).

In a series of NCT calculations (Cases **nciapunhct11_*nn*_3**), the $k_{eff} + 2\sigma$ values are above the USL of 0.925 for mass loadings between 8,000 and 24,000-g UNH crystals. Credit is not taken for water tightness that is demonstrated by the NCT (and HAC) tests. Therefore, mass loading is limited to 7,000-g UNH crystals. The CSI is 0.0 [10 CFR 71.59(a)(1) and 10 CFR 71.59(b)] for ES-3100 packages having a maximum of 3,297-g ^{235}U. The suitability of this determination depends upon satisfactory results under the HAC evaluation of Sect. 6.6.4 [10 CFR 71.59(a)(2) and 10 CFR 71.59(b)].

The $k_{eff} + 2\sigma$ values are expected to range from subcritical to critical for array configurations where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. This requires intrusion of water into the containment vessel, dissolving of UNH crystals in the influent, and leakage of solution out of the containment vessels in each package of an array (catastrophic failure of all packages in an infinite array). Given that loss of containment is deemed not credible by merit of the 10 CFR 71.71 and 10 CFR 71.73 tests performed on the ES-3100, this accident condition is not credible.

For Cases **ncf1punhct12_*nn*_3**, the $k_{eff} + 2\sigma$ values are below the USL of 0.925. Given that the results for NCT and HAC (Sect. 6.6.4) are adequately subcritical, packages may be shipped

under a CSI = 0.4 for packages with a maximum of 24,000-g UNH crystals [10 CFR 71.59(a)(1) and 10 CFR 71.59(b)]. Likewise, the suitability of this determination depends upon satisfactory results under the HAC evaluation of Sect. 6.6.4.

6.6 EVALUATION OF PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

Except for UNH crystals, the package content is confined within the containment vessel for the HAC array evaluation of ES-3100 packages, consistent with the result of the tests specified in 10 CFR 71.73 (Hypothetical Accident Conditions). The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, 5×5×2, ETP 16×3, and the degenerate single unit. The "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: N = ∞, CSI = 0; N =162, CSI = 0.4; N = 73, CSI = 0.7; N = 25, CSI = 2.0; and N = 24, CSI = 2.1. All arrays, except the infinite array, are reflected with 30 cm (1 ft) of water. These array are nearly cubic in shape for optimum reactivity of the array, thus eliminating the need for placing criticality controls on package arrangements in terms of stack height, width, and depth of an array. The array configurations and the range of water contents (Table 6.4) evaluated bound all possible packaging arrangements and moderation conditions for HAC.

For the single damaged package, and for infinite and finite arrays of damaged packages with HEU metal, HEU oxide, or UNH crystal content, the neutron multiplication factor changes as a function of the ^{235}U mass, MOIFR, or applicable solution concentration in the same manner as in an array of undamaged packages.

6.6.1 Solid HEU Metal of Specified Geometric Shapes

For infinite and finite arrays of damaged packages with HEU metal, the neutron multiplication factor increases as a function of the ^{235}U mass and decreases as a function of MOIFR. For example, consider the ES-3100 package loaded with three convenience cans that contain a 3.24-in.-diam cylinder with 12,000-g ^{235}U for a total of 36,000-g ^{235}U. For package content without 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 1.027 to 0.967 with increasing MOIFR in the damaged packages [Cases **hciacyct12_36_1_1** through **hciacyt12_36_1_15** (Appendix 6.9.6, Table 6.9.6-3)]. For package content with 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.956 to 0.884 with increasing MOIFR in the damaged package [Cases **hciacyt12_36_2_1** through **hciacyt12_36_2_15** (Appendix 6.9.6, Table 6.9.6-3)].

The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. The neutron multiplication factor approaches k_{eff} for the single, water-reflected unit at a full content-water fraction (MOIFR = 1.0). Comparison of these results with the corresponding NCT cases (Sect. 6.5.1) indicates no significant differences. This result is as expected given that the neutron multiplication in an infinite array is independent of pitch between fissile contents but is dependent on changes in mass and moderation in the array. The changes in both the outer dimensions and the compositions of the Kaolite and 277-4 of the ES-3100 package due to HAC result in changes to the neutron multiplication factor on the order of ~0.001 to 0.002.

Repeated for 4.25-in.-diam cylinders (Appendix 6.9.6, Table 6.9.6-7); 2.29-in.-square bars (Table 6.9.6-5); and 1.5-in.-diam × 2-in.-tall slugs (Table 6.9.6-9), this type of analysis for the 3.24-in.-diam cylinders demonstrates that arrays of damaged packages with restricted fissile material (^{235}U) loading remain subcritical over the entire range of water content or MOIFR. HEU metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited.

Cases **hciatriga_1_1_3** through **hciatriga_1_15_3** (Appendix 6.9.6, Table 6.9.6-20) represent infinite arrays of damaged packages containing the bounding TRIGA fuel content (20 % enrichment with 45 wt % U containing 307-g ^{235}U), without 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.218 to 0.526 as MOIFR increases. The $k_{eff} + 2\sigma = 0.526$ for Case **hciatriga_1_15_3** is substantially below the USL of 0.925, indicating that canned spacers are not required for criticality control. Given that the results for NCT (Sect. 6.5.2) and HAC are adequately subcritical, packages with TRIGA fuel content ≤ 921-g ^{235}U may be shipped under a CSI = 0.

As stated in Sect. 6.5.1, calculation results presented in Table 6.9.6-20d for an infinite array of ES-3100 packages (NCT packaging with extremely damaged TRIGA fuel content) is substantially below the USL of 0.925. Similar results are expected for an infinite array of ES-3100 packages (HAC packaging with extremely damaged TRIGA fuel content) given that changes external to the containment vessel due to the HAC do not result in an appreciable change in the neutron multiplication for the an array of packages. Therefore, the 10 CFR 71.55(e)(1) requirement that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration is satisfied.

The array results for three slug configurations presented in Table 6.9.6-9 (Appendix 6.9.6) are for five or ten slugs touching or spaced apart in a pentagonal ring (Cases **hcia5st12** and **hcia5est12**) and for seven slugs formed by a hexagonal ring of slugs with one slug in the center of the ring **(hcia70st12**). These cases are used to establish the mass loading limitations for damaged packages, which in turn limit the number of slugs in the package to less than the number required to assemble a critical configuration.

Cases **hcia5est12_1_1_8_3** through **hcia5est12_1_1_1_3** and Cases **hcia5st12_1_1_8_3** through **hcia5st12_1_1_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of damaged packages containing 18,277-g U without 277-4 canned spacers. Infinite array Cases **hcia70st11_2_8_3** through **hcia70st11_2_1_3** represent damaged packages containing 25,588-g U with 277-4 canned spacers while Cases **hcia5est12_2_2_8_3** through **hcia5est12_2_2_1_3** represent damaged packages containing 36,558-g U also with 277-4 canned spacers. Cases **hcf25est12_2_2_8_3** through **hcf25est12_2_2_1_3** represent a 9 × 9 × 4 array of damaged packages containing 36,558-g U with 277-4 canned spacers. The $k_{eff} + 2\sigma$ values for these cases representing arrays of damaged packages are slightly less than values for the corresponding cases representing undamaged packages. (The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.001 change in the neutron multiplication factor.) Therefore, the prospective CSI values determined in the NCT evaluation (Sect. 6.5.1) for arrays of undamaged packages with slug content are controlling.

6.6.2 HEU Broken Metal; Solid HEU Metal of Unspecified Geometric Shape and Characterized as Broken Metal; or Turnings, Fines, or Powder

The evaluation of various HAC array configurations for establishing the CSI for packages with broken metal (Table 6.9.6-11) reveals that 277-4 canned spacers are required in packages with enrichments >80%. As discussed in Sect. 6.4.2, credit for the presence of canned spacers required for criticality safety cannot be taken when determining the loading limits for HEU metal turnings, fines, or powder. An evaluation of HEU metal turnings, fines, or powder with enrichments ranging from 80% to 100% is presented in Appendix 6.9.11.

Like arrays of packages with solid HEU metal shapes, the neutron multiplication factor for arrays of packages with HEU broken metal, turnings, fines, or powder decreases as a function of MOIFR and increases as a function of the ^{235}U mass. Consider the ES-3100 package loaded with three convenience cans for a total of 35,142-g ^{235}U with no canned spacers between content locations. The $k_{eff} + 2\sigma$ values range from 1.14 to 0.939 with increasing MOIFR, Cases **hciabmt12_36_1_8_1** through **hciabmt12_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-11). The introduction of water above MOIFR = 0.01 shows the effect of isolating the individual array units from each other. Array reactivity

(k_{eff} + 2σ = 0.939) approaches the reactivity of the water-saturated, water-reflected single package (k_{eff} + 2σ = 0.891, Case **hcsrbmt12_36_1_15**, Table 6.9.6-11).

Cases **hciabmt12_1_*nn_mm*_3** through **hciabmt12_36_*nn_mm*_3** model the ES-3100 with the reduced-diameter HAC package model where the enrichment of the content is varied from 60 wt % to 100 wt % ^{235}U. These array cases with MOIFR = 1E-04 pertain specifically to HAC packages where the neutron poison of the body weldment liner inner cavity is at 90% moisture content, but the Kaolite is dry (in the as-manufactured condition), and neither recess of the package external to the containment vessel and the interstitial space between the drums of the array contains any residual moisture. As stated before, this HAC case is more reactive than all other HAC cases where more moisture is present in the Kaolite and recesses of the package. Increasing the interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents to a point where the packages of the array become isolated.

Evaluation of arrays of packages with HEU broken metal and canned spacers present. For enrichments < 95 wt % ^{235}U, the maximum amount of ^{235}U permissible in a flooded ES-3100 package is 25,894-g ^{235}U in the broken metal. With 277-4 canned spacers present in the HAC package, the potential fissile mass loading limit for broken metal >95 to 100 wt % ^{235}U and for a CSI = 0 must be limited to 2,774-g ^{235}U (Case **hciabmt12_3_2_8_3**) in order for the k_{eff} + 2σ value (= 0.905) to be below the USL of 0.925. Given that the results for NCT (Sect. 6.5.2) and HAC are adequately subcritical, packages ≤ 2,774-g ^{235}U and enrichment >95 wt % ^{235}U may be shipped under a CSI = 0.

The loading limits for solid HEU metal of unspecified geometric shape or for HEU broken metal are summarized in Table 6.2a based on array calculations performed using the uniform dispersal approximation "**cha**" model (Fig. 6.9.1-5d). The calculation results on which the determination of the loading limits is based are summarized in Table 6.1c.

As discussed in Sect. 6.5.2, criticality calculations with the "**cha**" model for a packing fraction of ~0.59 bound similar cases at the lower packing fractions. The "**cha**" model is characteristic of the situation where the dimensions of the broken metal pieces are sufficiently small to allow for HEU to pass between void space formed between the inner wall of the containment vessel and the exterior wall of each canned spacer.

As shown in Fig. 6.9.3.1-3, HEU broken metal content typically consists of irregular pieces, sufficiently large (0.5 in. to several inches on a side), that will not pass between the 277-4 canned spacer locations. The packing fraction calculation model "**fl**" and the dispersed content calculation model "**fd**" better represent broken metal content which does not pass between the canned spacer locations.

HAC cases are documented in Table 6.9.6-11c. The reference case results based on the uniform dispersal approximation "**cha**" model are highlighted. The corresponding cases for the packaging fraction ("**fl**") and for the dispersed content ("**fd**") calculation models are given in the rows below the reference case.

An increase of ~0.08 in the k_{eff} + 2σ value is observed as the packing fraction is reduced and more water is homogenized with the fissile material (i.e., Cases **hciapbmtfl11_1_6_4_5** through **hciapbmtfl11_1_2_4_5**, Table 6.9.6-11c). As the packing fraction is reduced and the volume of the content location is increased, moderation of the fissile material increases. A considerable increase of ~0.22 in the k_{eff} + 2σ value is observed when fissile material in the upper can location is homogenized with water in the upper content location and dispersed over that region (i.e., Case **hciapbmtfl11_1_6_4_5** vs Case **hciapbmtfd11_1_6_4_5**, Table 6.9.6-11c). Nevertheless, the k_{eff} + 2σ values for the packaging fraction "**fl**" and dispersed content calculation "**fd**" models are lower than values for the corresponding uniform dispersal approximation "**cha**" model. The "**cha**" model evaluated without polyethylene bounds

results for the more realistic "**fl**" and "**fd**" models evaluated with 500 g polyethylene and the HEU content of the package confined to the specific content locations.

Powder, particulate, or small pieces of HEU potentially present in broken metal are capable of passing between content locations. The quantity of this material, potentially present, represents a small fraction of the total HEU broken metal content. The placement of a limit on content size for criticality control is adopted as a package content loading restriction (Sect. 6.2.4, Item 6). Moreover, the loading limits for broken metal content established based on the "**cha**" model are retained, recognizing that the use of polyethylene is not addressed in "**cha**" model. Therefore, the only hydrogenous packing materials that can be used in the containment vessel when broken metal content is present are those that have a hydrogen density less than or equal to water (Sect. 6.2.4, Item 7).

Evaluation of arrays of packages with HEU broken metal, turnings, fines, or powder, and no canned spacers. For enrichments >70 and ≤ 80 wt % ^{235}U, the maximum amount of ^{235}U permissible in a flooded ES-3100 package is 27,443-g ^{235}U for broken metal or 19,284-g ^{235}U for metal turnings, fines, or powder. As discussed in Sect. 6.4.2, credit for the presence of 277-4 canned spacers for criticality safety cannot be taken when determining the loading limits for metal turnings, fines, and powder. Without 277-4 canned spacers present in the HAC package containing broken metal, turnings, fines, or powder, the potential fissile mass loading limit over the range >70 and ≤80 wt % ^{235}U and for a CSI = 0 must be 2,967-g ^{235}U (Case **hciabmt12_4_1_5_3**) in order for the k_{eff} + 2σ value (0.925) to be at the USL of 0.925. Given that the results for NCT (Sect. 6.5.2) and HAC are adequately subcritical, packages ≤ 2,967-g ^{235}U and enrichment >70 and ≤ 80 wt % ^{235}U may be shipped under a CSI = 0.

Repetition of the evaluation technique. This evaluation technique for determination of mass loading limits for enrichment intervals is repeated over the range of HEU enrichments identified in Tables 6.1c and 6.1d. At HEU enrichments ≤ 60 wt % ^{235}U, the evaluated package mass loading limit of 35.32-kg uranium is achieved, so further delineation of fissile mass loading limits by g ^{235}U is not required.

6.6.3 HEU Oxide

Like packages with HEU metal or broken metal, the neutron multiplication factor for an array of HAC packages with HEU product oxide decreases as a function of decreasing ^{235}U mass [parametric Cases **hciapdoxt11_1_*n*_24_3**, **hciapdoxt11_1_*n*_20_3**, **hciapdoxt11_1_*n*_15_3**, **hciapdoxt11_1_*n*_12_3**, **hciapdoxt11_1_*n*_11_3**, and **hciapdoxt11_1_1_10_3** through **hciapdoxt11_1_1_6_3** (Table 6.9.6-13b)]. For these HAC cases, the MOIFR is set at 1.0E-04 such that neutronic interaction between packages of an array is maximized. Results for the parametric cases reveal the same consistent increase in the k_{eff} + 2σ values with decreasing bulk density as observed in the single package calculation results (Sect. 6.4.3). Results for Cases **hciapdoxt11_1_*n*_11_3** and **hciapdoxt11_1_1_10_3** through **hciapdoxt11_1_1_6_3** demonstrate that over the range of HEU oxide bulk densities from 6.54 to 2.0 g/cm^3, the k_{eff} + 2σ values are below the USL of 0.925. Given that the results for NCT (Sect. 6.5.3) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.0 for an infinite array of packages having product oxide with a maximum of 9,682-g ^{235}U.

Cases **hciask_1_15** through **hciask_10_15** (Appendix 6.9.6, Table 6.9.6-18b) evaluate infinite arrays of damaged packages having the 10 skull oxide compositions described in Sect. 6.4.3. The differences between the HAC case results and the NCT case results are not statistically significant. The k_{eff} + 2σ values, ranging from 0.658 to 0.767, are substantially below the USL value of 0.925. Given that the results for NCT (Sect. 6.5.3) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.0 for an infinite array of packages having skull oxide content with a maximum of 16,399-g ^{235}U and 921 g graphite.

6.6.4 UNH Crystals

Unlike the HEU metal, broken metal, or oxide content, UNH crystals are soluble in water (Sect. 6.4.4). The most reactive content condition occurs at an optimum solution concentration derived from the UNH crystal loading and the volume of water flooding the containment vessel. Both flooding of the containment vessel and a reduced loading of UNH crystals going into solution is required to achieve the most reactive configuration.

Similar to packages with HEU metal, broken metal, or oxide, the neutron multiplication factor for an array of damaged packages with UNH crystals decreases as a function of increasing MOIFR. Cases **hciaunhct12_8_24_1_1** through **hciaunhct12_8_24_1_15** for content without polyethylene and Cases **hciapunhct12_24_1** and **hciapunhct12_24_15** for content with 500 g polyethylene (Table 6.9.6-15) reveal the effect of isolating the individual array units from each other with the introduction of water above ~0.01 MOIFR. Array reactivity ($k_{eff} + 2\sigma = 0.729$ without polyethylene and 0.733 with polyethylene) approaches the reactivity of the water-saturated, water-reflected unit single package ($k_{eff} + 2\sigma = 0.704$ without polyethylene and 0.711 with polyethylene).

In a series of HAC calculations (Cases **hciapunhct11_*nn*_3**), the calculated $k_{eff} + 2\sigma$ values are below the USL of 0.925 for loading with <8,000-g UNH crystals. Given that the results for NCT (Sect. 6.5.4) and HAC are adequately subcritical, the CSI is 0.0 [10 CFR 71.59(a)(2) and 10 CFR 71.59(b)] for packages having a maximum of 3,297-g ^{235}U.

The $k_{eff} + 2\sigma$ values are expected to range from subcritical to critical for array configurations where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. This requires intrusion of water into the containment vessel, dissolving of UNH crystals in the influent, and leakage of solution out of the containment vessels in each package of an array. The leakage out of the containment vessel of content moderated "to such an extent as to cause maximum reactivity consistent with the physical and chemical form of material" is not considered credible HAC based on results for tests specified in 10 CFR 71.73.

In a series of HAC calculations (Cases **hcf2punhct12_*nn*_3**), the calculated $k_{eff} + 2\sigma$ values are below the USL of 0.925. Given that the results for NCT (Sect. 6.5.4) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.4 for packages with a maximum of 24,000-g UNH crystals.

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

A series of calculations is performed for determining the most reactive configuration of the content and surrounding packaging material in an ES-3100 package that undergoes catastrophic destruction. Fissile content mass loadings that remain under the USL for these catastrophic events are identified. Subcriticality is demonstrated after due consideration of such aspects as the efficiency of moderator, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes and temperature effects. The six calculation models used in this evaluation are described in Sect. 6.3.1.4. Key model dimensions and parameters are tabulated in Tables 6.9.6-21 through 6.9.6-23, Appendix 6.9.6.

6.7.1 Results for HEU Metal (Excluding TRIGA Fuel Elements)

In this section, "HEU metal" refers to HEU metal content of specified geometric shape (cylinder, bar, or slug), of an unspecified geometric shape (characterized as broken metal), or broken metal. The uranium is homogenized with hydrogenous packaging material and evaluated as a distinct lump ("fissile core") that is not mixed with other packing or packaging materials.

Cases **atdmr_10_8** through **atdmr_7_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 1 (Fig. 6.11, Sect. 6.3.1.4). HEU metal of three convenience cans is homogenized with 500 g of polyethylene, representing the potential use of hydrogenous packing materials in the ES-3100. The fissile core is configured into a spherical shape with an exterior 20 cm water reflector. As shown in Fig. 6.20 and Table 6.9.6-21, the k_{eff} + 2σ values decrease as a function of both enrichment and ^{235}U mass. The k_{eff} + 2σ values are substantially below the USL of 0.925. The k_{eff} + 2σ value for 7 kg of HEU at 100 % enrichment is 0.791.

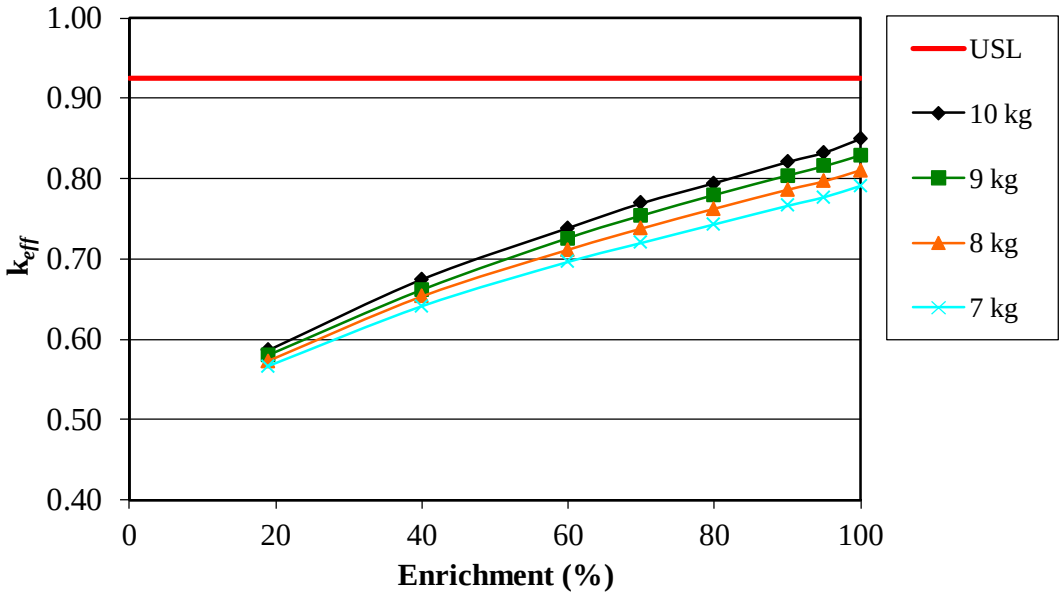


Fig. 6.20. k_{eff} vs enrichment (wt % ^{235}U) for HEU ranging from 7 to 10 kg.

Cases **atdmsr_7_8_11** through **atdmsr_7_1_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 2 (Fig. 6.12, Sect. 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness stainless steel shell and an exterior 20 cm water reflector. As shown in Fig. 6.21 and Table 6.9.6-21, the maximum k_{eff} + 2σ values occur at zero stainless steel thickness. The k_{eff} + 2σ value for 7 kg of HEU at 100% enrichment and zero stainless steel thickness is 0.791. The k_{eff} + 2σ values decrease to minimum values for steel thicknesses of 2.49 cm over the range of 100% enrichment to 19% enrichment while the NLF decreases from ~ 0.07 to 0.05. The NLF further decreases to a value of 0.03 as stainless steel is added up to the 66,133 g amount of the containment vessel, and the liner and drum assembly. At maximum stainless steel thickness, the k_{eff} + 2σ values increase to within 0.02 of the values for zero stainless steel thickness. The stainless steel of the ES-3100 packaging is not as effective a reflector as the 20 cm water surrounding the core. The overall effect of adding the stainless steel of the ES-3100 packaging to the configuration is the reduction in the neutron multiplication factor for the system. The k_{eff} + 2σ values are substantially below the USL of 0.925.

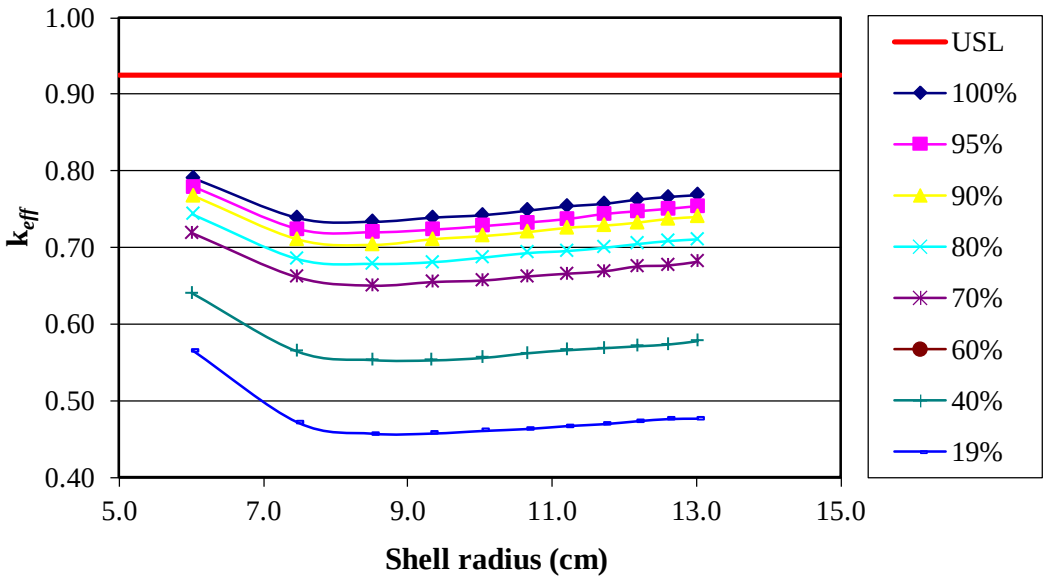


Fig. 6.21. k_{eff} vs stainless steel shell radius (cm) for 7 kg HEU with enrichments ranging from 19 to 100 wt % ^{235}U.

Cases **atdm15kr_7_8_6** through **atdm15kr_7_1_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 3 (Fig. 6.13, Sect. 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness wet-Kaolite shell and an exterior 20 cm water reflector. As explained in Sect. 6.3.1.4, wet Kaolite to a maximum of 60,223 g consists of the dry Kaolite [51,214.9 g vermiculite-cement and 2,204.7 g bound water from inside the body weldment outer liner and the drum top plug] and up to 6,803.8 g free water—moisture which dampens the Kaolite and may also be present in the containment vessel well. As shown in Fig. 6.22 and Table 6.9.6-21, the maximum $k_{eff} + 2\sigma$ values at various enrichments occur at zero shell-thickness for the wet Kaolite. Consider the curve for 7 kg of HEU at 100 % enrichment where $k_{eff} + 2\sigma = 0.790$. At a shell radius of ~ 23 cm (24,089.2 g wet Kaolite with a shell thickness of ~ 17 cm), $k_{eff} + 2\sigma$ becomes quasi-asymptotic and the decrease in the NLF from ~ 0.07 to 0.05 is slight. With the addition of ~8.1 cm of wet Kaolite to the shell, the NLF decreases further from 0.05 to 0.04. The $k_{eff} + 2\sigma$ value decreases to a minimum value at a shell radius of 31.08 cm (60,223 g wet Kaolite with a steel thickness of 25.06 cm). In the range of 17 to 25 cm shell thickness, the quasi-asymptotic values for $k_{eff} + 2\sigma$ are ~ 0.04 below maximum $k_{eff} + 2\sigma$ values occurring at zero Kaolite thickness. To summarize, a significant drop in the neutron multiplication factor is observed for the addition of the initial 17 cm of wet-Kaolite shell to the fissile core, but an asymptotic value is not reached. With increasing build-up in the shell thickness, neutron multiplication decreases rather than increases, and the decrease in neutron leakage from the system is small. This behavior occurs because water at saturation levels, which is required for the Kaolite to act as a modest reflector, is not present in the wet Kaolite.

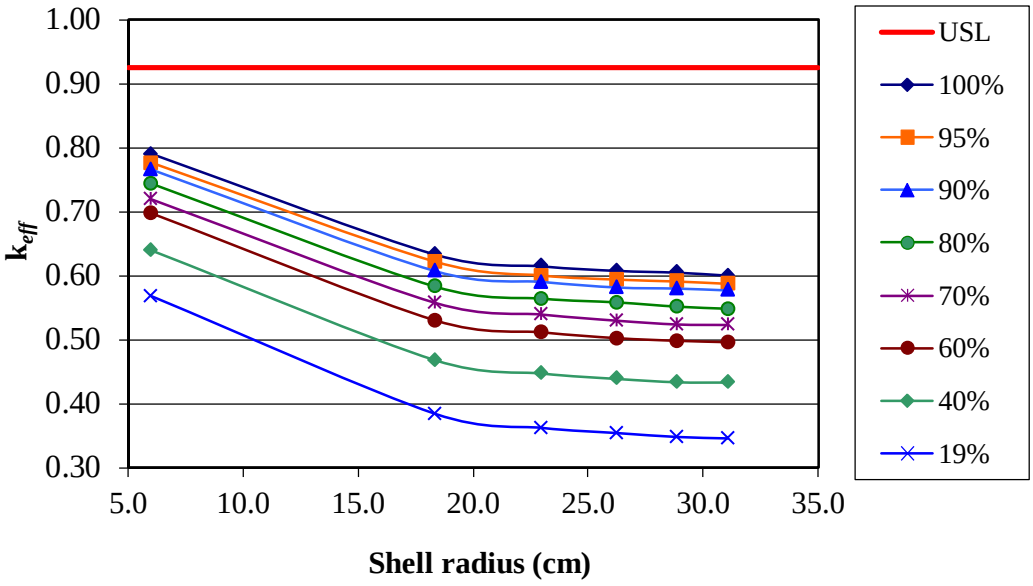


Fig. 6.22. k_{eff} vs wet Kaolite shell radius (cm) for 7 kg HEU with enrichments ranging from 19 to 100 wt % ^{235}U.

Cases **atdmdkr_7_8_6** through **atdmdkr_7_8_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 3 (Fig. 6.13, Sect. 6.3.1.4), where dry Kaolite is being evaluated consistent with test results of 10 CFR 71.55(d). As explained in Sect. 6.3.1.4, 53,419.1 g of dry Kaolite contained inside the body weldment outer liner and the drum top plug is NCT Kaolite (51,214.9 g vermiculite-cement and 2,204.7 g bound water). Only 7 kg of HEU at 100% enrichment is evaluated in the "atdmdkr" cases. As shown in Fig. 6.23 and Table 6.9.6-21, the behavior in $k_{eff} + 2\sigma$ for dry Kaolite where the value decreases to a minimum at a shell radius of 31.08 cm (shell thickness of 25.06 cm) is the same as for wet Kaolite. The $k_{eff} + 2\sigma$ values for the system with dry or wet Kaolite are substantially below the USL of 0.925. The decrease in NLF from ~ 0.07 to 0.05 for dry Kaolite is slightly less than from ~ 0.07 to 0.04 for wet Kaolite. The overall effect of adding dry or wet Kaolite to the system is the reduction in neutron multiplication in the system. NCT Kaolite of the ES-3100 packaging or wet Kaolite is not as effective a reflector as the 20 cm water surrounding the core. The absence of water in the Kaolite minimizes its effect.

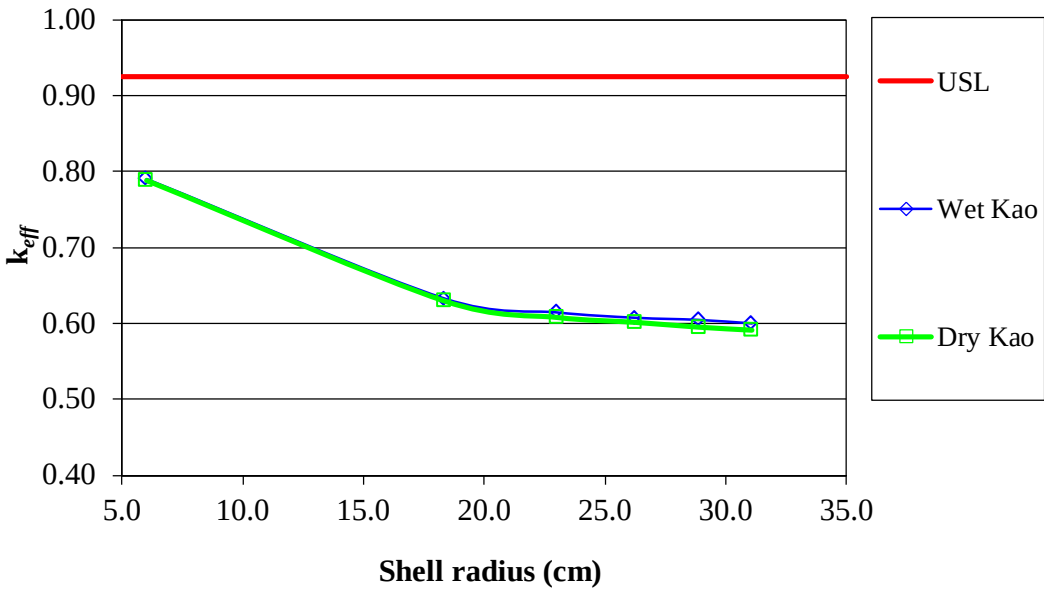


Fig. 6.23. k_{eff} vs shell radius for wet and dry Kaolite for 7 kg HEU at 100% enrichment.

A uranium alloy is conservatively assessed when scattering media (aluminum or molybdenum) is treated as multiplying media (^{235}U) in the calculation models. Thus, limits established for HEU metal apply to the alloy.

6.7.2 Results for TRIGA Fuel Elements, Three Pieces per Convenience Can

Case **atdzr** pertains to Model 1 (Fig. 6.11, Sect. 6.3.1.4), in which 10.4 kg of $UZrH_x$ (921-g ^{235}U) of three TRIGA fuel elements is homogenized with 500 g polyethylene. The fissile core is configured into a spherical shape with an exterior 20 cm water reflector. The $k_{eff} + 2\sigma$ value of 0.679 (Table 6.9.6-22a, Appendix 6.9.6) is substantially below the USL of 0.925. Similarly, Case **atdzr_70** pertains to Model 1, in which 6.85 kg of $UZrH_x$ (408-g ^{235}U) of three TRIGA fuel elements is homogenized with 500 g polyethylene. The fissile core is configured into a spherical shape with an exterior 20 cm water reflector. The $k_{eff} + 2\sigma$ value is 0.682 (Table 6.9.6-22b, Appendix 6.9.6). The statistical difference between the $k_{eff} + 2\sigma$ values for Cases **atdzr** and **atdzr_70** is not significant.

Cases **atdzsr_11** through **atdzsr_1** pertain to Model 2 (Fig. 6.12, Sect. 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness stainless steel shell with an exterior 20 cm water reflector. As shown in Fig. 6.24 and Table 6.9.6-22a (Appendix 6.9.6), the maximum $k_{eff} + 2\sigma$ value occurs at zero steel thickness. The $k_{eff} + 2\sigma$ value for 10.4 kg of $UZrH_x$ and zero stainless steel thickness is 0.678. The $k_{eff} + 2\sigma$ value decreases to minimum value for a stainless steel thickness of 1.87 cm while the NLF decreases from ~ 0.06 to 0.04. The NLF decreases to 0.03 as stainless steel is added up to the 66,133 g amount of the containment vessel and the liner and drum assembly. At maximum stainless steel thickness, the $k_{eff} + 2\sigma$ values increase to within 0.058 of the values for zero stainless steel thickness. The overall effect of adding stainless steel to the system is the reduction in neutron multiplication in the system. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925.

Cases **atdzsr70_11** through **atdzsr70_1** for 6,847 g of $UZrH_x$ at 70% enrichment having 408-g ^{235}U also pertain to Model 2 (Fig. 6.12, Sect. 6.3.1.4). Case results (Table 6.9.6-22b, Appendix 6.9.6) manifest the same behavior as results for corresponding Cases **atdzsr_11** through **atdzsr_1** for 10.4 kg of $UZrH_x$ at 20% enrichment having 921-g ^{235}U.

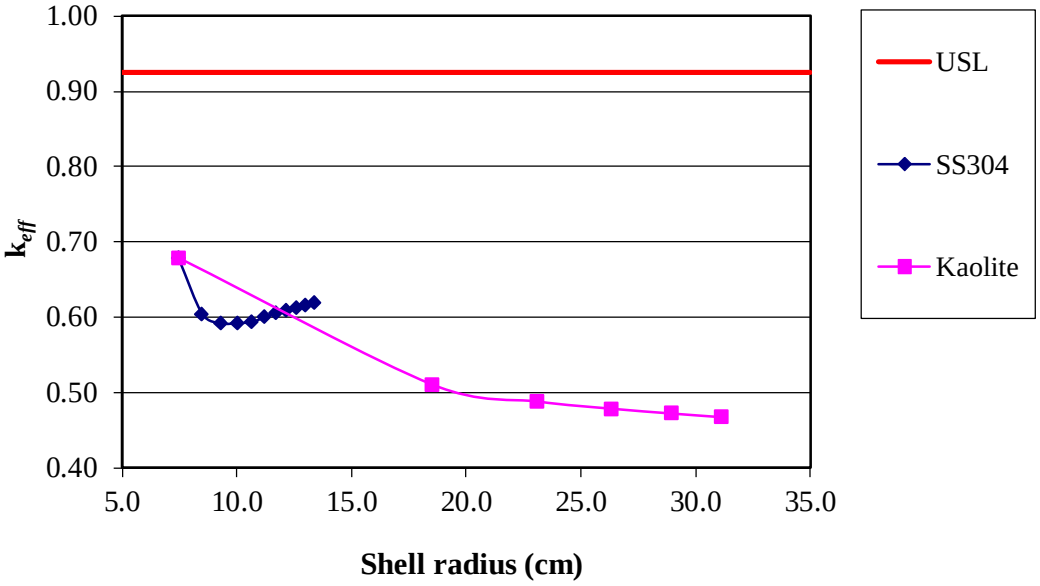


Fig. 6.24. k_{eff} vs shell radius (cm) for 10.4 kg core of $UZrH_x$ with stainless steel or wet Kaolite shell.

Cases **atdz15kr_6** through **atdz15kr_1** pertain to Model 3 (Fig. 6.13, Sect. 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness wet-Kaolite shell with an exterior 20 cm water reflector. As explained in Sect. 6.3.1.4, wet Kaolite to a maximum of 60,223 g consists of the dry Kaolite [51,214.9 g vermiculite-cement and 2,204.7 g bound water from inside the body weldment outer liner and the drum top plug] and up to 6,803.8 g free water—moisture which dampens the Kaolite and may also be present in the containment vessel well. As shown in Fig. 6.24 and Table 6.9.6-22a (Appendix 6.9.6), the maximum $k_{eff} + 2\sigma$ value occurs at zero shell-thickness for the wet Kaolite. The $k_{eff} + 2\sigma = 0.679$ for 10.4 kg of $UZrH_x$. At a shell radius of ~23 cm (24,089.2 g wet Kaolite with a shell thickness of ~ 17 cm), $k_{eff} + 2\sigma$ becomes quasi-asymptotic and the decrease in the NLF from ~ 0.06 to 0.05 is slight. With the addition of ~8.1 cm of wet Kaolite to the shell, the NLF decreases further from 0.05 to 0.04. The $k_{eff} + 2\sigma$ value decreases to a minimum value at a shell radius of 31.08 cm (60,223 g wet Kaolite with a steel thickness of 25.06 cm). The quasi-asymptotic values for $k_{eff} + 2\sigma$ are ~ 0.21 below the maximum $k_{eff} + 2\sigma$ value occurring at zero Kaolite thickness. To summarize, a significant drop in the neutron multiplication factor is observed for the addition of the initial 17 cm of wet-Kaolite shell to the fissile core, but an asymptotic value is not reached. With increasing build-up in the shell thickness, neutron multiplication decreases rather than increases, and the decrease in neutron leakage from the system is small. This behavior occurs because water at saturation levels, which is required for the Kaolite to act as a modest reflector, is not present in the wet Kaolite.

Dry Kaolite is consistent with test results of 10 CFR 71.55(d). As explained in Sect. 6.3.1.4, 53,419.1 g of dry Kaolite contained inside the body weldment outer liner and the drum top plug is NCT Kaolite (51,214.9 g vermiculite-cement and 2,204.7 g bound water). Demonstrated for HEU metal in Sect. 6.7.1, the behavior in $k_{eff} + 2\sigma$ where the value decreases to a minimum at a shell radius of 31.08 cm (shell thickness of 25.06 cm) is the same in dry Kaolite as for wet Kaolite. The overall effect of adding

dry or wet Kaolite to the system is the reduction in neutron multiplication in the system. NCT Kaolite of the ES-3100 packaging or wet Kaolite is not as effective a reflector as the 20 cm water surrounding the core. The absence of water in the Kaolite minimizes its effect. The $k_{eff} + 2\sigma$ values for Model 3 with dry or wet Kaolite are substantially below the USL of 0.925.

Cases **atdz15kr70_6** through **atdz15kr70_1** for 6,847 g of $UZrH_x$ at 70% enrichment having 408-g ^{235}U also pertain to Model 3 (Fig. 6.13, Sect. 6.3.1.4). Case results (Table 6.9.6-22b, Appendix 6.9.6) manifest the same behavior as results for corresponding Cases **atdz15kr_6** through **atdz15kr_1** for 10.4 kg of $UZrH_x$ at 20% enrichment having 921-g ^{235}U.

Cases **athzp15kr_5** through **athzp15kr_1** pertain to Model 4 (Fig. 6.14, Sect. 6.3.1.4). The homogenized core consists of 10.4 kg of $UZrH_x$ at 19.7% enrichment having 921-g ^{235}U, 500 g of polyethylene, and Kaolite. For this set of parametric cases, the Kaolite water content ranges from the wet condition (9,008.5 g water) to the dry condition (2,204.7 g water) [Table 6.9.6-22a, Appendix 6.9.6]. For Model 4, the overall radius at 31.1484 cm is constant for several reasons. First, the 500 g of polyethylene has a fixed volume. Second, the Kaolite is a porous material and its volume does not change appreciably as the material is dried out or absorbs water.

Cases **athzp15kr70_6** through **athzp15kr70_1** for 6,847 g of $UZrH_x$ at 70% enrichment having 408-g ^{235}U also pertain to Model 4 (Fig. 6.14, Sect. 6.3.1.4). While the $k_{eff} + 2\sigma$ values are lower, the results for these cases (Table 6.9.6-22b, Appendix 6.9.6) manifest the same behavior as corresponding Cases **athzp15kr_6** through **athzp15kr_1** for 10.4 kg of $UZrH_x$ at 20% enrichment having 921-g ^{235}U.

As shown in Fig. 6.25 and Tables 6.9.6-22a and 6.9.6-22b, a gradual increase in $k_{eff} + 2\sigma$ occurs from dry condition to the wet condition. The homogenization of the Kaolite shell and the fissile material core from Model 3 produces two competing effects in Model 4:

- homogenization expands the fissile material core resulting in a decrease in neutron multiplication (from $k_{eff} + 2ó = 0.4675$ in Case **atdz15kr_6** to $k_{eff} + 2ó = 0.3577$ in Case **athzp15kr_5**), and

- the increase in the free water content of the Kaolite (and containment vessel well) increases neutron multiplication in the core (from $k_{eff} + 2ó = 0.3100$ in Case **athpz15kr_1** to $k_{eff} + 2ó = 0.3577$ in Case **athzp15kr_5**).

Consequently, the scenario of water penetration of fissile material core under Model 5 requires evaluation.

Cases **athzpw15kr_5** through **athzpw15kr_1** pertain to Model 5 (Fig. 6.15, Sect. 6.3.1.4). Model 5 is a variation of Model 3, which represents a fissile material core blanketed with wet Kaolite and reflected by 20 cm of water. In Model 5, excess water from the wet Kaolite shell is assumed to migrate into the homogenized core. The homogenized core consists of 10.4 kg of $UZrH_x$ at 19.7% enrichment having 921-g ^{235}U, 500 g of polyethylene, and excess water from the wet Kaolite. The water content of the Kaolite shell ranges from the wet condition (9,008.5 g water) to the dry condition (2,204.7 g water) [Table 6.9.6-22a, Appendix 6.9.6]. As excess water migrates from the wet Kaolite shell into the homogenized core, the core radius expands from 7.4677 to 12.6903 cm. However, the volume of the Kaolite shell remains constant because the Kaolite is a porous material and its volume does not change appreciably as the material loses or gains water. Consequently, the overall radius of the system increases from 31.1484 to 31.6977 cm.

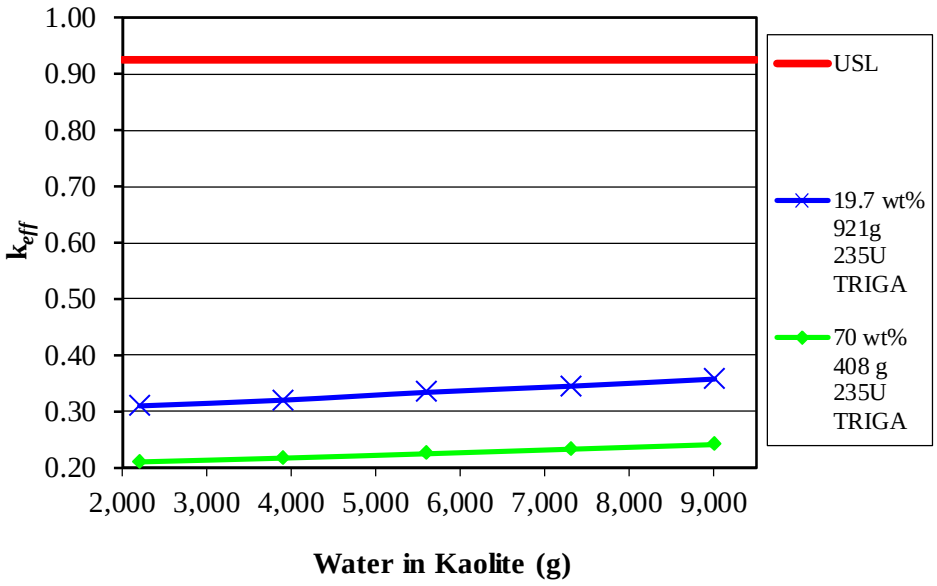


Fig. 6.25. k_{eff} vs water content (g) for homogenized core of $UZrH_x$, 500 g polyethylene and Kaolite where the Kaolite water content ranges from the dry to the wet condition.

Cases **athzpw15kr70_6** through **athzpw15kr70_1** for 6,847 g of $UZrH_x$ at 70% enrichment having 408-g ^{235}U also pertain to Model 5 (Fig. 6.15, Sect. 6.3.1.4). While the $k_{eff} + 2\sigma$ values are lower, the results for these cases (Table 6.9.6-22b, Appendix 6.9.6) manifest the same behavior as corresponding Cases **athzpw15kr_6** through **athzpw15kr_1** for 10.4 kg of $UZrH_x$ at 20% enrichment having 921-g ^{235}U.

As shown in Fig. 6.26 and Tables 6.9.6-22a and 6.9.6-22b (Appendix 6.9.6), the $k_{eff} + 2\sigma$ values increase to maximums of 0.8078 and 0.7215 with the addition of the entire 6,803.9 g of water from wet Kaolite into the fissile material core. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925. The homogenized core is under moderated because sufficient water is not present in the wet Kaolite and containment vessel well to reach the point of optimum moderation. The total free water is conservatively evaluated up to 15 lb (6,803.9 g).

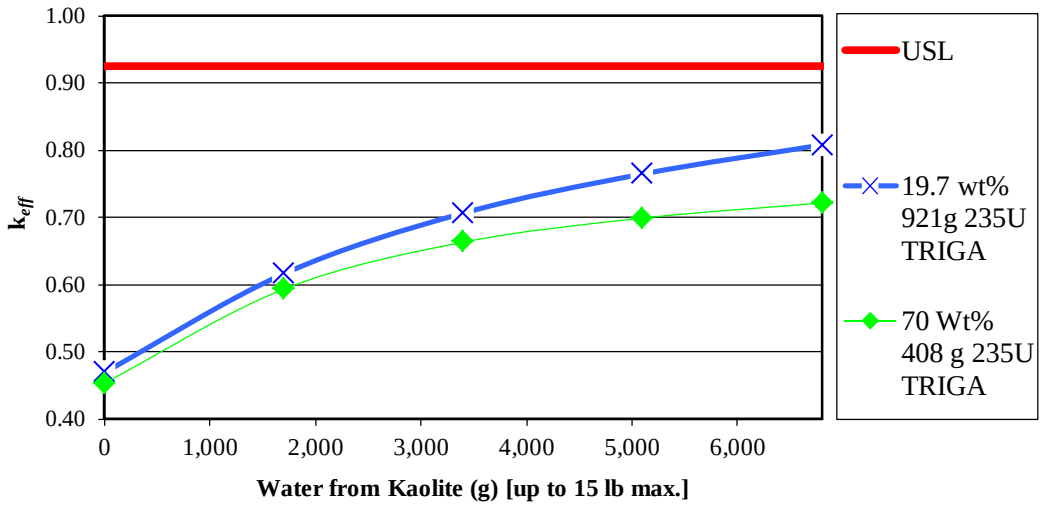


Fig. 6.26. k_{eff} vs excess water (g) from wet Kaolite for fissile core blanketed with a variable thickness Kaolite shell.

In the absence of 10 CFR 71.55(f) test data or dynamic impact simulations per Type-C test criteria, the assumption of water penetration of the fissile material core is valid under the severe air transport evaluation criteria. Model 5 is applicable to air transport of the ES-3100 package given that the geometric form of the TRIGA fuel content following the air transport accident cannot be established.

Case results are presented in Table 6.9.6-22c (Cases **athopw15kr20_1** through **athopw15kr20_5**, Cases **athopw15kr70_1** through **athopw15kr70_5**, and Cases **athopw15kr93_1** through **athopw15kr93_5**) for U_3O_8-Al at the TRIGA content limits of 921-g ^{235}U for 20% enrichment and 408-g ^{235}U for 70% and 93.2% enrichments, respectively. As shown in Fig. 6.27 and Table 6.9.6-22c (Appendix 6.9.6), the $k_{eff} + 2\sigma$ values for U_3O_8-Al are exceeded by values for TRIGA content; therefore, the TRIGA loading limits are bounding for the research reactor related contents of U_3O_8 and U_3O_8-Al oxide.

Case results are presented in Table 6.9.6-22d (Cases **athupw15kr09_1** through **athupw15kr09_5**, Cases **athupw15kr20_1** through **athupw15kr20_5**, and Cases **athupw15kr93_1** through **athupw15kr93_5**) for UO_2-Mg in Al cladding at content limits of 921-g ^{235}U for 9.89% and 20% and 408-g ^{235}U for 93.2% enrichment, respectively. Cases **athbpw15kr93_1** through **athbpwskr93_5** for UO_2 are at content limits of 408-g ^{235}U for 93.2% enrichment. As shown in Fig. 6.28 and Table 6.9.6-22d (Appendix 6.9.6), the $k_{eff} + 2\sigma$ values for research reactor contents of UO_2-Mg or UO_2 exceed values for TRIGA content. These values are well below the USL; therefore, the TRIGA loading limits may be applied to the research reactor related contents of UO_2 and UO_2-Mg oxide.

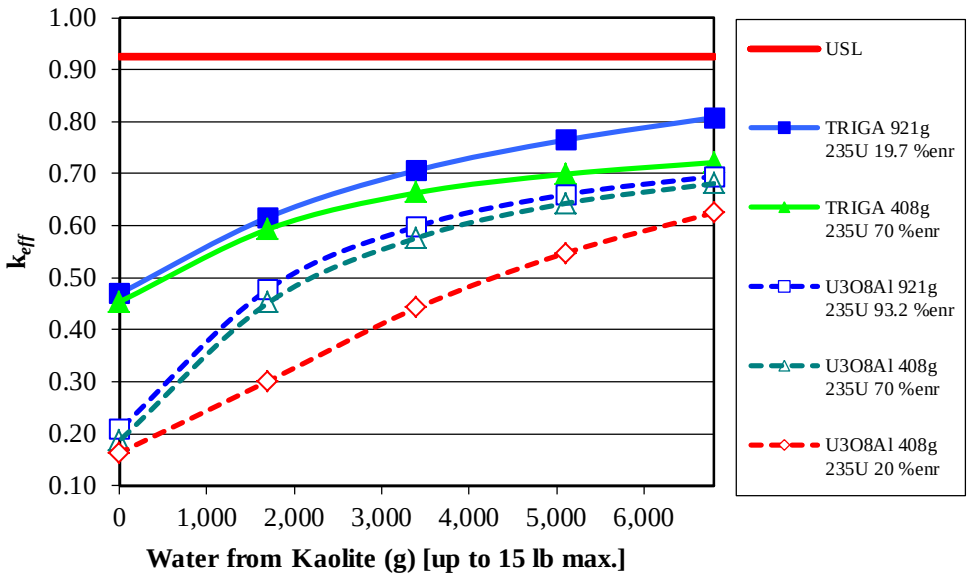


Fig. 6.27. k_{eff} vs excess water (g) from wet Kaolite for fissile material core blanketed with a variable thickness Kaolite shell.

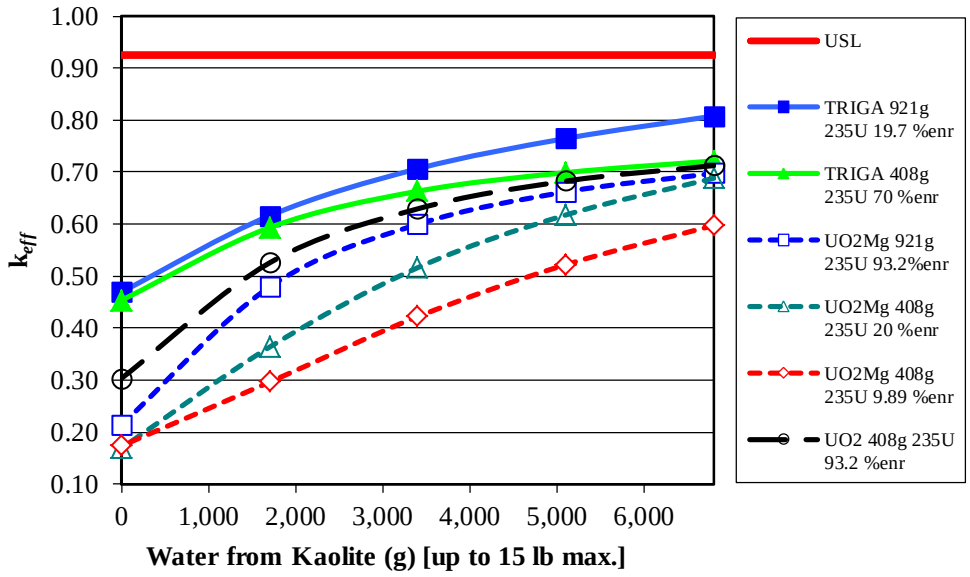


Fig. 6.28. k_{eff} vs excess water (g) from wet Kaolite for fissile material core blanketed with a variable thickness Kaolite shell.

Model 6 (Fig. 6.16, Sect. 6.3.1.4) pertains to the case where fissile material from the homogenized core of Model 4 forms a shell external to the core. Given that the total amount of fissile material is limited to 921-g ^{235}U, the quantity is not sufficient to form a critical configuration. As shown in Section 6.7.3, this is apparent even if kilogram quantities of additional fissile material were located in the shell adjacent to the core.

6.7.3 Results for HEU Broken Metal, Turnings, Fines, or Powder

The results for Models 1–3 presented in Sect. 6.7.1 address HEU metal evaluated as a fissile core uranium metal and hydrogenous packing material surrounded by but not mixed with other materials. Results for Models 4–6 presented in this section address HEU metal evaluated as a fissile core but where the integrity of the fissile core is lost. Preferential mixing of the fissile core with packing material (non-hydrogenous) and packaging material (stainless steel, Kaolite) is evaluated. Also, reconfiguration of the fissile core is evaluated. This evaluation addresses broken metal, metal turnings, fines, and powder. HEU oxide content for air transport is addressed in Appendix 6.9.10.

Cases **athmp15kr_12_8_5** through **athmp15kr_12_8_1** and Cases **athmp15kr_12_1_5** through **athmp15kr_12_1_1** (Table 6.9.6-23, Appendix 6.9.6) pertain to Model 4 (Fig. 6.14, Sect. 6.3.1.4). In the former set of cases, the homogenized core consists of 7 kg of HEU metal at 100% enrichment, 500 g of polyethylene, and Kaolite. In the latter set of cases, the homogenized core consists of 35 kg of HEU metal at 20% enrichment having 7 kg ^{235}U, 500 g of polyethylene, and Kaolite. For these sets of parametric cases, the Kaolite water content ranges from the wet condition (9,008.5 g water) to the dry condition (2,204.7 g water) [Table 6.9.6-23, Appendix 6.9.6]. For Model 4, the overall radius is 31.0803 cm for homogenized core with 100% enrichment and is 31.2009 cm for homogenized core with 20% enrichment. The core radius is constant with changing moisture conditions for the following reasons. First, the 500 g of polyethylene has a fixed volume. Second, the Kaolite is a porous material and its volume does not change appreciably as the material is dried out or absorbs water.

As shown in Fig. 6.29 and Table 6.9.6-23, a gradual increase in the $k_{eff} + 2\sigma$ value occurs from the dry condition to the wet condition. The homogenization of the Kaolite shell and the fissile material core from Model 3 produces two competing effects in Model 4:

- homogenization expands the fissile material core resulting in a slight decrease in neutron multiplication (from $k_{eff} + 2ó = 0.6001$ in Case **atdm15kr_7_8_6** to $k_{eff} + 2ó = 0.5909$ in Case **athmp15kr_12_8_5**) and

- the increase in the free water content of the Kaolite (and containment vessel well) increases neutron multiplication in the core (from $k_{eff} + 2ó = 0.5024$ in Case **athmp15kr_1** to $k_{eff} + 2ó = 0.5909$ in Case **athmp15kr_5**).

Consequently, the scenario of water penetration of fissile material core under Model 5 requires evaluation.

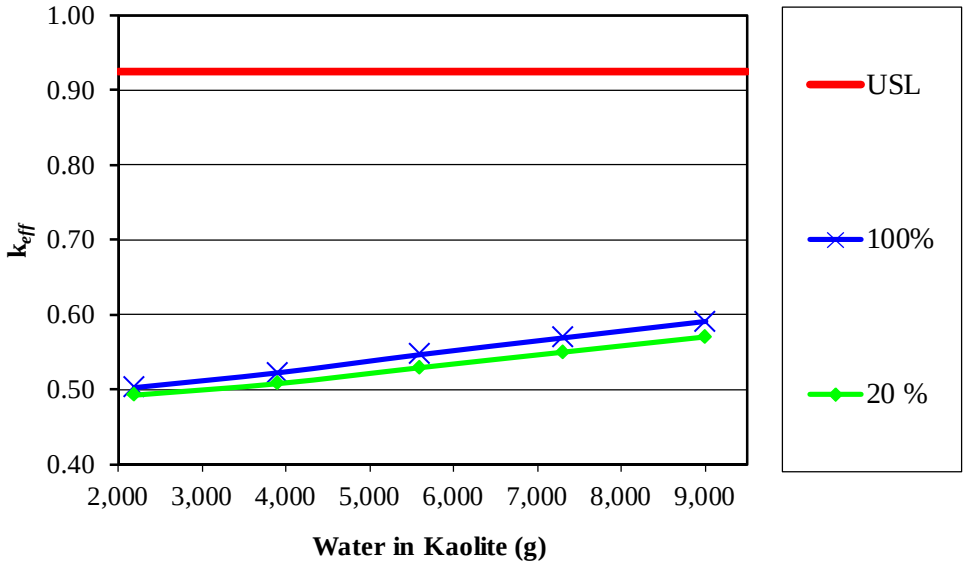


Fig. 6.29. k_{eff} vs water content (g) for homogenized core of HEU with 7 kg ^{235}U, 500 g polyethylene, and Kaolite where the Kaolite water content ranges from the dry to the wet condition.

Cases **athmpw15kr_12_8_5** through **athmpw15kr12_8_1**, Cases **athmpw13kr_12_8_5** through **athmpw13kr12_8_1**, and Cases **athzpw12kr70_5** through **athzpw12kr70_1** pertain to Model 5 (Fig. 6.15, Sect. 6.3.1.4). Model 5 is a variation of Model 3, which represents a fissile material core blanketed with wet Kaolite and reflected by 20 cm of water. In Model 5, excess water from the wet Kaolite shell is assumed to migrate into the homogenized core. In each set of cases, the homogenized core consists of HEU metal loading of 7 kg ^{235}U for uranium at 100% enrichment, 500 g of polyethylene, and excess water from the wet Kaolite. In the three sets of cases "**athmpw15kr**," "**athmpw13kr**," and "**athmpw12kr**," the corresponding amounts of free water for the wet condition are 15 lb (6,803.9 g), 13 lb (5,896.7 g), and 12 lb (5,443.1 g), respectively. For all of these sets of parametric cases, the water content of the Kaolite shell ranges from the wet condition (9,008.5 g water or 8,101.4 g or 7,647.8 g) to the dry condition (2,204.7 g water) [Table 6.9.6-23, Appendix 6.9.6]. As excess water migrates from the wet Kaolite shell into the homogenized core, the radius for either fuel type expands accordingly but the volume of the Kaolite shell remains constant. Consequently, the overall radius of the system increases. As stated previously, the 500 g of polyethylene has a fixed volume. Also, Kaolite is a porous material and its volume does not change appreciably as the material looses or gains water.

As shown in Fig. 6.30 and Table 6.9.6-23 (Appendix 6.9.6), the $k_{eff} + 2\sigma$ values increase to maximums of 0.9062, 0.9272, and 0.9596 with the addition to the fissile core of the entire 12 lb, 13 lb, and 15 lb amounts of free water from wet Kaolite. The homogenized core is under moderated because sufficient water is not present in the wet Kaolite and containment vessel well to reach the point of optimum moderation. However, $k_{eff} + 2\sigma$ exceeds the USL of 0.925 for those cases where the total free water is greater than 12 lb (5,443.1 g). This signifies the fissile mass loading limit for HEU is 7 kg ^{235}U and the range of excess water cannot exceed 12 lb from the Kaolite and the containment vessel well in order for the content to be shipped by air transport. Therefore, the evaluation of Model 6 is focused on this limit.

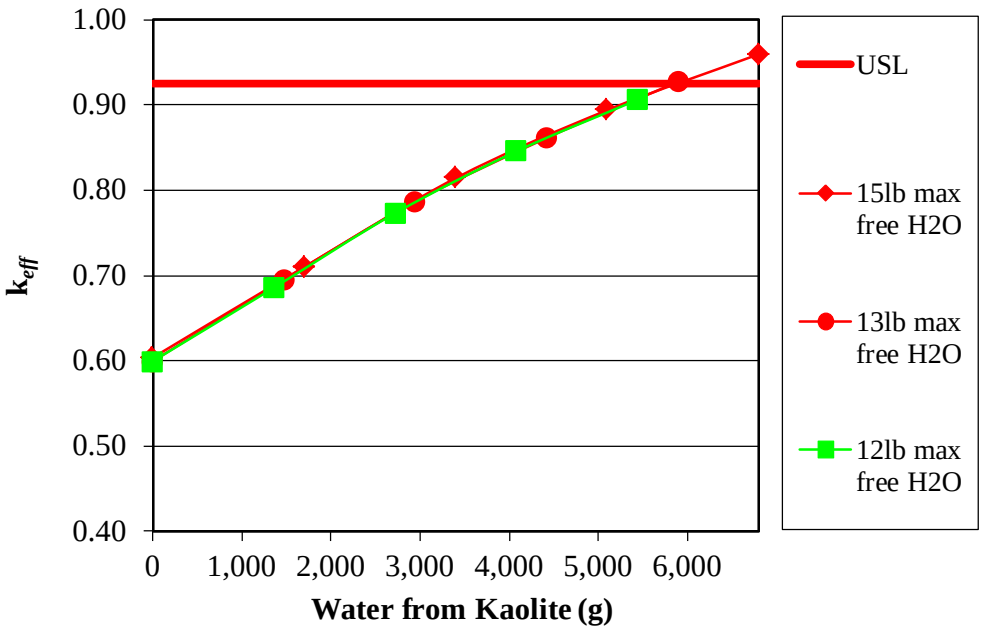
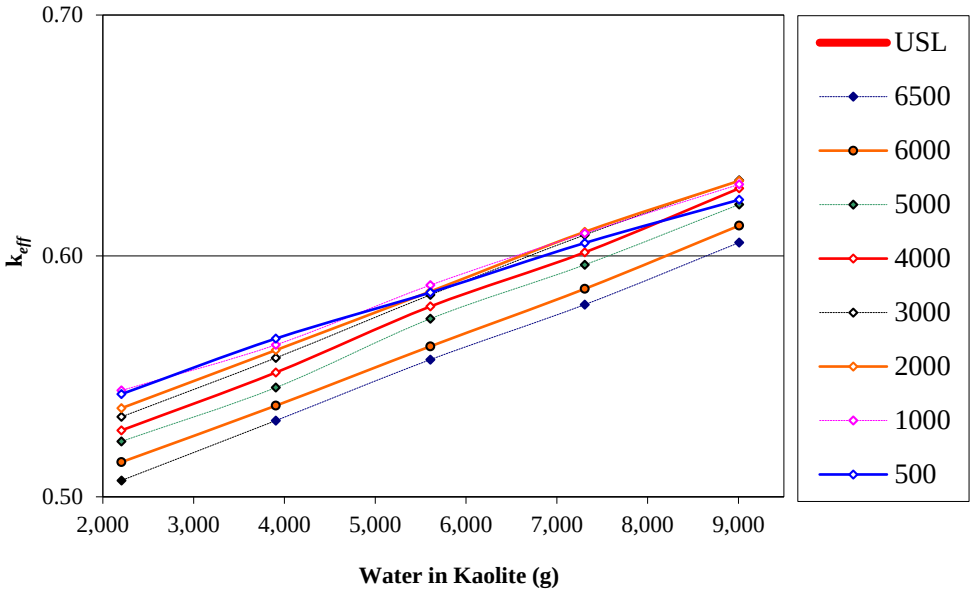


Fig. 6.30. k_{eff} vs excess water (g) from wet Kaolite for fissile core blanketed with a variable thickness Kaolite shell.

Cases **athmp15kmr_13_1_8_5** through **athmp15kmr_1_13_8_1** (Table 6.9.6-23, Appendix 6.9.6) pertain to Model 6 (Fig. 6.16, Sect. 6.3.1.4), where fissile material from the homogenized core of Model 4 forms a shell external to the core. The homogenized core consists of HEU at 100% enrichment, 500 g polyethylene, and Kaolite. In a series of cases, the amount of HEU in the shell is varied from 500 g to 6,500-g ^{235}U in 500 g increments and the remainder of the 7 kg ^{235}U is contained in the homogenized core. For these sets of parametric cases, the Kaolite water content ranges from the wet condition (9,008.5 g water) to the dry condition (2,204.7 g water). As shown in Fig. 6.31, all $k_{eff} + 2\sigma$ values are adequately below the USL of 0.925.

As stated previously, uranium alloy is conservatively assessed when alloy constituents, such as aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium, are modeled as ^{235}U. Thus, limits established for HEU metal apply to the uranium alloys where the content mass of ^{235}U includes the mass of the non-uranium alloy constituents.



Note: Total quantity of HEU is 7-kg ^{235}U where the shell ranges from 500-g to 6,500-g ^{235}U and the remainder of the HEU is contained in the homogenized core.

Fig. 6.31. k_{eff} vs water (g) in Kaolite for homogenized core of HEU at 100% enrichment, 500-g polyethylene, and wet Kaolite encompassed by shell of ^{235}U.

6.7.4 Conclusions

Given that the results for catastrophic damage are adequately subcritical, ES-3100 packages may be shipped via air transport with:

- up to 7-kg ^{235}U HEU metal in the form of solid shapes (cylinders, bars, billets, buttons, or slugs), broken metal, metal turnings, fines, powder, or as an unspecified geometric shape (characterized as broken metal) unless a lesser amount is determined by ground transport consideration (Table 6.2a);
- up to 7-kg ^{235}U with enrichment up to 100%;
- three fuel sections ("meats") of $UZrH_x$ per loaded convenience can and up to three loaded cans per package where the ^{235}U does not exceed 921 g at 20% enrichment or 408-g ^{235}U at 70%;
- ~15-in.-long clad fuel rods, each rod derived from a single TRIGA fuel element, and where per package ^{235}U does not exceed 921 g at 20% enrichment or 408-g ^{235}U at 70%; or
- research reactor related contents of U_3O_8-Al, UO_2, and UO_2-Mg where the per package ^{235}U content does not exceed 921 g at enrichments less than or equal to 20% or 408-g ^{235}U at enrichments greater than 20%.

6.8 BENCHMARK EXPERIMENTS

6.8.1 Applicability of Benchmark Experiments

The criticality validation is specific to uranium, plutonium, and uranium-233 systems encompassing a substantial subset of the database used to prepare the Organization for Economic Cooperation and Development (OECD) Handbook, Volumes I–VI. The benchmark specifications are intended for use by criticality safety engineers to validate the application of criticality calculation techniques such as SCALE 4.4a. Example calculations presented in the handbook do not constitute a validation of the codes or cross-section data sets by themselves, but the Handbook information can be and has been used to validate SCALE 4.4a by competent nuclear criticality safety persons.

The data from the benchmark experiments involving uranium represent a sufficiently wide range of enrichments and physical and chemical forms to cover many existing or presently planned activities for Y-12. These include enriched uranium with ^{235}U only and natural and depleted uranium, as well as highly enriched uranium, intermediate enriched uranium, and low enriched uranium. Data analyzed from critical experiments in this validation include systems having fast, intermediate, and thermal neutron energy spectra, and they include materials in various physical and chemical forms such as uranium metals, solutions, and oxide compounds. With the benchmark experiments that are directly applicable to uranium systems, there is a high level of confidence that the calculated results presented in this evaluation are sufficiently accurate to establish the safety of the package under both NCT and HAC. This conclusion is based on the validation of the code and cross-section library described in Sect. 6.3.3.

6.8.2 Details of Benchmark Calculations

The validation of CSAS25 control module of SCALE 4.4a with the 238-group ENDF/B-V cross-section library is documented in Y/DD-896/R1 and Y/DD-972R1. Y/DD-896/R1 addresses the establishment of bias, bias trends, and uncertainty associated with the use of SCALE 4.4a for performance of criticality calculations. This evaluation is directed at uranium systems consisting of fissile and fissionable material in metallic, solution, and other physical forms, as well as plutonium and ^{233}U systems, as described in the OECD Handbook [NEA/NSC/DOC(95)03]. The focus is on comparison of k_{eff} with the associated experimental results for establishment of bias, bias trends, and uncertainty as a final step. Compiled data for 1217 critical experiments are used as the basis for the calculation models. The calculated results from SCALE 4.4a using the 238-group ENDF/B-V cross-section library have been compared with reported results for the benchmark experiments. Comparison of results demonstrates that SCALE 4.4a run on the SAE HP J-5600 unclassified workstation (CMODB) produces the same results within the statistical uncertainty of the Monte Carlo calculations as reported by the OECD for the experiments.

Y/DD-972R1 addresses determining USL and for incorporating uncertainty and margin into this USL. Y/DD-972R1 establishes subcritical limits determined through an evaluation of statistical parameters of calculation results for critical experiments. The correlating parameters (i.e., mass, enrichment, geometry, absorption, moderation, reflection) and values for applying additional margin to the subcritical limits are application dependent. The determination of correlating parameters and additional margin is an integral part of the process analysis for a particular application. For the critical experiment results, no correlation between calculation results and neutron energy causing fission was found. As such, this document does not specify “final” USL values as has been done in the past.

6.8.3 Bias Determination

The USL is based on the non-parametric statistics-based lower tolerance limit (LTL) for greater than 0.99/99% where there is a probability of greater than 0.99 that 99% of the population is greater than

a specified result, reduced by additional margin. From Table 1 of Y/DD-972R1, the LTL combining bias and bias uncertainty is 0.975 for uranium systems, including HEU metal. Tables 4.2, 4.3, and 4.4 of Y/DD-896/R1 list the maximum (positive) and minimum (negative) biases for HEU (metal, compound, solution), IEU (metal, compound) and LEU (compound, solution) systems. Since the positive bias is conservatively treated as a "zero" bias in the validation analysis, the negative bias is applied to determine the USL for the systems. The minimum bias for the HEU, IEU, and LEU systems is given as −0.14356, −0.0055 and −0.0247, respectively.

The minimum result for the HEU systems is from one of four k-infinite models, which are somewhat different than the actual benchmark experiments. As discussed in Sect 5.3 of Y/DD-896/R1, four outlier results are for benchmark experiments that were modeled infinite in extent. The models required additional interpretation and adjustment form the actual finite experiment configuration to create an infinite benchmark model. After eliminating the outlier models from the bias determination, the minimum bias determined from data in Table 4.2 (Y/DD-896/R1) is −0.0203 for HEU systems.

The global minimum bias for these uranium systems [−0.0247 (conservatively rounded to −0.025)] is applied to all uranium enrichments. Ordinarily, the USL would be 0.955 where an additional margin of subcriticality of 0.02 is subtracted from the LTL of 0.975. However, NUREG/CR-5661 provides guidance that the USL should be established with a minimum margin of subcriticality of 0.05. Thus, the USL is equal to 0.95 plus the minimum bias (−0.025), giving a value of 0.925.

6.9 APPENDICES

6.9.1 Fissile Content and Packaging Models

6.9.2 HAC Package Model

6.9.3 Package Material Compositions

6.9.4 Qualification of a Neutron-absorber Material for the ES-3100

6.9.5 Miscellaneous Information and Data

6.9.6 Abridged Summary Tables of Criticality Calculation Results

6.9.7 Input Listings of ES-3100 Calculation Models for Select Cases

6.9.8 Criticality Evaluation of Additional Content

6.9.9 Criticality Evaluation for Increasing the Fissile Loading Limit for HEU Oxide

6.9.10 Criticality Evaluation of HEU Oxide Product Content for Air Transportation

6.9.11 Criticality Evaluation of HEU Metal Turnings, Fines, or Powders (>80% enriched); Removal of Carbon Limits for Oxides; Low Density Oxides; Removal of Cladding Limits; and Uranium Tetrafluoride at a Criticality Safety Index of 2.0

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Appendix 6.9.1

Fissile Content and Packaging Models

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Appendix 6.9.1

Fissile Content and Packaging Models

Calculation model for solid HEU metal, 3.24-in.-diam cylinders. Figure 6.9.1-1 depicts the wire-mesh view of the 3.24-in.-diam highly enriched uranium (HEU) cylindrical content configuration inside the containment vessel. The interstitial water has been removed for illustration purposes. As can be seen from Fig. 6.9.1-1, the cylindrical content model contains one cylinder per convenience can and 1.4-in.-thick 277-4 canned spacers between the can locations. Cylinders are at the maximum diameter that will fit through the opening of a press-fit lid type convenience can. The cylindrical content shown is at the maximum mass loading; the height of the cylinders may change depending upon the mass loading. Figure 6.9.1-1b depicts a section view of the containment vessel with 3.24-in.-diam cylinders at 4.826 and 0.254 cm separation.

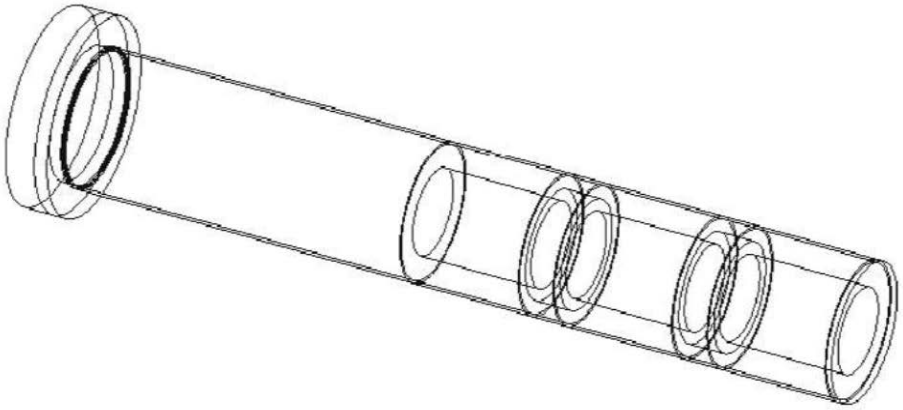


Fig. 6.9.1-1. Containment vessel containing 3.24-in.-diam cylinders and 1.4-in.-thick 277-4 canned spacers.

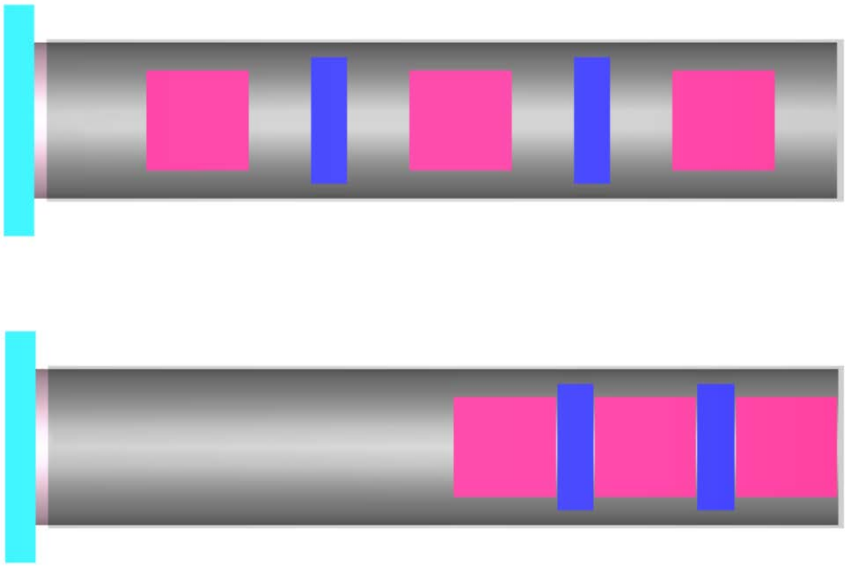


Fig. 6.9.1-1b. Section view of the containment vessel depicting 4.826 and 0.254 cm separation distances for 3.24-in.-diam cylinders (pink) with 1.4-in.-thick canned spacers (blue).

Calculation model for solid HEU metal, 4.25-in.-diam cylinders. Figure 6.9.1-2 depicts the wire-mesh view of the 4.25-in.-diam HEU cylindrical content configuration inside the containment vessel. The interstitial water has been removed for illustration purposes. As can be seen from Fig. 6.9.1-2, the cylindrical content model contains one cylinder per convenience can and 1.4-in.-thick 277-4 canned spacers between the can locations. Cylinders are at the maximum diameter that will fit through the opening of a crimp-seal lid type convenience can. The cylindrical content shown is at the maximum mass loading; the height of the cylinders may change depending upon the mass loading.

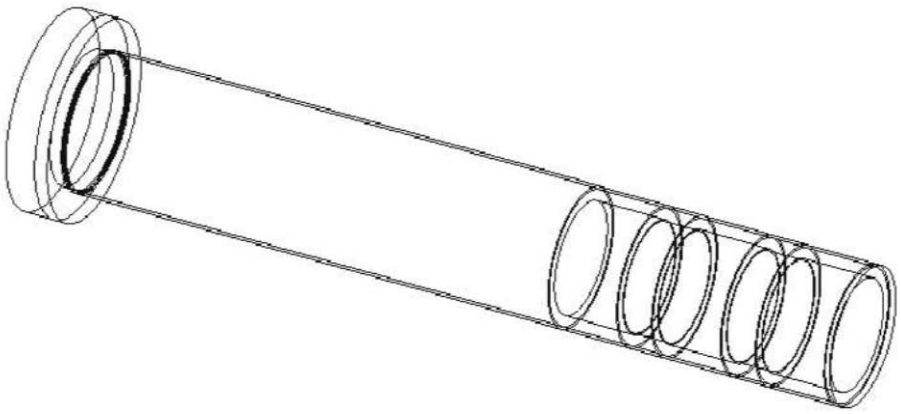


Fig. 6.9.1-2. Containment vessel containing 4.25-in.-diam cylinders and 1.4-in.-thick 277-4 canned spacers.

Calculation model for solid HEU metal, bars. Figure 6.9.1-3 depicts the wire-mesh view of the 2.29-in.-square HEU bar content configuration inside the containment vessel. The interstitial water inside the containment vessel has been removed for illustration purposes. The square bar content model contains one bar per convenience can and 1.4-in.-thick 277-4 canned spacers between the can locations. The 2.29-in.-square bar is the largest size that will fit through the 3.24-in.-diam opening of a press-fit lid type convenience can. Similar to the cylindrical model, the height of the square bar is dependent upon the HEU mass.

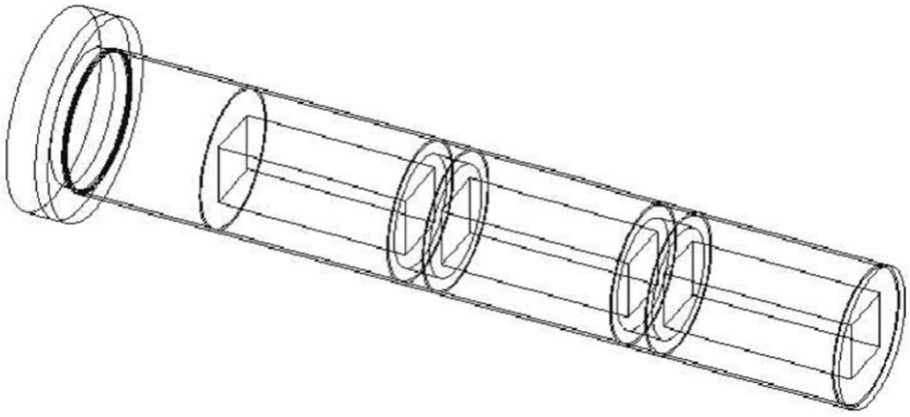


Fig. 6.9.1-3. Containment vessel containing 2.29-in.-square bars and 1.4-in.-thick 277-4 canned spacers.

Calculation model for solid HEU metal, slugs. Figure 6.9.1-4 depicts the wire-mesh view of a pentagonal ring configuration of the 1.5-in.-diam × 2.0-in.-tall slugs inside the containment vessel. The axial centerline of each slug is located 1.27598 in. from the origin of the pentagon such that a tight fitting configuration of slugs is modeled (i.e., there are no gaps between adjacent slugs). The slug content model contains two rings of the 1.5-in.-diam × 2.0-in.-tall slugs per convenience can and the 277-4 canned spacers between the convenience cans locations. The interstitial water inside the containment vessel has been removed for illustration purposes. Figure 6.9.1-4b depicts typical slug configurations that were evaluated.

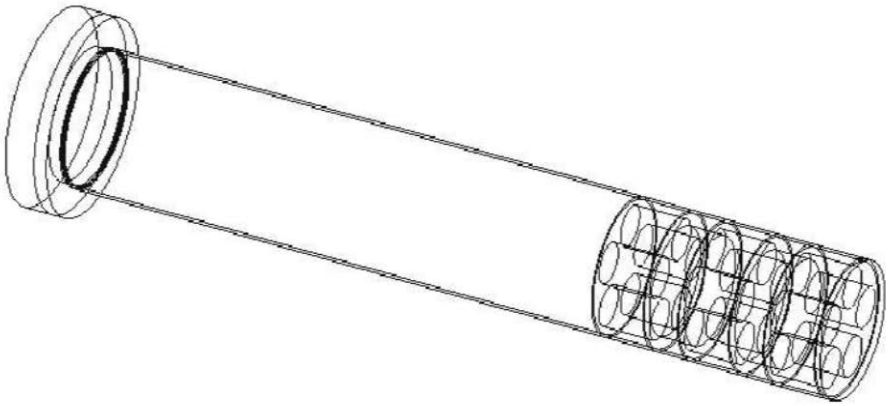
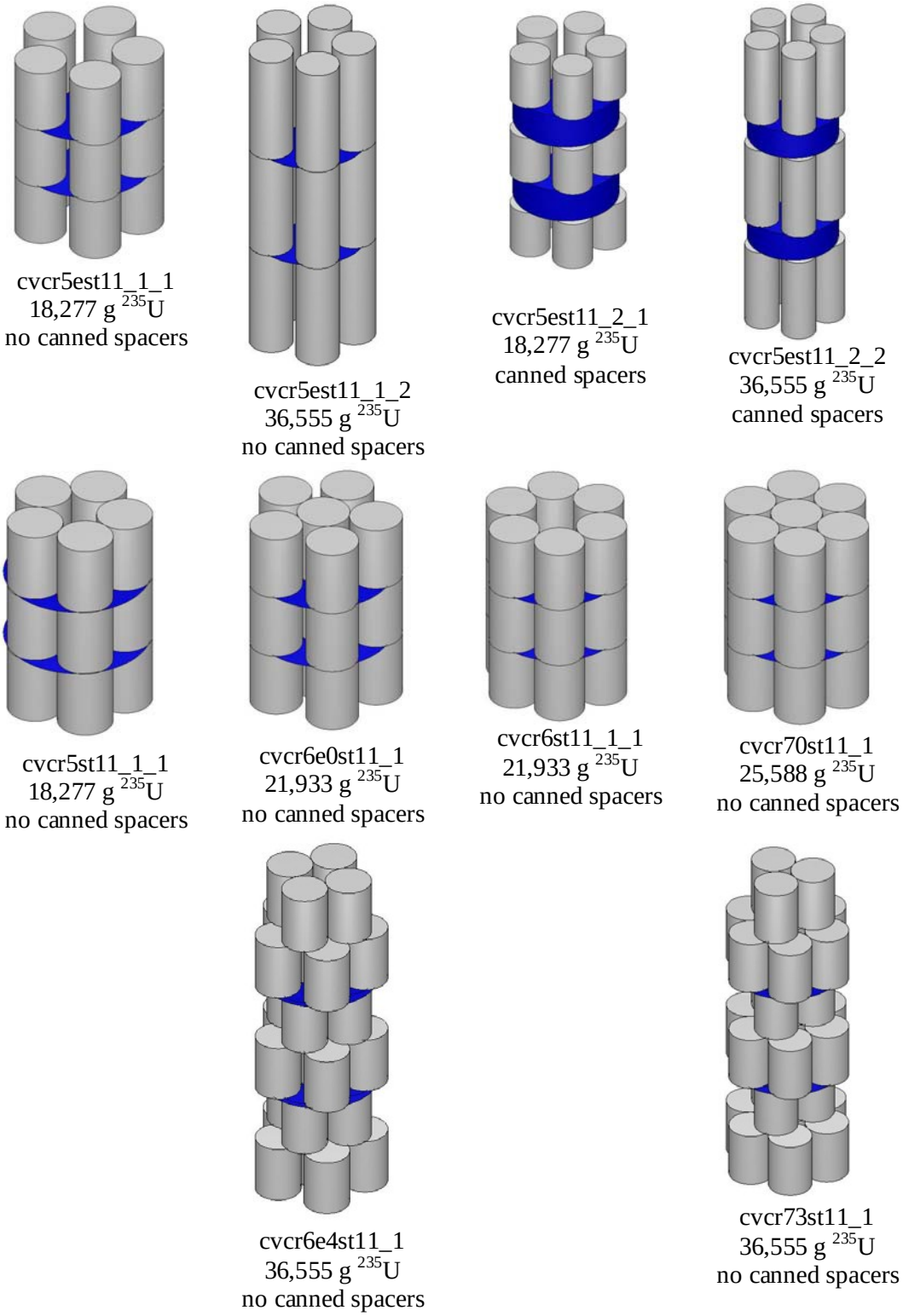


Fig. 6.9.1-4. Containment vessel containing the 1.5-in.-diam × 2.0-in.–tall slugs in a pentagonal ring configuration with 0.0-cm spacing between slugs and 1.4-in.-thick 277-4 canned spacers.

A 1.5-in.–diam × 2.0-in.–tall slug was modeled with a maximum tolerance of 1/16 in. applied to both the radius and height. The resulting dimensions are 1.984375 cm in radius and 5.23875 cm in height; the calculated volume of a single slug is 64.80746 cm^3. For 100% enriched uranium (density = 18.81109 g/cm^3), the calculated mass of 15 slugs is 18,286.5 g. Subsequently, the radius of each slug was reduced by 0.0005 cm thus eliminating a geometry intersection error in KENO V.a which occurs when the hole option is used to place slugs into an encompassing piece of the geometry unit. In the case of a pentagonal ring with spaced-apart slugs (Case **cvcr5est11_1_1**, Fig. 6.9.1-4b), the calculated volume reported for 15 slugs in KENO V.a is 971.622 cm^3 and the corresponding mass is 18277.3 g or 1,218.5 g per slug. This reduction in mass of 0.6333 g per slug is insignificant when considering the mass of a slug is nominally 1,089 g.

The maximum tolerance slug was also used in other slug geometry configurations, such as, “cvcr5s”, “cvcr6e0s”, “cvcr6s”, “cvcr70s”, “cvcr6e4s”, and “cvcr73s” orientations shown in Fig. 6.9.1-4b. For the pentagonal geometry configuration with slugs stacked two high in a ring (Case **cvcr5est11_1_2** or **cvcr5st11_1_2**), the model volume and mass of the slugs are twice the values of the single ring (Case **cvcr5est11_1_1** or **cvcr5st11_1_1**). For a pentagonal geometry configuration with a central slug (“cvcr6e0s”) and the hexagonal geometry configuration (“cvcr6"), the calculated volume reported in KENO V.a is 1,165.95 cm^3 and the corresponding mass is 21,932.7 g. For a hexagonal geometry configuration with a central slug (“cvcr70s”), the calculated volume reported in KENO V.a is 1,360.27 cm^3 and the corresponding mass is 25,588.2 g. For the compact ten-slug-per-can configurations (“cvcr5est”, “cvcr5est”, “cvcr6e4s”, and “cvcr73s”), the calculated volume reported in KENO V.a is 1,943.24 cm^3, and the corresponding mass is 36,554.6 g.



Note: Blue marker depicted for configurations without 1.4-in.-thick 277-4 canned spacers.

Fig. 6.9.1-4b. Isometric views for typical slug configurations.

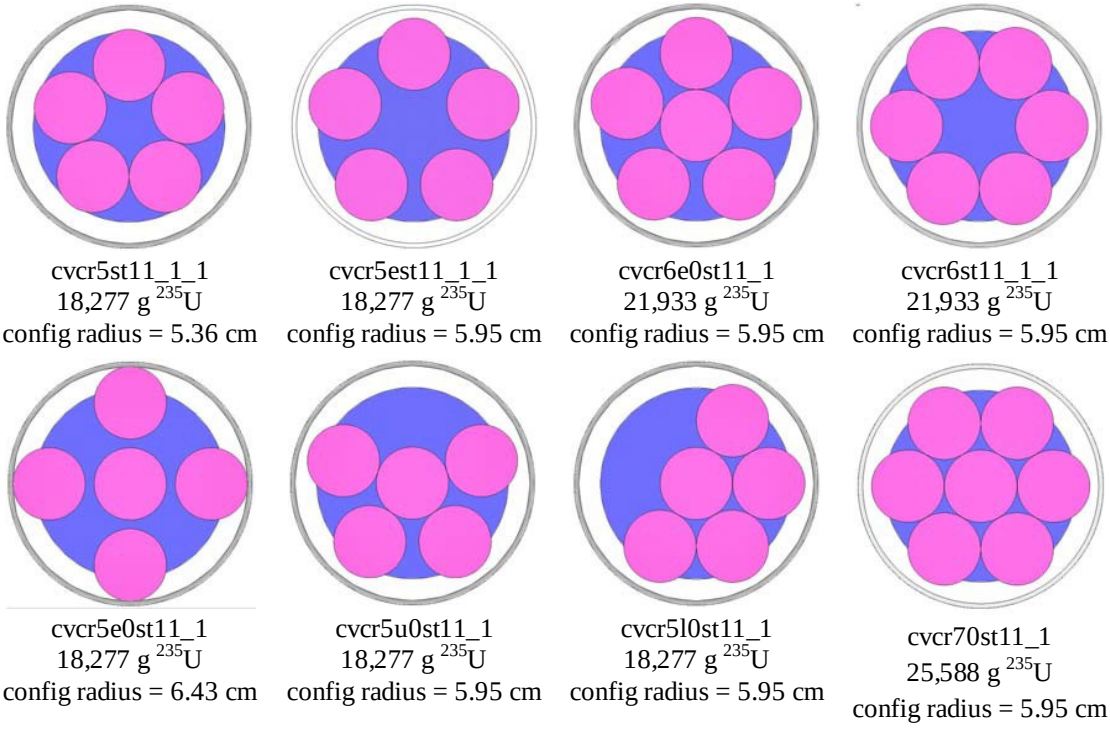
Several slug arrangements were evaluated for demonstrating that the most conservative arrangement of slugs has been analyzed. Figure 6.9.1-4c depicts radial section views of the containment vessel showing the slugs (pink) in relation to the footprint (blue) for a 4.25-in.–diam (5.3975-cm) convenience can. Cases **cvcr5st11_1_1**, **cvcr5est11_1_1**, **cvcr5e0st11_1**, **cvcr5u0st11_1**, and **cvcr5l0st11_1** depict different arrangements with five slugs per convenience can, three cans per package. Cases **cvcr6e0st11_1_1** and **cvcr6st11_1_1** depict arrangements with six slugs per convenience can, and Case **cvcr70st11_1** depicts seven slugs per convenience can. (Considerable deformation of a 4.25-in.–diam convenience can wall is required to achieve all but the simple pentagonal-ring arrangement of slugs.) The 277-4 canned spacers are not present in these calculation models.

Calculation models for solid HEU metal of unspecified geometric shapes characterized as broken metal. The intended use of the "broken metal" category is for shipment of solid HEU metal of unspecified geometric shape characterized as broken metal, packed in 4.25-in.-diam convenience cans where the packing fraction would not exceed 0.59. The packing fraction is a parameter which characterizes the volume that broken metal occupies. A typical broken metal content is depicted in Fig. 6.9.3.1-3 where the packing fraction for content in a convenience can ranges from 0.2 to ~0.6.

In the criticality evaluation of broken metal, convenience cans are not credited for containing the content nor for maintaining spacing between the 277-4 canned spacers. Consequently, the shape and size of the broken metal pieces establishes the separation between canned spacers which in turn determines the size of the HEU content locations inside the containment vessel. Given the irregular shape of broken metal, the packing fraction is the parameter which quantifies the volume of space that the broken metal occupies. The use of a large packing fraction (~0.6) results in minimum separation between canned spacers which minimizes the size of the lower and middle content locations and maximizes the size of the upper content location. Reactivity of the containment vessel is driven by the oversized upper content location. Conversely, the use of a small packing fraction (~0.2) results in greater separation between the canned spacers which increases the size of the lower and middle content locations while reducing the size of the upper content location. Reactivity of the containment vessel decreases accordingly.

The "**sqa**", "**lha**", and "**cha**" calculation models are devised for evaluating broken metal in the idealized forms described in the following paragraphs. The heights of the lower can locations and separation between the first and second 277-4 canned spacers inside the containment vessel are conservatively established on the basis that broken metal is confined within a rectangular lattice formed by the unit cells of fissile material having a packing fraction of ~0.59.

In the "sqa" model for HEU broken metal, a uniform-size metal cube is contained inside a unit cell of content. The unit cells are configured into arrays with one array for each can location inside the containment vessel. HEU metal cubes ranging in size from 1.0 to 0.25 in. are correspondingly arranged into 3 × 3, 6 × 6, or 12 × 12 configurations with ***N*** layers stacked vertically. A rectangular lattice of unit cells is defined by a square prism circumscribed by the wall of the containment vessel with an inner diameter of 5.06 in. (12.8524 cm). The width and depth of the square base is 3.57796 in. (9.08802 cm). The height of the lattice is determined by both the size of a cube and the number of layers of cubes required for a given HEU mass loading.



Note: Blue marker depicts 4.25-in.–diam wall of the convenience can.

Fig. 6.9.1-4c. Plan view of slug configurations in the confines of the containment vessel.

Figure 6.9.1-5 depicts a wire mesh view of the containment vessel and lid with three 12 × 12 × 18 arrays of HEU content separated by 277-4 canned spacers. Figure 6.9.1-5b depicts an isometric view of this same content with the **evaluation** water surrounding the HEU removed for illustration. The corner unit cells touch the inside wall of the containment vessel. The HEU cubes are centered within the individual unit cells and uniform spacing between cubes is modeled. The 277-4 canned spacers are modeled as cylindrical disks with dimensions of 4.13-in. diam × 1.37-in. height.

Uranium mass is reduced in the calculation model by removing one or more cubes from the array and filling these vacancies with water. The location of the 277-4 canned spacers between the arrays of cubes decreases as complete layers of cubes are removed from each array. The volume of the containment vessel above the top layer of the top array of cubes is filled with full-density water.

In the "lha" model of HEU broken metal, the metal cubes of the "sqa" model are homogeneously mixed with **evaluation** water within the square prism of the "sqa" model. Figure 6.9.1-5c depicts an isometric view of the "lha" model. The boundaries of each square prism shown in the figure are defined by the 12 × 12 × 18 array of unit cells of the explicit "sqa" model. Each prism contains the same mass of HEU and **evaluation** water that the respective explicit cube model contains. The volume outside the prisms and the canned spacers is filled with full density water.

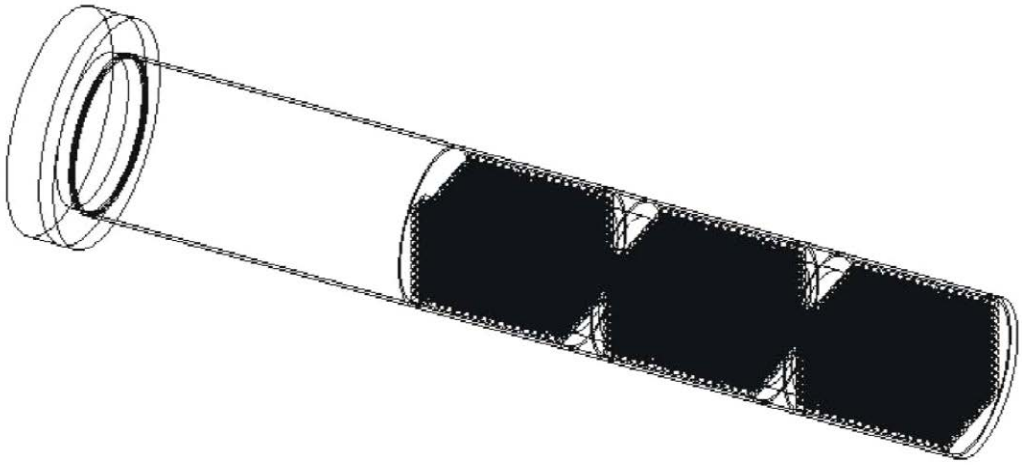


Fig. 6.9.1-5. Wire mesh view of the "sqa" model with three 12 × 12 × 18 lattices of HEU broken metal as 1-in. cubes separated by 1.4-in. 277-4 canned spacers.

In the "cha" model of HEU broken metal, the metal cubes of the "sqa" model are homogeneously mixed with the **evaluation** water within the free volume of the containment vessel. Figure 6.9.1-5d depicts an isometric view of the "cha" model. The 277-4 canned spacers are positioned for similarity with the "sqa" and "lha" models using the height of the prism, defined in this case by the 12 × 12 × 18 array of unit cells of the explicit "sqa" model. The mass of HEU and **evaluation** water of the explicit "sqa" model is preserved.

Once the locations of the canned spacers in the containment vessel are established based on the height of the square prism, the HEU broken metal and evaluation water inside the containment vessel are homogenized over the internal volume of the 12.8524-cm-diam containment vessel not being occupied by the canned spacers. The homogenization of fissile material with moderator to represent discrete solid HEU metal of unspecified geometric shape characterized as broken metal is unquestionably bounding only when the overall volume (and shape) containing HEU and interstitial moderator between the pieces of HEU is preserved in the approximation model.

In the "cha" model, the uniform dispersal of the homogenized HEU and evaluation water over the residual internal volume of the containment vessel has the effect of relocating ^{235}U from the two lower can locations into the upper can location. When the 277-4 canned spacers are present, the neutronic coupling of can locations is weak and the reactivity of the packaged content is determined by the reactivity of the largest can location. This model may not be conservative when canned spacers are absent because nothing would prevent settling of content inside the containment vessel into a single mass given that the convenience cans are not credited for containing the content nor for maintaining spacing between the contents of each can.

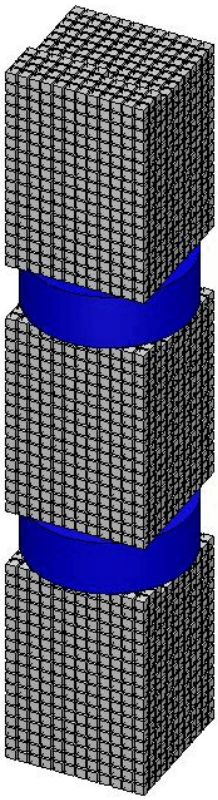


Fig. 6.9.1-5b. Detailed isometric view of the explicit "sqa" model for HEU broken metal. Three 12 × 12 × 18 lattices of 1-in. cubes separated by 1.4-in. 277-4 spacers are shown.

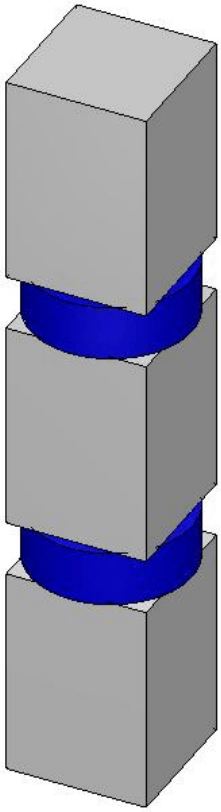


Fig. 6.9.1-5c. Isometric view of the homogeneous "lha" model with HEU homogeneously mixed with evaluation water within the rectangular lattices formed by the units cells.

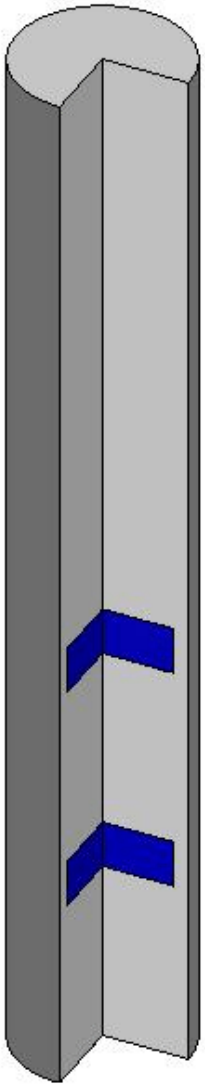


Fig. 6.9.1-5d. Isometric view of the homogeneous "cha" model with HEU homogeneously mixed with evaluation water within the interior of the containment vessel.

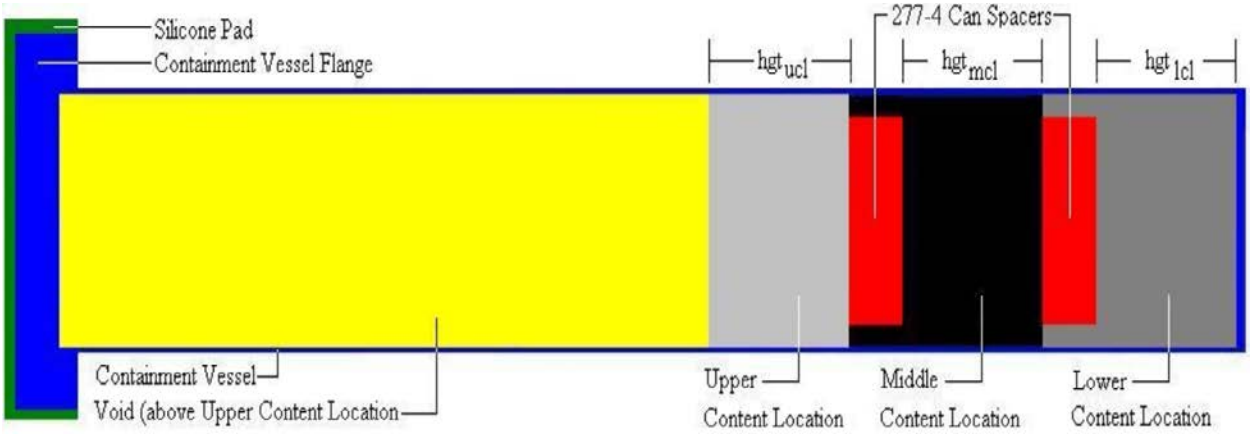
As stated in Sect. 6.9.3.1, the "cha" model is used to represent broken metal in single packages and the array of packages under NCT and HAC. For addressing the issue that the uniform dispersal approximation model ("cha") may not be conservative, especially when the 277-4 canned spacers are absent, the settling of content may be evaluated by establishing the material geometry and composition based on a maximum packing fraction. The packing fraction calculation model is described for this purpose.

In the packing fraction model, the material within a variable height can location is evaluated over the range of packing fractions from loosely packed material (PF ~0.2) to densely packed material (PF ~0.6). The height of can locations is determined based on the packing fraction instead of the fictitious cube stacking algorithm which was used in the "cha" uniform dispersal approximation model. The height of can locations used in the packing fraction calculation model is given by the following formula:

$$hgt = [(HEU_{vol} / PF) + Poly_{vol}] / CV_{area}$$

(500 g of polyethylene is included in the calculation model to represent the potential use of packing material.)

Fig. 6.9.1-5e depicts a section view of the containment vessel for the packing fraction calculation model. The height of the lower, middle, and upper can locations are equal. Only in the upper location does the can location coincide with the content location. The "**fl**" is used in the case name to designate calculations are based on the packing fraction model.



Note: The height (hgt) of the upper, middle, and lower can locations are determined by the HEU packing fraction.

Fig. 6.9.1-5e. Section view of the containment vessel for the packaging fraction calculation model depicting the content locations for broken metal.

The volume fractions for material constituents in the middle and lower content locations are calculated as follows:

$$VF_{HEU} = HEU_{vol} / (hgt \times CV_{area} + Spacer_{void})$$

where HEU_{vol} is the volume of HEU at theoretical density and $Spacer_{void}$ is the volume of the void region between the CV wall an the can spacer assumed filled with evaluation water.

$$VF_{H2O} = [(HEU_{vol} / PF) - HEU_{vol} + Spacer_{void}] / (hgt \times CV_{area} + Spacer_{void})$$
$$VF_{Poly} = Poly_{vol} / (hgt \times CV_{area} + Spacer_{void})$$

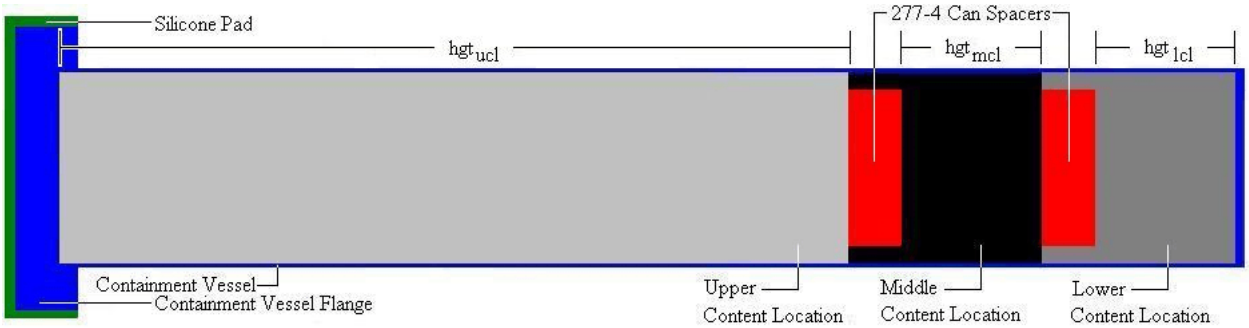
The volume fractions for material constituents in the upper content location are calculated as follows:

$$VF_{HEU} = HEU_{vol} / (hgt \times CV_{area})$$
$$VF_{H2O} = [(HEU_{vol} / PF) - HEU_{vol}] / (hgt \times CV_{area})$$
$$VF_{Poly} = Poly_{vol} / (hgt \times CV_{area})$$

The void region above the upper content location (Vol_{above}) is filled with full density water.

In addressing the issue that the uniform dispersal approximation "cha" model may not be conservative because homogenization of HEU is performed over a much larger volume and shape than the HEU content conceivably occupies, the effect of dispersing content within a can location may be evaluated using a variation of the packing fraction calculation model. The dispersed content calculation model is described for this purpose.

In the dispersed content calculation model, the HEU, the polyethylene, and the evaluation water of the upper content location is homogenized over the entire volume of this location. Figure 6.9.1-5f depicts a section view of the containment vessel for the dispersed content calculation model. The height of the lower and middle content locations are equal while the height of the upper content location extends to the top of the containment vessel cavity. The "**fd**" designation in the case name is used to identify the dispersed content calculation model.



Note: The height (hgt) of the middle and lower content locations are determined by the HEU packing fraction. The height of the upper content location extends to the top of the containment vessel cavity.

Fig. 6.9.1-5f. Section view of the containment vessel in the dispersed content calculation model depicting the content locations for broken metal.

The volume fractions for material constituents in the middle and lower content locations are specified the same as in the "**fl**" model. However, the volume fractions for material constituents dispersed into the upper content location are calculated as follows:

$$VF_{HEU} = HEU_{vol} / (hgt \times CV_{area} + Vol_{above})$$

where Vol_{above} is the void region above the upper can location into which the content is dispersed.

$$VF_{H2O} = [(HEU_{vol} / PF) - HEU_{vol} + Vol_{above}] / (hgt \times CV_{area} + Vol_{above})$$
$$VF_{H2O} = Poly_{vol} / (hgt \times CV_{area} + Vol_{above})$$

For example, consider reference Case **hciabmt12_4_1_5_3** (Table 6.9.6-11) which defines the loading limit for broken metal in the 70% < enr. ≤ 80% range where canned spacers are not used in the containment vessel. In revised Case **hciapbmflt12_1_6_4_5**, HEU broken metal with a packing fraction of 0.6, the 500 g of polyethylene and evaluation water in each can location is homogenized over the content location. Case **hciapbmflt12_1_2_4_5** is the same as Case **hciapbmflt12_1_6_4_5**, except the packing fraction is 0.2. In Case **hciapbmfdt12_1_6_4_5**, HEU broken metal with a packing fraction of 0.6, the 500 g of polyethylene and evaluation water in each content location is homogenized over the content location. Case **hciapbmfdt12_1_2_4_5** is the same as Case **hciapbmfdt12_1_6_4_5,** except the packing fraction is 0.2. Table 6.9.1.0 provides details for the packing fraction and dispersed content calculation models.

Table 6.9.1.0. Details for the packing fraction "fl" and dispersed content "fd" calculation models

Location	Height (cm)	Material	Density × VF × region volume	HEU (g)	Water (g)	Polyethylene (g)
Case hciapbmflt12_1_6_4_5, packing fraction = 0.6						
Lower	2.30470	HEU	(18.85873)(0.23645)(299.031)	1333.4		
		Water	(0.9982)(1.5773E-01)(299.031)		47.1	
		Poly	(0.9200)(6.0582E-01)(299.031)			166.7
Spacer	0.00030	Water	(0.9982)(8.64286E-03)		0.0	
Middle	2.30470	HEU	(18.85873)(0.23645)(299.031)	1333.4		
		Water	(0.9982)(1.5773E-01)(299.031)		47.1	
		Poly	(0.9200)(6.0582E-01)(299.031)			166.7
Spacer	0.00030	Water	(0.9982)(8.64286E-03)		0.0	
Top	2.30470	HEU	(18.85873)(0.23647)(299.001)	1333.4		
		Water	(0.9982)(1.5765E-01)(299.001)		47.1	
		Poly	(0.9200)(6.0588E-01)(299.001)			166.7
Above	71.82530	Water	(0.9982)(1.0)(9318.28)		9301.5	
Total	**78.74000**			**4000.2**	**9442.8**	**500.0**
Case hciapbmflt12_1_2_4_5, packing fraction = 0.2						
Lower	4.12133	HEU	(18.85873)(0.13223)(534.713)	1333.4		
		Water	(0.9982)(5.2897E-01)(534.713)		282.3	
		Poly	(0.9200)(3.3880E-01)(534.713)			166.7
Spacer	0.00030	Water	(0.9982)(8.64286E-03)		0.0	
Middle	4.12133	HEU	(18.85873)(0.13223)(534.713)	1333.4		
		Water	(0.9982)(5.2897E-01)(534.713)		282.3	
		Poly	(0.9200)(3.3880E-01)(534.713)			166.7
Spacer	0.00030	Water	(0.9982)(8.64286E-03)		0.0	

Table 6.9.1.0. Details for the packing fraction "fl" and dispersed content "fd" calculation models

Location	Height (cm)	Material	Density × VF × region volume	HEU (g)	Water (g)	Polyethylene (g)
Top	4.12133	HEU	(18.85873)(0.13224)(534.682)	1333.4		
		Water	(0.9982)(5.2895E-01)(534.682)		282.3	
		Poly	(0.9200)(3.3882E-01)(534.682)			166.7
Above	66.37541	Water	(0.9982)(1.0)(8.61124E+03)		8595.7	
Total	**78.74000**			**4000.2**	**9442.7**	**500.0**
			Case hciapbmfdt12_1_6_4_5, packing fraction = 0.6			
Lower	2.30470	HEU	(18.85873)(0.23645)(299.031)	1333.4		
		Water	(0.9982)(1.5773E-01)(299.031)		47.1	
		Poly	(0.9200)(6.0582E-01)(299.031)			166.7
Spacer	0.00030	Water	(0.9982)(8.64286E-03)		0.0	
Middle	2.30470	HEU	(18.85873)(0.23645)(299.031)	1333.4		
		Water	(0.9982)(1.5773E-01)(299.031)		47.1	
		Poly	(0.9200)(6.0582E-01)(299.031)			166.7
Spacer	0.00030	Water	(0.9982)(8.64286E-03)		0.0	
Top	74.13000	HEU	(18.85873)(0.00735)(9617.28)	1333.4		
		Water	(0.9982)(9.7381E-01)(9617.28)		9348.5	
		Poly	(0.9200)(1.8837E-02)(9617.28)			166.7
Total	**78.74000**			**4000.2**	**9442.7**	**500.0**
			Case hciapbmfdt12_1_2_4_5, packing fraction = 0.2			
Lower	4.12133	HEU	(18.85873)(0.13223)(534.713)	1333.4		
		Water	(0.9982)(5.2897E-01)(534.713)		282.3	
		Poly	(0.9200)(3.3880E-01)(534.713)			166.7
Spacer	0.00030	Water	(0.9982)(8.64286E-03)		0.0	
Middle	4.12133	HEU	(18.85873)(0.13223)(534.713)	1333.4		
		Water	(0.9982)(5.2897E-01)(534.713)		282.3	
		Poly	(0.9200)(3.3880E-01)(534.713)			166.7
Spacer	0.00030	Water	(0.9982)(8.64286E-03)		0.0	
Top	4.12133	HEU	(18.8587)(0.00773)(9145.92)	1333.3		
		Water	(0.9982)(9.7246E-01)(9145.92)		8878.0	
		Poly	(0.9200)(1.9808E-02)(9145.92)			166.7
Total	**12.36459**			**4000.1**	**9442.7**	**500.0**

Powder, particulate, or small pieces of HEU potentially present in broken metal are capable of passing between content locations. The quantity of this material represents a small fraction of the total broken metal content. The placement of a limit on content size for criticality control is adopted as a package content loading restriction (Sect. 6.2.4, Item 6).

Calculation model for solid HEU of unspecified geometric shape, HEU oxides. Figure 6.9.1-6 depicts the wire-mesh view of the HEU oxide content inside the containment vessel. The interstitial water inside the containment vessel has been removed for illustration purposes. The HEU oxide mixture at bulk density is located at the bottom of the containment vessel and fills the space to the wall of the containment vessel. The height of the HEU oxide mixture is dependant upon the mass loading.

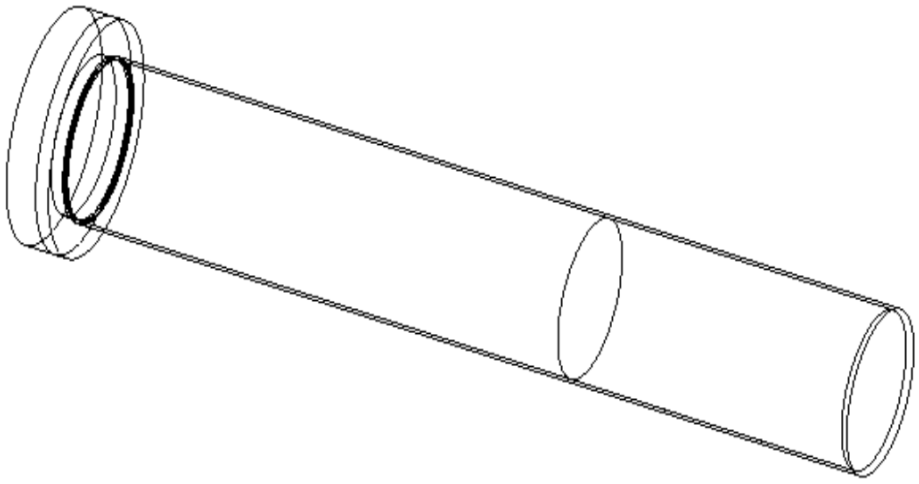


Fig. 6.9.1-6. Wire-mesh view of the containment vessel containing the HEU oxide mixture.

HEU product oxide is assumed to be saturated with water in the criticality calculation models. Maximum saturation in the oxide material occurs in a volume defined as the difference between the specific volume of bulk oxide and the minimum specific volume of the product oxide. Product oxide has a bulk density of 6.54 g/cm^3 or a specific volume of 0.152905 cm^3/g (Sect. 6.9.3.1). UO_2 has a theoretical density of 10.96 g/cm^3 or a minimum specific volume of 0.091241 cm^3/g. Therefore, the maximum volume per gram of UO_2 available for saturation by water is 0.061664 cm^3/g. Additionally, an assumed maximum of 500 g of polyethylene is homogenized with the water-saturated product oxide. The homogenized oxide containing polyethylene (density = 0.92 g/cm^3) occupies an additional 543.47826 cm^3.

The height of polyethylene homogenized with water-saturated product oxide inside the containment vessel is calculated by dividing the volume of the homogenized oxide by the internal area of the base of the containment vessel. The area of the base is 129.73536 cm^2 for the containment vessel with an inner diameter of 5.06 in. (12.8524 cm). The height of the void space above the homogenized oxide is calculated by subtracting the homogenized oxide height from the 78.84-cm (31.0-in.) inside height of the containment vessel.

As an example, consider Case **cvcrpoxt11_1_21_15** where 21,000 g of UO_2 (18,484.3 g ^{235}U) is saturated with 1,292.62 g water (Table 6.9.6-12). The calculated H/X ratio for the water saturated product oxide is 1.83. The water-saturated product oxide homogenized with 500 g of polyethylene rises to a height of ~28.93955 cm inside the containment vessel. The 6,460.87 cm^3 of void space is flooded with 6449.2 g of evaluation water, such that the calculated H/X ratio inside the containment vessel is 11.84. The 500 g of polyethylene adds 0.90 to the calculated H/X ratio of water-saturated product oxide. The calculated H/X ratio for the water-saturated product oxide homogenized with 500 g of polyethylene in a dry containment vessel is 1.83 + 0.90 = 2.73 (Case **cvcrpoxt11_1_21_1**). In all cases, the H/X ratio is a computed value rather than an evaluation parameter.

The same modeling technique is applied to product oxides of U_3O_8 and UO_3. U_3O_8 has a theoretical density of 8.30 g/cm^3 or a minimum specific volume of 0.120482 cm^3/g. UO_3 has a theoretical density of 7.29 g/cm^3 or a minimum specific volume of 0.137174 cm^3/g. The maximum volumes per gram of U_3O_8 and UO_3 available for saturation by water are 0.032423 cm^3/g and 0.015731 cm^3/g, respectively.

The eight skull oxide content compositions described in Table 6.9.3.1-3b for evaluating skull oxide are derived from 292 samples of canned skull oxide. Two additional compositions are listed in the table for addressing skull oxides with an enrichment of 93.2 wt %. The skull oxide content is assumed to be U_3O_8 plus polyethylene, graphite, and unidentified material. A maximum of 513 g of polyethylene is assumed to be present in the skull oxide content. The volume of skull oxide content in the containment vessel (**vsoc**) is calculated as the grams of skull oxide content (**gsoc**) divided by the bulk density of the skull oxide content (**densoc**). The height of skull oxide content inside the containment vessel is calculated by dividing the volume of skull oxide content (**vsoc**) by the internal area of the base of the containment vessel (129.73536 cm^3).

Calculation model for solid HEU of unspecified geometric shape, UNH crystals. Figure 6.9.1-7 depicts the wire-mesh view of the UNH crystal content inside the containment vessel. A solution of UNH crystals dissolved in water fills the entire volume of the containment vessel.

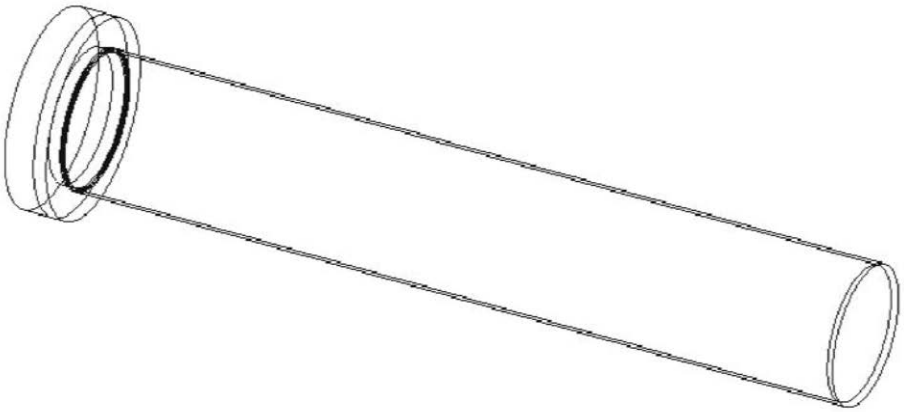


Fig. 6.9.1-7. Wire mesh view of the containment vessel containing the UNH crystal mixture.

Table 6.9.1.1 provides details of the calculation models used to establish the mass loading limits identified in Table 6.2a for surface-only modes of transportation. The table provides exact dimensions of the fissile material used in the analyses; the mass of fissile material, enrichment, and density of the fissile material used in the analysis; moderating properties of materials inside the containment vessel (water, hydrogenous packing material, represented by polyethylene, etc.), moderator density and h/x ratios; and arrangement of the fissile material including amount of spacing (if any) between the fissile material and/or 277-4 canned spacers. In the creation of a generalized geometry model for treatment of 277-4 canned spacers, the use of a non-zero thickness spacer was required by KENO V.a. An insignificant thickness of 0.0001 cm was used for representing this imaginary region.

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
Cylinders (d ≤ 3.24 in.)			
nciacyt11_18_1_3	r = 4.1148 cm h = 5.99639 cm	100	18.81109
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked cylindrical contents. The contents have an overall stack height of 17.99171 cm (7.08335 in.). No polyethylene was used in this model. Each cylindrical content is separated by a 0.0001 cm 277-4 canned spacer and 0.0012 cm of moderating material. The bottom cylinder has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cylinder content has 2.3114 cm of moderating material around each side and 60.74779 cm of moderating material above. The modeled material masses are: 18 kg ^{235}U, 9.2418 kg H_2O, resulting in an h/x ratio of ~13.40.			
nciacyt11_30_2_3	r = 4.11480 cm h = 9.99399 cm	100	18.81109
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked cylindrical contents separated by 277-4 canned spacers between each cylindrical content. The contents (uranium and spacers) have an overall stack height of 37.09657 cm (14.60495 in.). No polyethylene was used in this model. Each cylindrical content is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom cylinder has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cylinder content has 2.3114 cm of moderating material around each side and 41.64293 cm of moderating material above. The modeled material masses are: 30 kg ^{235}U, 7.9915 kg H_2O, resulting in an h/x ratio of ~6.95.			
Cylinders (3.24 in. < d ≤ 4.25 in.)			
nciacyct11_15_1_3	r = 5.39750 cm h = 2.90416 cm	100	18.81109
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked cylindrical contents separated by 277-4 canned spacers. The contents have an overall stack height of 8.71508 cm (3.43133 in.). No polyethylene was used in this model. Each cylindrical content is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom cylinder has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cylinder content has 1.0287 cm of moderating material around each side and 70.02442 cm of moderating material above. The modeled material masses are: 15 kg ^{235}U, 9.4010 kg H_2O, resulting in an h/x ratio of ~16.36.			
nciacyct11_25_2_3	r = 5.39750 cm h = 4.84031 cm	100	18.81109
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked cylindrical contents separated by 277-4 canned spacers. The contents have an overall stack height of 21.63433 cm (8.517453 in.). No polyethylene was used in this model. Each cylindrical content is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom cylinder has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cylinder content has 1.0287 cm of moderating material around each side and 57.10417 cm of moderating material above. The modeled material masses are: 25 kg ^{235}U, 8.2568 kg H_2O, resulting in an h/x ratio of ~8.62.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
Bars			
hciasqt12_30_1_3	x = 5.81920 cm y = 5.81920 cm z = 15.69855 cm	100	18.81109
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked square or cuboid contents separated by 277-4 canned spacers. The contents have an overall stack height of 47.09825 cm (18.54262 in.). No polyethylene was used in this model. Each cuboid content is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom cuboid has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. Therefore, the cuboid content is surrounded by moderating material ranging from 3.6166 to 2.4144 cm (center to outer edge) and 31.64125 cm of moderating material above. The modeled material masses are: 30 kg ^{235}U, 8.6050 kg H_2O, resulting in an h/x ratio of ~7.49.			
nciasqt11_36_2_3	x = 5.81920 cm y = 5.81920 cm z = 18.83826 cm	100	18.81109
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked square or cuboid contents separated by 277-4 canned spacers. The contents have an overall stack height of 63.62938 cm (25.05094 in.). No polyethylene was used in this model. Each cuboid content is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom cuboid has a 0.0005 cm gap between it and the bottom of the containment vessel. Therefore, the cuboid content is surrounded by moderating material ranging from 3.6166 to 2.4144 cm (center to outer edge) and 15.11012 cm of moderating material above. The modeled material masses are: 36 kg ^{235}U, 7.6731 kg H_2O, resulting in an h/x ratio of ~5.56.			
Slugs (enr. ≤ 95%–no can spacers)			
ncia5st11_1_1_7_3	r = 1.983875 cm h = 5.23875 cm	95	18.82298
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked pentagonal rings of slug content separated by 277-4 canned spacers. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) The contents have an overall stack height of 15.71885 cm (6.18852 in.). No polyethylene is used in this model. Each ring is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom ring of slugs has a 0.0005 cm gap between it and the bottom of the containment vessel. Above the stack of slugs is 63.02065 cm of moderating material. The modeled material masses are: 18.288 kg U (17.374 kg ^{235}U), 9.2269 kg H_2O, resulting in an h/x ratio of ~13.86. The loading arrangement of slugs is depicted in Fig. 6.9.1-4b for the Case **cvcr5st11_1_1**.			
Slugs (80% < enr. ≤ 95%–with can spacers)			
hcia70st12_2_7_3	r = 1.983875 cm h = 5.23875 cm	95	18.82298
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked rings of slugs, each ring with a central slug surrounded by slugs in a hexagonal pattern. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) Each ring is separated by a 277-4 canned spacer. The contents (uranium and spacers) have an overall stack height of 22.83085 cm (8.98852 in.). No polyethylene was used in this model. Each ring is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom ring has a 0.0005 cm gap between it and the bottom of the containment vessel. The stack of slugs has 55.90865 cm of moderating material above. The modeled material masses are: 25.604 kg U (24.324 kg ^{235}U), 8.2253 kg H_2O, resulting in an h/x ratio of ~8.83. The loading arrangement of slugs is similar to that depicted in Fig. 6.9.1-4b for the Case **cvcr70st11_1** except that the canned spacers are present.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
ncf15est11_2_2_7_3	r = 1.983875 cm h = 5.23875 cm	95	18.82298
The moderator is full density water (0.9982 g/cm^3) surrounding three rings of double stacked slugs, each ring separated by a 277-4 canned spacer. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) The contents (uranium and spacers) have an overall stack height of 22.83085 cm (8.98852 in.). No polyethylene was used in this model. Each ring is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom ring has a 0.0005 cm gap between it and the bottom of the containment vessel. The stack of slugs has 55.90865 cm of moderating material above. The modeled material masses are: 36.578 kg U (34.749 kg ^{235}U), 7.6434 kg H_2O, resulting in an h/x ratio of ~5.74. The loading arrangement of slugs is depicted in Fig. 6.9.1-4b for the Case **cvcr5est11_2_2**.			
Slugs (enr. ≤ 80%–with can spacers)			
hcia5est12_2_2_5_3	r = 1.983875 cm h = 5.23875 cm	80	18.85873
The moderator is full density water (0.9982 g/cm^3) surrounding three rings of double stacked slugs, each ring separated by a 277-4 canned spacer. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) The contents (uranium and spacers) have an overall stack height of 22.83085 cm (8.98852 in.). No polyethylene was used in this model. Each ring is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom ring has a 0.0005 cm gap between it and the bottom of the containment vessel. The stack of slugs has 55.90865 cm of moderating material above. The modeled material masses are: 36.647 kg U (29.318 kg ^{235}U), 7.6434 kg H_2O, resulting in an h/x ratio of ~6.80. The loading arrangement of slugs is depicted in Fig. 6.9.1-4b for the Case **cvcr5est11_2_2**.			
ncf15est11_2_2_5_3	r = 1.983875 cm h = 5.23875 cm	80	18.85873
The moderator is full density water (0.9982 g/cm^3) surrounding three rings of double stacked slugs, each ring separated by a 277-4 canned spacer. (Slugs are inserted into the cylindrical geometry segment of the containment vessel using the hole option.) The contents (uranium and spacers) have an overall stack height of 22.83085 cm (8.98852 in.). No polyethylene was used in this model. Each ring is separated by a 3.5561 cm spacer and 0.0012 cm of moderating material. The bottom ring has a 0.0005 cm gap between it and the bottom of the containment vessel. The stack of slugs has 55.90865 cm of moderating material above. The modeled material masses are: 36.647 kg U (29.318 kg ^{235}U), 7.6434 kg H_2O, resulting in an h/x ratio of ~6.80. The loading arrangement of slugs is depicted in Fig. 6.9.1-4b for the Case **cvcr5est11_2_2**.			
Broken Metal for CSI=0.0			
hciabmt12_4_1_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 3.7085 kg U (2.9668 kg ^{235}U), 10.0007 kg H_2O, resulting in an h/x ratio of ~87.98.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
hciabmt12_5_1_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 4.6415 kg U (3.2490 kg ^{235}U), 9.9516 kg H_2O, resulting in an h/x ratio of ~79.95.			
nciabmt11_6_1_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 5.5768 kg U (3.3461 kg ^{235}U), 9.9025 kg H_2O, resulting in an h/x ratio of ~77.24.			
hciabmt12_3_2_8_3	r = 6.52620 cm h = 78.74000 cm	100	18.81109
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 2.7743 kg ^{235}U, 9.4362 kg H_2O, resulting in an h/x ratio of ~88.78.			
hciabmt12_4_2_7_3	r = 6.52620 cm h = 78.74000 cm	95	18.82298
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 3.7014 kg U (3.5164 kg ^{235}U), 9.3871 kg H_2O, resulting in an h/x ratio of ~69.68.			
hciabmt12_4_2_6_3	r = 6.52620 cm h = 78.74000 cm	90	18.83488
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 3.7038 kg U (3.3334 kg ^{235}U), 9.3871 kg H_2O, resulting in an h/x ratio of ~73.50.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
hciabmt12_6_2_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 5.5627 kg U (4.4502 kg ^{235}U), 9.2890 kg H_2O, resulting in an h/x ratio of ~54.48.			
nciabmt11_8_2_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 7.4263 kg U (5.1984 kg ^{235}U), 9.1908 kg H_2O, resulting in an h/x ratio of ~46.15.			
hciabmt12_12_2_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 11.1537 kg U (6.6922 kg ^{235}U), 8.9945 kg H_2O, resulting in an h/x ratio of ~35.08.			
Broken Metal for CSI=0.4			
ncf1bmt11_7_1_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 6.4898 kg U (5.1919 kg ^{235}U), 9.8535 kg H_2O, resulting in an h/x ratio of ~49.54.			
ncf1bmt11_9_1_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 8.3546 kg U (5.8482 kg ^{235}U), 9.7553 kg H_2O, resulting in an h/x ratio of ~43.54.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
ncf1bmt11_15_1_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 14.8715 kg U (8.9229 kg ^{235}U), 9.4118 kg H_2O, resulting in an h/x ratio of ~27.53.			
ncf1bmt11_6_2_8_3	r = 6.52620 cm h = 78.74000 cm	100	18.81109
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 5.5487 kg ^{235}U, 9.2890 kg H_2O, resulting in an h/x ratio of ~43.70.			
ncf1bmt11_7_2_7_3	r = 6.52620 cm h = 78.74000 cm	95	18.82298
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 6.4775 kg U (6.1536 kg ^{235}U), 9.2399 kg H_2O, resulting in an h/x ratio of ~39.19.			
ncf1bmt11_9_2_6_3	r = 6.52620 cm h = 78.74000 cm	90	18.83488
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 8.3335 kg U (7.5002 kg ^{235}U), 9.1417 kg H_2O, resulting in an h/x ratio of ~31.81.			
ncf1bmt11_12_2_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 11.1254 kg U (8.9003 kg ^{235}U), 8.9945 kg H_2O, resulting in an h/x ratio of ~26.38.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
ncf1bmt11_19_2_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 18.5659 kg U (12.9961 kg ^{235}U), 8.6019 kg H_2O, resulting in an h/x ratio of ~17.28.			
ncf1bmt11_29_2_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 28.8136 kg U (17.2882 kg ^{235}U), 8.0621 kg H_2O, resulting in an h/x ratio of ~12.17.			
Broken metal for CSI=0.8			
ncf2bmt11_12_1_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 11.1254 kg U (8.9003 kg ^{235}U), 9.6081 kg H_2O, resulting in an h/x ratio of ~28.18.			
ncf2bmt11_20_1_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 19.4942 kg U (13.6459 kg ^{235}U), 9.1664 kg H_2O, resulting in an h/x ratio of ~17.53.			
ncf2bmt11_29_1_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 28.8136 kg U (17.2882 kg ^{235}U), 8.6757 kg H_2O, resulting in an h/x ratio of ~13.10.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
ncf2bmt11_10_2_8_3	r = 6.52620 cm h = 78.74000 cm	100	18.81109
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 9.2478 kg ^{235}U, 9.0927 kg H_2O, resulting in an h/x ratio of ~25.66.			
ncf2bmt11_12_2_7_3	r = 6.52620 cm h = 78.74000 cm	95	18.82298
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 11.1043 kg U (10.5491 kg ^{235}U), 8.9945 kg H_2O, resulting in an h/x ratio of ~22.25.			
ncf2bmt11_14_2_6_3	r = 6.52620 cm h = 78.74000 cm	90	18.83488
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 13.8892 kg U (12.5003 kg ^{235}U), 8.8473 kg H_2O, resulting in an h/x ratio of ~31.81.			
ncf2bmt11_21_2_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 20.3966 kg U (16.3173 kg ^{235}U), 8.5038 kg H_2O, resulting in an h/x ratio of ~13.60.			
ncf2bmt11_30_2_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 29.7054 kg U (20.7938 kg ^{235}U), 8.0131 kg H_2O, resulting in an h/x ratio of ~10.06.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
ncf2bmt11_36_2_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.3199 kg U (21.1920 kg ^{235}U), 7.7186 kg H_2O, resulting in an h/x ratio of ~9.51.			
Broken metal for CSI=2.0			
ncf3bmt11_22_1_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 21.3237 kg U (17.0590 kg ^{235}U), 9.0683 kg H_2O, resulting in an h/x ratio of ~13.87.			
ncf3bmt11_31_1_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 30.6337 kg U (21.4436 kg ^{235}U), 8.5776 kg H_2O, resulting in an h/x ratio of ~10.44.			
ncf3bmt11_36_1_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.3199 kg U (21.1920 kg ^{235}U), 8.3322 kg H_2O, resulting in an h/x ratio of ~10.26.			
ncf3bmt11_14_2_8_3	r = 6.52620 cm h = 78.74000 cm	100	18.81109
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 13.8716 kg ^{235}U, 8.8473 kg H_2O, resulting in an h/x ratio of ~16.65.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
ncf3bmt11_20_2_7_3	r = 6.52620 cm h = 78.74000 cm	95	18.82298
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 19.4326 kg U (18.4609 kg ^{235}U), 8.5529 kg H_2O, resulting in an h/x ratio of ~12.09.			
ncf3bmt11_23_2_6_3	r = 6.52620 cm h = 78.74000 cm	90	18.83488
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 22.2227 kg U (20.0004 kg ^{235}U), 8.4057 kg H_2O, resulting in an h/x ratio of ~10.97.			
ncf3bmt11_32_2_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 31.5220 kg U (25.2176 kg ^{235}U), 7.9149 kg H_2O, resulting in an h/x ratio of ~8.19.			
ncf3bmt11_36_2_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.2751 kg U (24.6926 kg ^{235}U), 7.7186 kg H_2O, resulting in an h/x ratio of ~8.16.			
ncf3bmt11_36_2_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.3199 kg U (21.1920 kg ^{235}U), 7.7186 kg H_2O, resulting in an h/x ratio of ~9.51.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
Broken metal for CSI=3.2			
ncf5bmt11_35_1_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 34.3034 kg U (27.4427 kg ^{235}U), 8.3813 kg H_2O, resulting in an h/x ratio of ~7.97.			
ncf5bmt11_36_1_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 35.2751 kg U (24.6926 kg ^{235}U), 8.3322 kg H_2O, resulting in an h/x ratio of ~8.81.			
ncf5bmt11_36_1_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. No 277-4 canned spacers are used in this calculation. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls. The modeled material masses are: 35.3199 kg U (21.1920 kg ^{235}U), 8.3322 kg H_2O, resulting in an h/x ratio of ~10.26.			
ncf5bmt11_25_2_8_3	r = 6.52620 cm h = 78.74000 cm	100	18.81109
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 24.9689 kg ^{235}U, 8.2584 kg H_2O, resulting in an h/x ratio of ~8.63.			
ncf5bmt11_28_2_7_3	r = 6.52620 cm h = 78.74000 cm	95	18.82298
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 27.7608 kg U (26.3728 kg ^{235}U), 8.1112 kg H_2O, resulting in an h/x ratio of ~8.03.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
ncf5bmt11_35_2_6_3	r = 6.52620 cm h = 78.74000 cm	90	18.83488
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 34.2600 kg U (30.8340 kg ^{235}U), 7.7677 kg H_2O, resulting in an h/x ratio of ~6.58.			
ncf5bmt11_36_2_5_3	r = 6.52620 cm h = 78.74000 cm	80	18.85873
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.2305 kg U (28.1844 kg ^{235}U), 7.7186 kg H_2O, resulting in an h/x ratio of ~7.15.			
ncf5bmt11_36_2_4_3	r = 6.52620 cm h = 78.74000 cm	70	18.88264
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.2751 kg U (24.6926 kg ^{235}U), 7.7186 kg H_2O, resulting in an h/x ratio of ~8.16.			
ncf5bmt11_36_2_3_3	r = 6.52620 cm h = 78.74000 cm	60	18.90661
The uranium "broken metal" content is homogenized with a moderator of water with a specific gravity of 1.0×10^{-4} over the interior volume of the containment vessel. The 277-4 canned spacers with a thickness of 3.5561 cm (1.4000 in.) are used and are modeled at 3.02984 cm and 9.61638 cm above the bottom of the containment vessel. No polyethylene was used in this calculation. Since the contents are homogenized over the internal volume of the containment vessel, there is no moderating material between the content and the containment vessel walls or the spacers. The modeled material masses are: 35.3199 kg U (21.1920 kg ^{235}U), 7.7186 kg H_2O, resulting in an h/x ratio of ~9.51.			
Product oxide			
hciapdoxt12_1_1_11_3	r = 6.42620 cm h = 46.58351 cm	100	2.00000
Water-saturated HEU product oxide with 500 g polyethylene (0.9200 g/cm^3) is dispersed within the containment vessel to a height determined by the mass of the product oxide, polyethylene, and saturation moisture. The product oxide is saturated with 4.488 kg H_2O of full density water (0.9982 g/cm^3). Since the product oxide content is assumed to be dispersed within the containment vessel, there are no gaps between the content and the containment vessel wall or bottom. There are 32.15649 cm of moderator above the product oxide content. No 277-4 canned spacers are used in this analysis. The modeled material masses are: 11.00 kg UO_2 (9.682 kg ^{235}U), 8,652.6 kg H_2O, and 500 g polyethylene resulting in an h/x ratio of ~25.06.			

Table 6.9.1.1. Details of calculation models used to establish mass loading limits for surface-only modes of transportation identified in Table 6.2a

Case	Dimensions (cm)	Enrichment (wt % ^{235}U)	Density (g/cm^3)
Skull oxide			
nciask_9_15	r = 6.42620 cm h = 28.18623 cm	100	6.54000
The skull oxide is dispersed within the containment vessel to a height determined by the mass of the skull oxide. The skull oxide is saturated with a moderator of full density water (0.9982 g/cm^3). No polyethylene is used in this analysis. Since the skull oxide content is assumed to be dispersed within the containment vessel, there are no gaps between the content and the containment vessel wall or bottom. There are 50.55377 cm of moderator above the skull oxide content. No 277-4 canned spacers are used in this analysis. The modeled material masses are: 21.3000 kg skull oxide, 19.8653 kg U_3O_8, 15.6728 kg ^{235}U, 3.8014 kg H_2O, resulting in an h/x ratio of ~7.43.			
UNX crystals			
nciapunhct11_7_3	r = 6.42620 cm h = 78.74000 cm	100	2.79329
The UNX crystals are homogenized with 1515.7 g full density water (0.9982 g/cm^3) and 500 g polyethylene (0.9200 g/cm^3) dispersed over the entire inner volume of the containment vessel. There is no gap between the homogenized UNX content and the containment vessel bottom or sides. Since the content is homogenized over the inner volume of the containment vessel, no moderating material is above the content. No 277-4 canned spacers are used in this model. The modeled material masses are 7.0 kg UNX crystals (3.2968 kg ^{235}U), 8.6886 kg H_2O, and 500 g polyethylene resulting in an h/x ratio of ~73.73.			
ncf1punhct11_24_3	r = 6.42620 cm h = 78.74000 cm	100	2.79329
The UNX crystals are homogenized with 5,196.7 g full density water (0.9982 g/cm^3) and 500 g polyethylene (0.9200 g/cm^3) dispersed over the entire inner volume of the containment vessel. There is no gap between the homogenized UNX crystals and the containment vessel bottom or sides. Since the content is homogenized over the inner volume of the containment vessel, no moderating material is above the content. No 277-4 canned spacers are used in this model. The modeled material masses are 24.0 kg UNX crystals (11.3031 kg ^{235}U), 6.2746 kg H_2O, and 500 g polyethylene, resulting in an h/x ratio of ~15.97.			
TRIGA fuel			
nciatriga_1_15_3	r = 1.8288 cm h = 12.7000 cm	20	8.65974
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked "bundles" of three TRIGA fuel elements separated by 277-4 canned spacers. The content has an overall height of 38.10310 cm (15.00122 in.). No polyethylene was used in this model. Each content is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom content has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. The modeled material masses are 10.4 kg $UZrH_x$, 0.9210 kg ^{235}U, and 8.9982 kg H_2O, resulting in an h/x ratio of ~255.01.			
nciatriga70_1_15_3	r = 1.8288 cm h = 12.7000 cm	70	5.70132
The moderator is full density water (0.9982 g/cm^3) surrounding three stacked "bundles" of three TRIGA fuel elements separated by 277-4 canned spacers. The content has an overall height of 38.10310 cm (15.00122 in.). No polyethylene was used in this model. Each content is separated by a 0.0001 cm spacer and 0.0012 cm of moderating material. The bottom content has a 0.0005 cm gap between it and the bottom of the containment vessel. The contents sit in the exact center on the bottom of the CV. The modeled material masses are 6.8471 kg $UZrH_x$, 0.4080 kg ^{235}U, and 8.9982 kg H_2O, resulting in an h/x ratio of ~575.64.			

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Appendix 6.9.2

HAC Package Model

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Appendix 6.9.2

HAC Package Model

6.9.2.1 Prediction of HAC Damage in the ES-3100 Package

Finite element analysis of an ES-3100 package under Hypothetical Accident Conditions (HAC) is used to predict the deformed outer diameters of the drum at node points along the vertical axis of an upright package. Selected node points are designated in a downward direction from the top of the drum as "UR," "MUR," "MR," "MLR," and "LR." Table 6.9.2.1-1 lists diameters at the five node points measured along the 90–270° and 0–180° axes. These dimensions represent major and minor axes at each deformation point on the assumption that the drum cross section is ellipsoidal. A corresponding equivalent circular diameter is also listed for each node point in Table 6.9.2.1-1.

A set of KENO V.a calculation models based on reduced package diameters at the "MR," "MLR," and "LR" deformation points are derived from the Normal Conditions of Transport (NCT) geometry model. These geometry models are evaluated for the purpose of establishing a bounding geometry model for representing the ES-3100 package under HAC. The primary changes made to the KENO V.a geometry input statements in the NCT model are reductions in the drum's radii. The change to the drum's inner radius also affects the outer radius of both the angle iron and the Kaolite located inside the containment vessel outer liner. The volume fractions for these materials are adjusted in the KENO V.a calculation models so that material masses of the affected package components are conserved. Table 6.9.2.1-2 provides data for transforming the KENO V.a calculation model from an NCT model into an HAC model.

6.9.2.2 Criticality Calculations

Sets of criticality calculations are performed for the "MR," "MLR," and "LR" models at five different package water contents over the range of HAC. The five package water contents of the void spaces external to the containment vessel and the interstitial space between drums are as follows: 1e-20 spg water, 1E-04 spg water, 0.1 spg water, 0.3 spg water, and 1.0 spg water. The water content in the Kaolite corresponds to the dry condition (VF= 0.0287) where neutronic interaction between the packages of an array is maximized.

An infinite array of packages is evaluated in order to eliminate any biases arising from spectral leakage effects in the reflector of the finite array. The k_{eff} values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data. Each package modeled has 36 kg of 100% enriched uranium in the form of broken metal content.

Each case is rerun using a different starting random number in order to produce sets of computed k_{eff} values that are statistically independent. The random starting number, the mean value (k_{eff}), and the corresponding standard error (s_i) computed for ten individual runs are shown in Tables 6.9.2.2-1, -2, and -3. The same statistical method (described in DAC-FS-900000-A014) used in the evaluation of Kaolite models (Appendix 6.9.3, Sect. 6.9.3.4) is also used here for determining whether or not differences in neutronic performance between the package models are statistically significant.

Table 6.9.2.1-1. Deformation of the ES-3100 drum at five node points, projected by finite element analysis "Case 3100 RUN1HL Lower Bound Kaolite May 2004"

Deformation point	FEA node	Diameter at 90° (in.)	Diameter at 180° (in.)	Equivalent circular diameter	
				(in.)	(cm)
UR	098194	20.02	15.60	17.6724	44.8878
MUR	100238	20.74	15.07	17.6791	44.9050
MR	101589	20.74	14.18	17.1492	43.5588
MLR	103012	22.00	13.44	17.1954	43.6762
LR	105786	20.92	12.92	16.4404	41.7586

Table 6.9.2.1-2. Parameter changes for converting an NCT package model into an HAC package model

Parameter	Reference NCT package model	HAC model at MR node point of package	HAC model at MLR node point of package	HAC model at LR node point of package
Package model dimension				
OR_{Drum} (cm)	23.32990	21.77942	21.83809	20.87929
IR_{Drum} (cm)	23.17750	21.62702	21.68569	20.72689
$th_{Drum\ wall}$ (cm)	0.15240	0.15240	0.15240	0.15240
OR_{Lid} (cm)	23.11400	21.56352	21.62219	20.66339
IR_{Lid} (cm)	22.96160	21.41112	21.46979	20.51099
$th_{Kaolite}$ (cm)	12.10310	10.55262	10.61129	9.65249
Kaolite of the body weldment inner liner				
Mass (g)	117,563.0	97,080.4	97,829.7	85,839.8
Volume (cm^3)	134,888.0	111,387.0	112,246.0	98,489.5
Volume fraction multiplier [a]	–	1.21099	1.20171	1.36956
VF for water component of Kaolite	0.52294	0.63327 [b]	0.62843 [b]	0.71620 [b]
VF for dry mix component of Kaolite	0.34864	0.42220 [b]	0.41897 [b]	0.47749 [b]
Angle iron				
Mass (g)	5,621.76	4,521.40	4,561.66	3,917.54
Volume (cm^3)	708.030	569.446	574.516	493.393
VF	1.0	1.24337	1.23239	1.43502
Drum steel				
Mass (g)	25,446.3	23,397.6	23,474.2	22,231.2
Volume (cm^3)	3,204.82	2,946.80	2,956.50	2,799.90
VF	1.0	1.08756	1.08401	1.14462

[a] Volume fraction multiplier is an NCT density multiplier for conserving mass in components having modified volumes in the HAC calculation models.

[b] Volume fraction (VF) for Kaolite components calculated by multiplying the VF used in the NCT model by volume fraction multiplier for the HAC model.

Table 6.9.2.2-1. Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MR" and "MLR" node points

MOIFR	Random number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
1.0E-20	109E77866CF6	mrandnum_01_01	1.04965	0.00119	mlrrandnum_01_01	1.05024	0.00139
1.0E-20	16AA4A58735C	mrandnum_01_02	1.05132	0.00131	mlrrandnum_01_02	1.05051	0.00135
1.0E-20	1814171B652A	mrandnum_01_03	1.05368	0.00123	mlrrandnum_01_03	1.05121	0.00128
1.0E-20	1A423B9472C7	mrandnum_01_04	1.05165	0.00145	mlrrandnum_01_04	1.04954	0.00120
1.0E-20	20E876D82248	mrandnum_01_05	1.05344	0.00106	mlrrandnum_01_05	1.05249	0.00110
1.0E-20	3F6E65CA7440	mrandnum_01_06	1.05188	0.00157	mlrrandnum_01_06	1.04924	0.00132
1.0E-20	479D21DB7509	mrandnum_01_07	1.05149	0.00148	mlrrandnum_01_07	1.05105	0.00111
1.0E-20	55D4371D3A23	mrandnum_01_08	1.05083	0.00113	mlrrandnum_01_08	1.05039	0.00129
1.0E-20	6E1A14672B8F	mrandnum_01_09	1.04910	0.00106	mlrrandnum_01_09	1.05161	0.00125
1.0E-20	77A0308C0E44	mrandnum_01_10	1.05254	0.00106	mlrrandnum_01_10	1.05041	0.00129
1.0E-04	109E77866CF6	mrandnum_03_01	1.04994	0.00132	mlrrandnum_03_01	1.05108	0.00151
1.0E-04	16AA4A58735C	mrandnum_03_02	1.05023	0.00118	mlrrandnum_03_02	1.05245	0.00116
1.0E-04	1814171B652A	mrandnum_03_03	1.05090	0.00139	mlrrandnum_03_03	1.05169	0.00138
1.0E-04	1A423B9472C7	mrandnum_03_04	1.05072	0.00115	mlrrandnum_03_04	1.05303	0.00102
1.0E-04	20E876D82248	mrandnum_03_05	1.05052	0.00119	mlrrandnum_03_05	1.05191	0.00115
1.0E-04	3F6E65CA7440	mrandnum_03_06	1.05383	0.00131	mlrrandnum_03_06	1.05017	0.00110
1.0E-04	479D21DB7509	mrandnum_03_07	1.05205	0.00153	mlrrandnum_03_07	1.05232	0.00128
1.0E-04	55D4371D3A23	mrandnum_03_08	1.05343	0.00106	mlrrandnum_03_08	1.05100	0.00144
1.0E-04	6E1A14672B8F	mrandnum_03_09	1.04831	0.00132	mlrrandnum_03_09	1.05046	0.00145
1.0E-04	77A0308C0E44	mrandnum_03_10	1.05353	0.00111	mlrrandnum_03_10	1.05130	0.00134
0.10	109E77866CF6	mrandnum_06_01	0.97948	0.00120	mlrrandnum_06_01	0.98071	0.00129
0.10	16AA4A58735C	mrandnum_06_02	0.98104	0.00125	mlrrandnum_06_02	0.98006	0.00110
0.10	1814171B652A	mrandnum_06_03	0.98056	0.00134	mlrrandnum_06_03	0.98043	0.00116
0.10	1A423B9472C7	mrandnum_06_04	0.97895	0.00114	mlrrandnum_06_04	0.98253	0.00109
0.10	20E876D82248	mrandnum_06_05	0.98058	0.00113	mlrrandnum_06_05	0.98256	0.00135
0.10	3F6E65CA7440	mrandnum_06_06	0.97966	0.00119	mlrrandnum_06_06	0.98093	0.00127
0.10	479D21DB7509	mrandnum_06_07	0.97953	0.00145	mlrrandnum_06_07	0.97959	0.00127
0.10	55D4371D3A23	mrandnum_06_08	0.97993	0.00130	mlrrandnum_06_08	0.98033	0.00111
0.10	6E1A14672B8F	mrandnum_06_09	0.97972	0.00138	mlrrandnum_06_09	0.97940	0.00117
0.10	77A0308C0E44	mrandnum_06_10	0.98157	0.00134	mlrrandnum_06_10	0.98318	0.00134
0.30	109E77866CF6	mrandnum_08_01	0.93412	0.00118	mlrrandnum_08_01	0.93254	0.00147
0.30	16AA4A58735C	mrandnum_08_02	0.93227	0.00138	mlrrandnum_08_02	0.93186	0.00142
0.30	1814171B652A	mrandnum_08_03	0.93390	0.00131	mlrrandnum_08_03	0.93200	0.00135
0.30	1A423B9472C7	mrandnum_08_04	0.93252	0.00144	mlrrandnum_08_04	0.93197	0.00150
0.30	20E876D82248	mrandnum_08_05	0.93334	0.00132	mlrrandnum_08_05	0.93601	0.00124
0.30	3F6E65CA7440	mrandnum_08_06	0.93168	0.00132	mlrrandnum_08_06	0.93249	0.00118
0.30	479D21DB7509	mrandnum_08_07	0.93514	0.00123	mlrrandnum_08_07	0.93299	0.00128
0.30	55D4371D3A23	mrandnum_08_08	0.93564	0.00132	mlrrandnum_08_08	0.93500	0.00133
0.30	6E1A14672B8F	mrandnum_08_09	0.93597	0.00136	mlrrandnum_08_09	0.93201	0.00122
0.30	77A0308C0E44	mrandnum_08_10	0.93525	0.00128	mlrrandnum_08_10	0.93238	0.00153

Table 6.9.2.2-1. Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MR" and "MLR" node points

MOIFR	Random number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
1.00	109E77866CF6	mrandnum_15_01	0.93103	0.00139	mlrrandnum_15_01	0.93180	0.00126
1.00	16AA4A58735C	mrandnum_15_02	0.93082	0.00131	mlrrandnum_15_02	0.93020	0.00159
1.00	1814171B652A	mrandnum_15_03	0.92890	0.00148	mlrrandnum_15_03	0.92956	0.00117
1.00	1A423B9472C7	mrandnum_15_04	0.93062	0.00145	mlrrandnum_15_04	0.92837	0.00165
1.00	20E876D82248	mrandnum_15_05	0.93055	0.00125	mlrrandnum_15_05	0.93220	0.00120
1.00	3F6E65CA7440	mrandnum_15_06	0.92950	0.00117	mlrrandnum_15_06	0.93177	0.00141
1.00	479D21DB7509	mrandnum_15_07	0.92952	0.00116	mlrrandnum_15_07	0.93217	0.00144
1.00	55D4371D3A23	mrandnum_15_08	0.92805	0.00154	mlrrandnum_15_08	0.92921	0.00125
1.00	6E1A14672B8F	mrandnum_15_09	0.93117	0.00140	mlrrandnum_15_09	0.92980	0.00177
1.00	77A0308C0E44	mrandnum_15_10	0.93218	0.00120	mlrrandnum_15_10	0.93070	0.00126

Table 6.9.2.2-2.Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MLR" and "LR" node points

MOIFR	Random number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
1.0E-20	109E77866CF6	mlrrandnum_01_01	1.05024	0.00139	lrrandnum_01_01	1.05093	0.00133
1.0E-20	16AA4A58735C	mlrrandnum_01_02	1.05051	0.00135	lrrandnum_01_02	1.05009	0.00118
1.0E-20	1814171B652A	mlrrandnum_01_03	1.05121	0.00128	lrrandnum_01_03	1.05057	0.00118
1.0E-20	1A423B9472C7	mlrrandnum_01_04	1.04954	0.00120	lrrandnum_01_04	1.05066	0.00120
1.0E-20	20E876D82248	mlrrandnum_01_05	1.05249	0.00110	lrrandnum_01_05	1.04882	0.00129
1.0E-20	3F6E65CA7440	mlrrandnum_01_06	1.04924	0.00132	lrrandnum_01_06	1.05316	0.00127
1.0E-20	479D21DB7509	mlrrandnum_01_07	1.05105	0.00111	lrrandnum_01_07	1.05229	0.00134
1.0E-20	55D4371D3A23	mlrrandnum_01_08	1.05039	0.00129	lrrandnum_01_08	1.05186	0.00131
1.0E-20	6E1A14672B8F	mlrrandnum_01_09	1.05161	0.00125	lrrandnum_01_09	1.05236	0.00113
1.0E-20	77A0308C0E44	mlrrandnum_01_10	1.05041	0.00129	lrrandnum_01_10	1.05098	0.00120
1.0E-04	109E77866CF6	mlrrandnum_03_01	1.05108	0.00151	lrrandnum_03_01	1.05122	0.00123
1.0E-04	16AA4A58735C	mlrrandnum_03_02	1.05245	0.00116	lrrandnum_03_02	1.05324	0.00121
1.0E-04	1814171B652A	mlrrandnum_03_03	1.05169	0.00138	lrrandnum_03_03	1.05143	0.00123
1.0E-04	1A423B9472C7	mlrrandnum_03_04	1.05303	0.00102	lrrandnum_03_04	1.05048	0.00121
1.0E-04	20E876D82248	mlrrandnum_03_05	1.05191	0.00115	lrrandnum_03_05	1.05095	0.00137
1.0E-04	3F6E65CA7440	mlrrandnum_03_06	1.05017	0.00110	lrrandnum_03_06	1.05029	0.00119
1.0E-04	479D21DB7509	mlrrandnum_03_07	1.05232	0.00128	lrrandnum_03_07	1.05124	0.00108
1.0E-04	55D4371D3A23	mlrrandnum_03_08	1.05100	0.00144	lrrandnum_03_08	1.05080	0.00116
1.0E-04	6E1A14672B8F	mlrrandnum_03_09	1.05046	0.00145	lrrandnum_03_09	1.05074	0.00122
1.0E-04	77A0308C0E44	mlrrandnum_03_10	1.05130	0.00134	lrrandnum_03_10	1.05094	0.00111
0.1	109E77866CF6	mlrrandnum_06_01	0.98071	0.00129	lrrandnum_06_01	0.98315	0.00118
0.1	16AA4A58735C	mlrrandnum_06_02	0.98006	0.00110	lrrandnum_06_02	0.98605	0.00124
0.1	1814171B652A	mlrrandnum_06_03	0.98043	0.00116	lrrandnum_06_03	0.98690	0.00120

Table 6.9.2.2-2.Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MLR" and "LR" node points

MOIFR	Random number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
0.1	1A423B9472C7	mlrrandnum_06_04	0.98253	0.00109	lrrandnum_06_04	0.98347	0.00126
0.1	20E876D82248	mlrrandnum_06_05	0.98256	0.00135	lrrandnum_06_05	0.98770	0.00124
0.1	3F6E65CA7440	mlrrandnum_06_06	0.98093	0.00127	lrrandnum_06_06	0.98734	0.00140
0.1	479D21DB7509	mlrrandnum_06_07	0.97959	0.00127	lrrandnum_06_07	0.98417	0.00133
0.1	55D4371D3A23	mlrrandnum_06_08	0.98033	0.00111	lrrandnum_06_08	0.98712	0.00136
0.1	6E1A14672B8F	mlrrandnum_06_09	0.97940	0.00117	lrrandnum_06_09	0.98533	0.00142
0.1	77A0308C0E44	mlrrandnum_06_10	0.98318	0.00134	lrrandnum_06_10	0.98412	0.00116
0.3	109E77866CF6	mlrrandnum_08_01	0.93254	0.00147	lrrandnum_08_01	0.93910	0.00146
0.3	16AA4A58735C	mlrrandnum_08_02	0.93186	0.00142	lrrandnum_08_02	0.93757	0.00117
0.3	1814171B652A	mlrrandnum_08_03	0.93200	0.00135	lrrandnum_08_03	0.93940	0.00146
0.3	1A423B9472C7	mlrrandnum_08_04	0.93197	0.00150	lrrandnum_08_04	0.93676	0.00130
0.3	20E876D82248	mlrrandnum_08_05	0.93601	0.00124	lrrandnum_08_05	0.93851	0.00111
0.3	3F6E65CA7440	mlrrandnum_08_06	0.93249	0.00118	lrrandnum_08_06	0.93914	0.00149
0.3	479D21DB7509	mlrrandnum_08_07	0.93299	0.00128	lrrandnum_08_07	0.94011	0.00131
0.3	55D4371D3A23	mlrrandnum_08_08	0.93500	0.00133	lrrandnum_08_08	0.93900	0.00139
0.3	6E1A14672B8F	mlrrandnum_08_09	0.93201	0.00122	lrrandnum_08_09	0.93781	0.00117
0.3	77A0308C0E44	mlrrandnum_08_10	0.93238	0.00153	lrrandnum_08_10	0.93965	0.00118
1.0	109E77866CF6	mlrrandnum_15_01	0.93180	0.00126	lrrandnum_15_01	0.93344	0.00126
1.0	16AA4A58735C	mlrrandnum_15_02	0.93020	0.00159	lrrandnum_15_02	0.93281	0.00121
1.0	1814171B652A	mlrrandnum_15_03	0.92956	0.00117	lrrandnum_15_03	0.93468	0.00132
1.0	1A423B9472C7	mlrrandnum_15_04	0.92837	0.00165	lrrandnum_15_04	0.93592	0.00126
1.0	20E876D82248	mlrrandnum_15_05	0.93220	0.00120	lrrandnum_15_05	0.93251	0.00143
1.0	3F6E65CA7440	mlrrandnum_15_06	0.93177	0.00141	lrrandnum_15_06	0.93374	0.00121
1.0	479D21DB7509	mlrrandnum_15_07	0.93217	0.00144	lrrandnum_15_07	0.93572	0.00138
1.0	55D4371D3A23	mlrrandnum_15_08	0.92921	0.00125	lrrandnum_15_08	0.93498	0.00145
1.0	6E1A14672B8F	mlrrandnum_15_09	0.92980	0.00177	lrrandnum_15_09	0.93224	0.00114
1.0	77A0308C0E44	mlrrandnum_15_10	0.93070	0.00126	lrrandnum_15_10	0.93158	0.00131

Table 6.9.2.2-3. Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MR" and "LR" node points

MOIFR	Random number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
1.0E-20	109E77866CF6	mrandnum_01_01	1.04965	0.00119	lrrandnum_01_01	1.05093	0.00133
1.0E-20	16AA4A58735C	mrandnum_01_02	1.05132	0.00131	lrrandnum_01_02	1.05009	0.00118
1.0E-20	1814171B652A	mrandnum_01_03	1.05368	0.00123	lrrandnum_01_03	1.05057	0.00118
1.0E-20	1A423B9472C7	mrandnum_01_04	1.05165	0.00145	lrrandnum_01_04	1.05066	0.00120
1.0E-20	20E876D82248	mrandnum_01_05	1.05344	0.00106	lrrandnum_01_05	1.04882	0.00129
1.0E-20	3F6E65CA7440	mrandnum_01_06	1.05188	0.00157	lrrandnum_01_06	1.05316	0.00127
1.0E-20	479D21DB7509	mrandnum_01_07	1.05149	0.00148	lrrandnum_01_07	1.05229	0.00134
1.0E-20	55D4371D3A23	mrandnum_01_08	1.05083	0.00113	lrrandnum_01_08	1.05186	0.00131
1.0E-20	6E1A14672B8F	mrandnum_01_09	1.04910	0.00106	lrrandnum_01_09	1.05236	0.00113
1.0E-20	77A0308C0E44	mrandnum_01_10	1.05254	0.00106	lrrandnum_01_10	1.05098	0.00120
1.0E-04	109E77866CF6	mrandnum_03_01	1.04994	0.00132	lrrandnum_03_01	1.05122	0.00123
1.0E-04	16AA4A58735C	mrandnum_03_02	1.05023	0.00118	lrrandnum_03_02	1.05324	0.00121
1.0E-04	1814171B652A	mrandnum_03_03	1.05090	0.00139	lrrandnum_03_03	1.05143	0.00123
1.0E-04	1A423B9472C7	mrandnum_03_04	1.05072	0.00115	lrrandnum_03_04	1.05048	0.00121
1.0E-04	20E876D82248	mrandnum_03_05	1.05052	0.00119	lrrandnum_03_05	1.05095	0.00137
1.0E-04	3F6E65CA7440	mrandnum_03_06	1.05383	0.00131	lrrandnum_03_06	1.05029	0.00119
1.0E-04	479D21DB7509	mrandnum_03_07	1.05205	0.00153	lrrandnum_03_07	1.05124	0.00108
1.0E-04	55D4371D3A23	mrandnum_03_08	1.05343	0.00106	lrrandnum_03_08	1.05080	0.00116
1.0E-04	6E1A14672B8F	mrandnum_03_09	1.04831	0.00132	lrrandnum_03_09	1.05074	0.00122
1.0E-04	77A0308C0E44	mrandnum_03_10	1.05353	0.00111	lrrandnum_03_10	1.05094	0.00111
0.10	109E77866CF6	mrandnum_06_01	0.97948	0.00120	lrrandnum_06_01	0.98315	0.00118
0.10	16AA4A58735C	mrandnum_06_02	0.98104	0.00125	lrrandnum_06_02	0.98605	0.00124
0.10	1814171B652A	mrandnum_06_03	0.98056	0.00134	lrrandnum_06_03	0.98690	0.00120
0.10	1A423B9472C7	mrandnum_06_04	0.97895	0.00114	lrrandnum_06_04	0.98347	0.00126
0.10	20E876D82248	mrandnum_06_05	0.98058	0.00113	lrrandnum_06_05	0.98770	0.00124
0.10	3F6E65CA7440	mrandnum_06_06	0.97966	0.00119	lrrandnum_06_06	0.98734	0.00140
0.10	479D21DB7509	mrandnum_06_07	0.97953	0.00145	lrrandnum_06_07	0.98417	0.00133
0.10	55D4371D3A23	mrandnum_06_08	0.97993	0.00130	lrrandnum_06_08	0.98712	0.00136
0.10	6E1A14672B8F	mrandnum_06_09	0.97972	0.00138	lrrandnum_06_09	0.98533	0.00142
0.10	77A0308C0E44	mrandnum_06_10	0.98157	0.00134	lrrandnum_06_10	0.98412	0.00116
0.30	109E77866CF6	mrandnum_08_01	0.93412	0.00118	lrrandnum_08_01	0.93910	0.00146
0.30	16AA4A58735C	mrandnum_08_02	0.93227	0.00138	lrrandnum_08_02	0.93757	0.00117
0.30	1814171B652A	mrandnum_08_03	0.93390	0.00131	lrrandnum_08_03	0.93940	0.00146
0.30	1A423B9472C7	mrandnum_08_04	0.93252	0.00144	lrrandnum_08_04	0.93676	0.00130
0.30	20E876D82248	mrandnum_08_05	0.93334	0.00132	lrrandnum_08_05	0.93851	0.00111
0.30	3F6E65CA7440	mrandnum_08_06	0.93168	0.00132	lrrandnum_08_06	0.93914	0.00149
0.30	479D21DB7509	mrandnum_08_07	0.93514	0.00123	lrrandnum_08_07	0.94011	0.00131
0.30	55D4371D3A23	mrandnum_08_08	0.93564	0.00132	lrrandnum_08_08	0.93900	0.00139
0.30	6E1A14672B8F	mrandnum_08_09	0.93597	0.00136	lrrandnum_08_09	0.93781	0.00117
0.30	77A0308C0E44	mrandnum_08_10	0.93525	0.00128	lrrandnum_08_10	0.93965	0.00118

Table 6.9.2.2-3. Neutron multiplication factors with standard deviations for the ES-3100 package models at the "MR" and "LR" node points

MOIFR	Random number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
1.00	109E77866CF6	mrandnum_15_01	0.93103	0.00139	lrrandnum_15_01	0.93344	0.00126
1.00	16AA4A58735C	mrandnum_15_02	0.93082	0.00131	lrrandnum_15_02	0.93281	0.00121
1.00	1814171B652A	mrandnum_15_03	0.92890	0.00148	lrrandnum_15_03	0.93468	0.00132
1.00	1A423B9472C7	mrandnum_15_04	0.93062	0.00145	lrrandnum_15_04	0.93592	0.00126
1.00	20E876D82248	mrandnum_15_05	0.93055	0.00125	lrrandnum_15_05	0.93251	0.00143
1.00	3F6E65CA7440	mrandnum_15_06	0.92950	0.00117	lrrandnum_15_06	0.93374	0.00121
1.00	479D21DB7509	mrandnum_15_07	0.92952	0.00116	lrrandnum_15_07	0.93572	0.00138
1.00	55D4371D3A23	mrandnum_15_08	0.92805	0.00154	lrrandnum_15_08	0.93498	0.00145
1.00	6E1A14672B8F	mrandnum_15_09	0.93117	0.00140	lrrandnum_15_09	0.93224	0.00114
1.00	77A0308C0E44	mrandnum_15_10	0.93218	0.00120	lrrandnum_15_10	0.93158	0.00131

6.9.2.3 Statistical Evaluation

An evaluation of KENO V.a calculation results is made to determine if there is a statistically significant difference between the mean k_{eff} for the "MR" and "MLR" models, for the "MLR" and "LR" models, and for the "MR" and "LR" models. Cases are classified into five groups based on the amount of water assumed to be present in the shipping package. The symbol "I" is used to specify the case. The mean difference and standard deviation for each of the five sets of pair-wise differences are defined as follows:

(a) $d_i = (k_{effBi} - k_{effAi})/n$ and

(b) $s_{di} = \sqrt{[\, n\Sigma d_i^{\,2} - (\Sigma d_i)^2 \,] / n(n-1)}$ (conservatively defined for the t-test appropriate for small sample sizes),

where A_i and B_i denote the model types, and n denotes the sample size of ten. It is reasonable to assume that the paired differences have been randomly selected from a normally distributed population of paired differences with mean (μ_d) and standard deviation (σ_d), then the sampling distribution of

$$(d - \mu_d) / (s_d/\sqrt{n})$$

is a *t* distribution having n-1 degrees of freedom.

The evaluation of the mean differences (d_i) for the 10 sets of cases is accomplished through hypothesis testing, a statistical tool used to provide evidence that a difference exists or does not exist. The t_i values are given in Table 6.9.2.3-1. A value of 3.25 is obtained from the standard table for critical values for the t distribution from which the decision to accept or reject the null hypothesis H_0 is made with a Type I error probability (α) of 0.01.

For $|t| < 3.25$, the H_o hypothesis is not rejected. Acceptance of the null hypothesis is the result of insufficient evidence to reject it. Thus, it can be concluded that the mean estimates of the difference in k_{eff} between the "MR" and "MLR" calculation models, between the "MLR" and "LR" calculation models, and between the "MR" and "LR" calculation models are not statistically significant for the dry condition where neutronic interaction between packages is significant. Also, the mean estimate of the difference in k_{eff} between the "MR" and "MLR" calculation models is not statistically significant for wet or flooded conditions where the packages of the array become isolated.

Table 6.9.2.3-1. T-test values for establishing the statistical significance of the differences in calculated k_{eff} values for the ES-3100 package models at the "MR," "MLR," and "LR" node points

MOIFR	"MR" cases (k_{eff})	"MLR" cases (k_{eff})	di	Sdi	ta
1.0E-20	1.05154	1.05075	0.00089	1.58991E-03	1.77
1.0E-04	1.05146	1.05165	-0.00019	2.17840E-03	-0.28
0.1	0.98008	0.98091	-0.00087	1.33870E-03	-2.06
0.3	0.93404	0.93300	0.00106	1.88912E-03	1.77
1.0	0.93030	0.93067	-0.00034	1.68664E-03	-0.65

MOIFR	"MLR" cases (k_{eff})	"LR" cases (k_{eff})	di	Sdi	t
1.0E-20	1.05075	1.05116	-0.00050	1.92087E-03	-0.83
1.0E-04	1.05165	1.05113	0.00041	9.36819E-04	1.38
0.1	0.98091	0.98546	-0.00456	2.28535E-03	-6.31
0.3	0.93300	0.93863	-0.00578	1.59574E-03	-11.45
1.0	0.93067	0.93369	-0.00318	2.30797E-03	-4.36

MOIFR	"MR" cases (k_{eff})	"LR" cases (k_{eff})	di	Sdi	t
1.0E-20	1.05154	1.05116	0.00039	2.35840E-03	0.52
1.0E-04	1.05146	1.05113	0.00021	2.19813E-03	0.31
0.10	0.98008	0.98546	-0.00543	1.66324E-03	-10.33
0.30	0.93404	0.93863	-0.00472	1.46294E-03	-10.21
1.00	0.93030	0.93369	-0.00353	2.50750E-03	-4.45

[a] critical value = 3.25 for 10 cases.

For $|t| > 3.25$, the H_o hypothesis is rejected. Therefore, it can be concluded that the mean estimate of the difference in k_{eff} between the "MLR" and "LR" calculation models, and between the "MR" and "LR" calculation models, is statistically significant for wet or flooded conditions where the packages of the array become isolated. The negative t-values indicate that the calculated k_{eff} value for the "LR" model is slightly higher than for the "MR" and "MLR" models. This result is consistent with an expected increase in k_{eff} due to "tighter or closer" water reflector surrounding the package content.

Although flattening of the side of the package represents a reduction in the diameter of the drum, the points at which minimum flattening occurs provide an indication of the reduction of lattice spacing between packages of an array under HAC. The composite of the minimum deformation points at perpendicular axes (90–270° and 0–180°) represents the modified lattice spacing in an array of ES-3100 packages. As illustrated in Table 6.9.2.3-2, the equivalent diameter of the package for "composite" lattice spacing is not significantly different from the 18.37-in. diam of the pre-test package. Even though significant crushing of the drum midsection and bottom occurs, the effective center-to-center spacing of the contents actually increases under HAC. Selective rearrangement of alternating packages would be required to achieve a more compact array; however, this event is not credible.

As described in Sect. 6.3.1.2, a close-pack (triangular-pitch) array of packages would be represented by a reduced package in a rectangular-pitch configuration. For HAC, the 17.26-in. reduced diameter for the "composite close-pack" package is slightly larger than the 17.20-in. diam of the "MLR" calculation model used in the HAC calculations of Sect. 6.6. Therefore, packages evaluated with the "MLR" calculation model of packages in a rectangular-pitch configuration are deemed adequate for the HAC criticality evaluation. Considering both the irregular shape of the deformed drums and that array spacing is determined by overall (maximum) dimensions rather than by mean or minimum dimensions of a damaged package, the use of the "MLR" model for representing the ES-3100 package under HAC is conservative and bounding.

Table 6.9.2.3-2. Deformation of the ES-3100 drum projected by finite element analysis "Case 3100 RUN1HL Lower Bound Kaolite May 2004"

	FEA node	Diameter at 90° (in.)	Diameter at 180° (in.)	Equivalent circular diameter (in.)
Composite	103012/098194	22.00	15.60	18.56
Pre-test drum	-	18.37	18.37	
Pre-test, close-pack	-	17.08	17.08	
Composite, close-pack	103012/098194	-	-	17.26

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Appendix 6.9.3

Package Material Compositions

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Appendix 6.9.3

Package Material Compositions

Table 6.4 (Sect. 6.3.2) provides basic information for deriving the compositions for the ES-3100 package (Figs. 6.1 and 6.2). The atomic densities presented in Table 6.4 can be verified using additional information provided in Appendix 6.9.5. The following sections provide the rationale, the justification, or both for the material compositions used in the criticality calculations.

6.9.3.1 HEU, Unirradiated TRIGA, and Research Reactor Related Contents

HEU considered for shipment in the ES-3100 is categorized into the following material forms: highly enriched uranium (HEU) solid or broken metal; HEU oxide; uranyl nitrate hexahydrate (UNH) crystals. In the interest of adding conservatism, uranium is modeled as ^{235}U and ^{238}U, while the ^{234}U and ^{236}U isotopes are excluded. Any positive change in neutron multiplication represented by the presence of the ^{234}U is covered by the higher than actual ^{235}U content (Rothe). The theoretical density of 100 wt % ^{235}U HEU is 18.8111 g/cm^3. This value is determined by adjusting the density of natural uranium included in the SCALE Standard Composition Library with 100 wt % weight factors. The theoretical density of HEU oxide types are 10.96 g/cm^3 for UO_2, 8.30 g/cm^3 for U_3O_8, and 7.29 g/cm^3 for UO_3. The theoretical density of UNH crystals is 2.79 g/cm^3. Table 6.9.3.1-1 provides details of the calculated weight percentages input to KENO V.a calculated on the basis of the stoichiometric formula of $UO_2(NO_3)_2$+$6H_2O$ and crystalline density. The maximum enrichment considered in the analysis is 100 wt % ^{235}U, although actual material enrichments are lower. The unirradiated solid form TRIGA fuel is uranium zirconium hydride ($UZrH_x$) where "x" is ≤ 2, having a density of 8.65 g/cm^3. Research reactor related contents are fuel elements or fuel components, broken metal, U-Al alloy, or oxides. These contents are described at the end of this subsection.

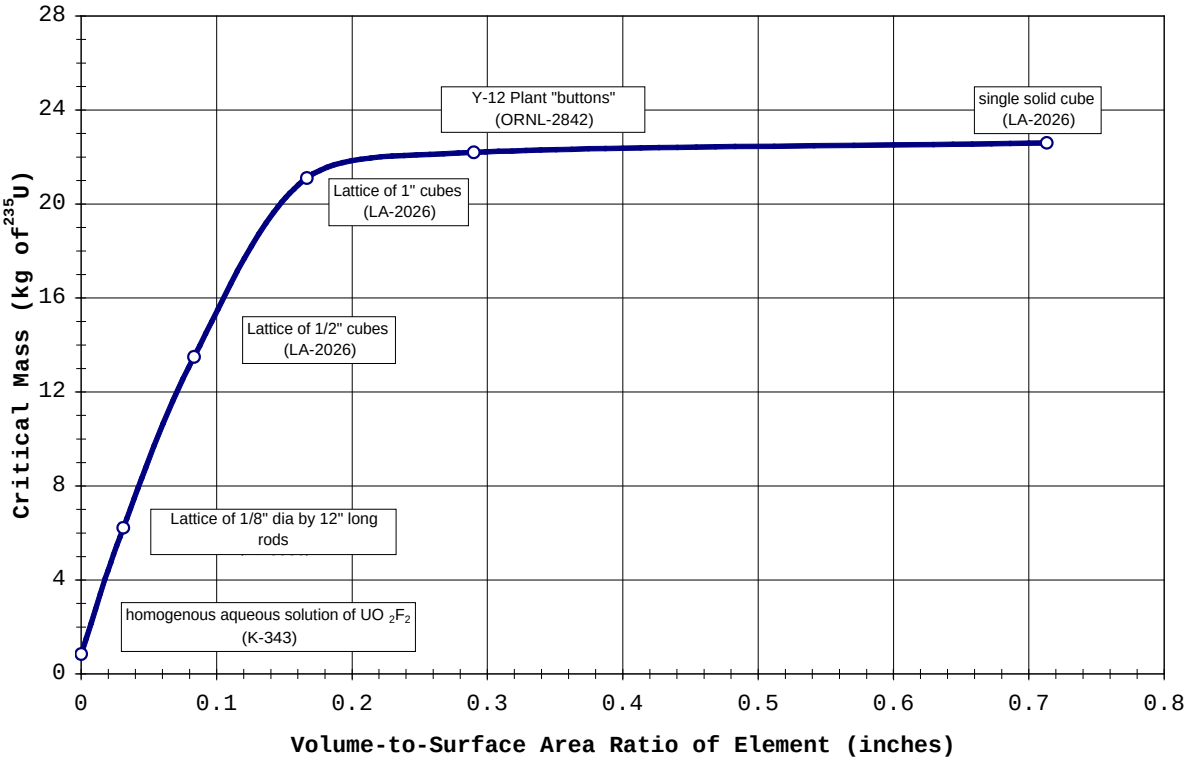
Table 6.9.3.1-1. Calculation of constituent weight-percentage values for uranyl nitrate hexahydrate crystals used in KENO V.a calculation models

Avogadro No. (N_o)	6.0221370E+23					
UNH						
$UO_2(NO_3)_2$+$6H_2O$	Atoms/Molecule	At. wt [a]	Mole. wt.	wt %	calc. Ni	NiAi
Hydrogen	12	1.0078	12.0936	2.4233	4.0401E+22	4.0716E+22
Nitrogen	2	14.0031	28.0062	5.6117	6.7333E+21	9.4286E+22
Oxygen	14	15.9949	223.9286	44.8690	4.7132E+22	7.5388E+23
U-235		235.0441		100.0000		
U-238		238.0510		0.0000		
Uranium	1	235.0441	235.0441	47.0962	3.3666E+21	7.9130E+23
			499.0725	100.0002		
summations				100.0002	9.7633E+22	1.6802E+24
At. wt. material assumed density	2.7900					
den.=($\sum N_i A_i$)/N_o						2.7900

[a] Source: Nuclides and Isotopes, Chart of the Nuclides, 14th ed., General Electric Company, 1989.

HEU broken metal. The critical mass of fissile material is dependent on factors such as the form and shape of the material, bulk density if the material is broken into pieces, and the enrichment. Broken metal can be compared to the minimum critical mass of submerged metal lattices of regular-shaped fissile material. Using experimental data, the approximation of a heterogeneous mixture of fissile material and moderator to a homogeneous mixture is justified as follows.

Figure 6.9.3.1-1 depicts the experimentally determined minimum critical mass of U (~ 94) lattices immersed in water as a function of the volume-to-surface area ratio of the fissile element (TID-7028). The critical mass is shown to increase from 850 g to 21 kg over the range of volume-to-surface ratios from 0 to 0.18 in. The critical mass is nearly constant in the range of volume-to-surface ratios from 0.18 to 0.8 in. For pieces greater than 1-in. cubes, the minimum critical mass will not be less than 21 kg. For smaller pieces, the minimum critical mass is a nearly linear function of the volume-to-surface-area ratio of the fissile element.

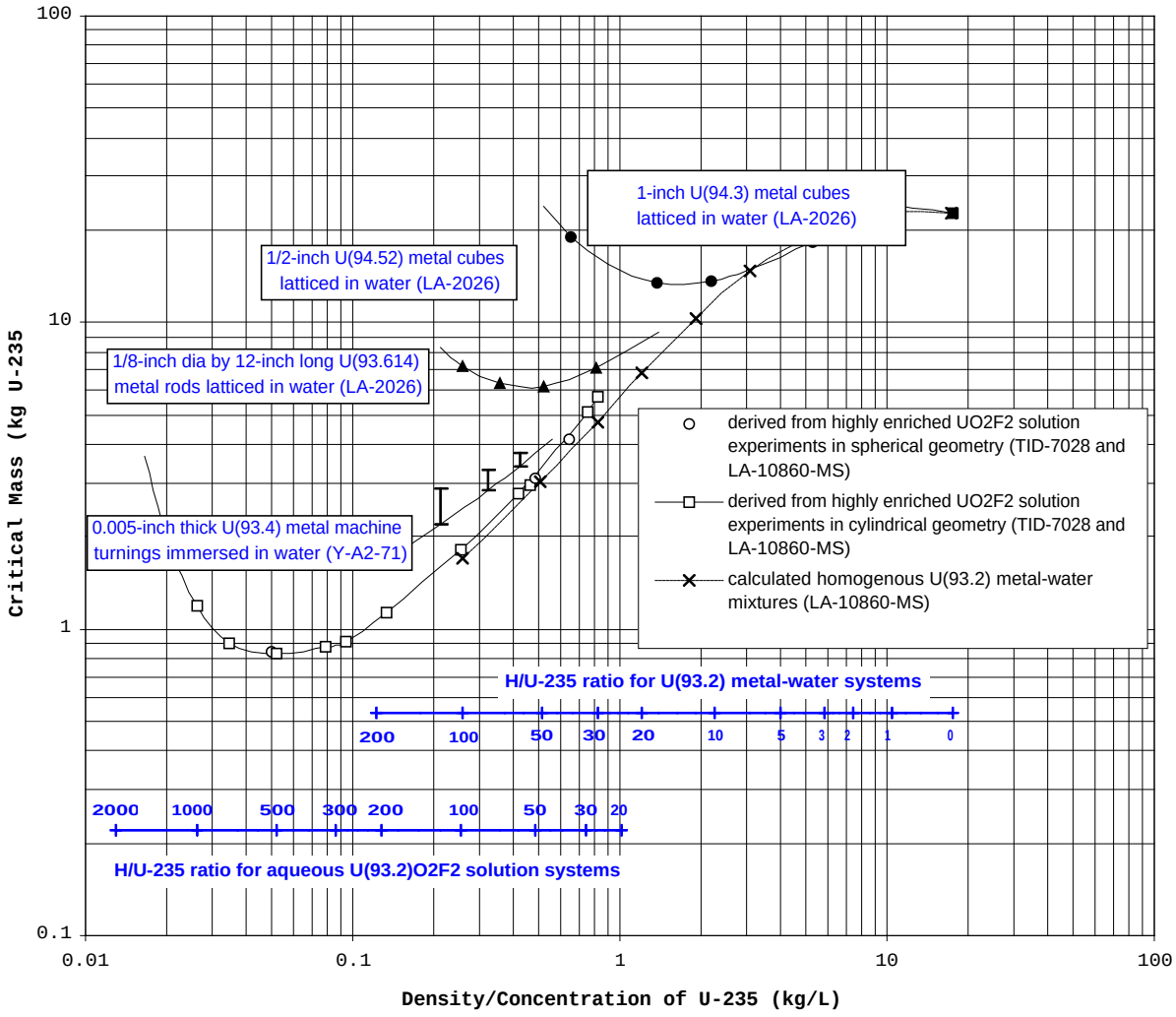


Source: H. C. Paxton et al., *Critical Dimensions of Systems Containing 235U*, TID-7028, Los Alamos Scientific Lab. and Oak Ridge Natl. Lab., June 1964, Fig. 19. Y-12 data have been added.

Fig. 6.9.3.1-1. Experimentally determined minimum critical mass U(~94) metal lattices immersed in water as a function of volume-to-surface area ratio of fissile material.

Figure 6.9.3.1-2 depicts the experimentally determined minimum critical mass of U (~ 94) metal water and solution systems as a function of the concentration of ^{235}U. The figure with added data reveals that: (1) a minimum critical mass exists for each metal lattice system plotted, and (2) as the bulk density of uranium or the uranium concentration increases, the curves for the critical mass of metal lattice systems converge with the curve for highly enriched solution experiments or the curve for calculated homogeneous metal water mixtures. Conversely stated, the critical mass is greater for a heterogenous system than for a homogeneous system, and this difference increases as the H/X ratio increases.

Therefore, the practice of approximating a heterogeneous mixture of fissile material and moderator as a homogeneous mixture is justifiable and also conservative at the higher H/X ratios.



Sources: A. W. Krass, *Survey of Experimental Data Concerning the Critical Mass of Highly Enriched Uranium–Water Systems*, CCG-365, Lockheed Martin Energy Systems, Inc., Oak Ridge Y-12 Plant, July 13, 2000, Fig. 1. Y-12 data added.

Fig. 6.9.3.1-2. Experimentally determined minimum critical mass of U(~94) metal water and solution systems as a function of the concentration of ^{235}U.

Approximating broken metal as a homogeneous mixture of uranium and water requires a defined space within which masses of the components are conserved. This space is generally characterized by a lattice constructed of unit cells and defined by the dimensions of the fissile material being approximated.

The broken HEU metal consists of large, irregular pieces ranging from 0.5 in. to several inches on a side as shown in Fig. 6.9.3.1-3. A lattice of cubes is chosen to represent broken metal inside the ES-3100 containment vessel. Due to the constraints of KENO V.a, an idealized configuration is defined by a square lattice circumscribed by the inner wall of the containment vessel. Water fills the truncated cylindrical regions between the inner wall of the containment vessel and the vertical faces of the lattice. Two additional models are developed to evaluate conservatism at various stages of model approximations for broken metal.



Fig. 6.9.3.1-3. Pan of HEU broken metal.

Together, these models include an explicit arrangement of HEU metal cubes forming a compact rectangular lattice inside the containment vessel, HEU metal homogeneously mixed with water within the rectangular lattice formed by the unit cells, and HEU metal homogeneously mixed with water within the volume of the containment vessel.

Parameters varied in each of these three models include (1) the cube size in the explicit model from 1.0 in. to 0.25 in. on a side, (2) water moderation inside the containment vessel from dry to the fully flooded condition, (3) enrichment from 100.0 wt % ^{235}U to 20.0 wt % ^{235}U, (4) thickness of the 277-4 canned spacers located between each convenience can, and (5) the mass of the uranium metal at each content location. One-quarter inch, 0.5-in., and 1.0-in. cubes are selected to evaluate "approach-to-homogeneity" of broken metal in this idealized form. The corresponding array configurations for 0.25-in., 0.5-in., and 1.0-in. cubes are 12 × 12 × N, 6 × 6 × N, and 3 × 3 × N. The N-th layer of unit cells for a given mass loading may not all contain HEU metal; the empty cells are filled with water. Nevertheless, a slight variation still arises in the total mass of HEU metal between these array configurations given whole cubes are contained in the calculation models.

The results for the calculation models representing the various configurations of broken uranium metal are shown in the Table 6.9.3.1-2. As the explicitly modeled cubes become smaller in size, the calculated k_{eff} values for the explicit "sqa" models approach values for the "lha" models where HEU metal cubes are homogenized with water within the rectangular lattice formed by the unit cells of the array. A representative or converged k_{eff} value is 0.87 for increasing by smaller cubes based on calculation results for the "lha" models. The "lha" results indicate a slight difference between the k_{eff} values for the three array sizes; these differences are attributed to the difference in the HEU for the arrays of whole cubes.

Calculation results reveal that the explicit ("sqa") model of HEU broken metal in a water moderated lattice is bounded by the homogeneous mixture ("lha") model of HEU metal and water. Calculation results for the "cha" models, where arrays of cubes are fully homogenized with the water

Table 6.9.3.1-2. Summary for evaluation of HEU broken metal models (95 wt % ^{235}U) in a flooded containment vessel, 1.4-in. canned spacers and full water reflection of containment vessel

Array type	U (g)	^{235}U (g)	H_2O (g)	h/x	k_{eff}	σ	$k_{eff} + 2\sigma$
Discrete array of cubes ("sqa" cases)							
$3 \times 3 \times n$	35,164	33,406	7,719	6.03	0.8352	0.0012	0.84
$6 \times 6 \times n$	35,973	34,175	7,676	5.86	0.8559	0.0011	0.86
$12 \times 12 \times n$	35,988	34,188	7,765	5.86	0.8603	0.0012	0.86
Cubes homogenized within footprint of lattice ("lha" cases)							
$3 \times 3 \times n$	35,164	33,406	7,719	6.03	0.8586	0.0011	0.86
$6 \times 6 \times n$	35,973	34,175	7,675	5.86	0.8650	0.0012	0.87
$12 \times 12 \times n$	35,988	34,188	7,675	5.86	0.8677	0.0010	0.87
Cubes homogenized within containment vessel ("cha" cases)							
$3 \times 3 \times n$	35,164	33,406	7,719	6.03	0.9427	0.0013	0.95
$6 \times 6 \times n$	35,973	34,175	7,676	5.86	0.9495	0.0015	0.95
$12 \times 12 \times n$	35,988	34,188	7,675	5.86	0.9517	0.0016	0.95

for the flooded containment vessel, indicate the highest k_{eff} values. The neutron multiplication factor jumps from 0.87 to 0.95. The "cha" model is deemed to be overly conservative when applied to broken metal for the following reasons:

- HEU metal does not dissolve in water.
- HEU metal is not in an oxide or powder form that will absorb moisture or readily mix and become homogenized with the water inside the flooded containment vessel.
- Because HEU metal is much denser than water, it will not float and become distributed throughout a flooded containment vessel; instead it will gravitate toward the bottom of the containment vessel.

However, the "cha" model is deemed an appropriate content model for the criticality evaluation when applied to HEU metal powder where fissile uranium as particulate is more fully homogenized with water than large pieces of broken metal and where fissile uranium could be in suspension. For simplicity, the "cha" model is chosen to represent HEU broken metal or metal powder inside a flooded containment vessel under full water reflection and as content in a single package or in arrays of packages under NCT and HAC. Details regarding the "sqa," "lha," and "cha" calculation models are presented in Appendix 6.9.1.

HEU Oxide. Theoretical (crystalline) densities for HEU oxide are 10.96 g/cm^3, 8.30 g/cm^3, and 7.29 g/cm^3 for UO_2, U_3O_8, and UO_3, respectively. While bulk densities of product oxides with enrichments ranging from 19 to 100 wt % ^{235}U are typically on the order of 6.54 g/cm^3, the bulk density of HEU oxides considered for shipment in the ES-3100 ranges from 2.0 to 6.54 g/cm^3. Therefore, only less-than-theoretical mass loadings would actually be achieved. Skull oxides are a mixture of graphite and U_3O_8 with densities on the order of 2.44 g/cm^3 for poured material and 2.78 g/cm^3 for tapped material. The combined water saturation and crystallization of the HEU oxide are not expected in the HAC, given that UO_2 and UO_3 are non-hygroscopic while U_3O_8 is only mildly hygroscopic. Table 6.9.3.1-3 provides summary data for 292 samples of canned skull oxide.

Table 6.9.3.1-3. Summary data for 292 samples of skull oxide

Statistic	wt % U	wt % ^{235}U	µg C/g U	µg C /g ^{235}U	Net wt (g)	U wt (g)	^{235}U wt (g)
Maximum	84.52	93.19	171,000	252,861	**7,072**	5,938	4,165
Minimum	12.93	20.28	13	17	442	312	221
Median	81.66	37.62	5,590	13,910	4,448	3,541	1,414
Mean	79.64	45.02	16,968	41,333	4,419	3,532	1,563
Std. dev.	6.87	16.40	24,304	59,027	745	698	606

Values of wt % U, wt % ^{235}U, µg C/g U, etc. for a given statistic (maximum, minimum, medium, or mean) do not occur simultaneously in a specific sample. Inspection of sample data reveals the following characteristics:

(1) the fissile material content is ≤ 221 g ^{235}U in samples with concentrations up to 252,861 µg C/g^{235}U,
(2) the enrichment is 93.2 wt % ^{235}U for samples with concentrations in the range of 12,600 to 18,600 µg C/gU,
(3) the enrichment ranges from 60 to 70.2 wt % ^{235}U for samples with concentrations in the range of 3,231 to 87,720 µg C/gU, and
(4) the enrichment ranges from 37 to 38 wt % ^{235}U for samples with concentrations in the range of 400 to 233,366 µg C/gU.

Eight skull oxide compositions representative of 292 samples of canned skull oxide were selected for establishing the bounding content calculation models. The skull oxide content is assumed to be U_3O_8 plus graphite, polyethylene, and unidentified material. Two additional compositions were derived for addressing skull oxides with an enrichment of 93.2 wt % ^{235}U where unidentified material is treated as ^{235}U and the carbon content is either maximized or minimized. Treatment of the unidentified material as fissile material in the criticality analysis assures that its presence in skull oxide does not increase reactivity beyond what is considered in the bounding analysis.

The composition of the skull oxide content is given in terms of the following parameters: the grams skull oxide content in a content can (**gramskul**), the content bulk density (**densoc**), the wt % uranium in skull oxide content (**wtpuskul**), the wt % ^{235}U in uranium (**wtpu25u**), and the grams of graphite in the content can (**gramg**). Values for the content specification parameters are provided in Table 6.9.3.1-3b.

Table 6.9.3.1-3b. Content specification parameters for skull oxide content

Content	gramskul (g)	densoc (g/cm^3)	wtpuskul (wt %)	wtpu25u (wt %)	gramg (g)
sk_01	3863	1.899	58.92	69.78	139
sk_02	4978	2.447	66.15	69.42	168
sk_03	4607	1.981	72.77	69.88	124
sk_04	5082	2.186	82.77	70.07	20
sk_05	7072	3.042	83.97	69.91	9
sk_06	5037	2.476	72.53	37.61	307
sk_07	4385	2.156	75.15	37.55	203
sk_08	4550	2.237	72.57	37.73	87
sk_09	7100	3.054	78.95	93.20	307
sk_10	7100	3.054	82.61	93.20	1.0E-05

The information in Table 6.9.3.1-3c is derived from the content specification parameters of Table 1-3b on the assumption that 513 g of polyethylene is present in the skull oxide content in three content locations inside the containment vessel.

The amount of skull oxide content (Column 2, Table 6.9.3.1-3c) is **gsoc** = 3.0 × **gramskul**.

The amount of uranium in the skull oxide content (Column 6, Table 6.9.3.1-3c) is
gusoc = **gsoc** × **wtpuskul** / 100.0.

The amount of ^{235}U (Column 7, Table 6.9.3.1-3c) is **gr235** = **gusoc** × **wtpu25u** / 100.0.

The amount of graphite in the skull oxide content (Column 8, Table 6.9.3.1-3c) is **ggsoc** = 3.0 × **gramg**.

The micrograms graphite per gram uranium in skull oxide content (Column 9, Table 6.9.3.1-3c) is
mggraphgu = **ggsoc** × 1.0e6 / **gusoc**.

The amount of U_3O_8 in the skull oxide content (**guox**) [Column 3, Table 6.9.3.1-3c] is
guox = **gusoc** / **wtpuuox**,

where **gusoc** (Column 6, Table 6.9.3.1-3c),
wtpuuox is the weight percent uranium in uranium oxide, and
wtpuuox = **mwu** / (**mwu** + **mwo**),

where **mwu** = (3){(235.0441 × wtpu25u) + [238.0510 × (100 − wtpu25u)]} /100.0 and
mwo = (8)(15.9949).

The amount of unidentified material in skull oxide content (**gramunid**) [Column 12, Table 6.9.3.1-3c] is
gramunid = (**gsoc** − **guox** − **ggsoc** − **grampoly**)

Skull oxide content is assumed to be saturated with water. The amount of saturation moisture (**gmsatm**) [Column 4, Table 6.9.3.1-3c] is **gmsatm** = 0.9982 × **volsatm**,

where **volsatm** is the volume of saturation moisture in the skull oxide content and
volsatm = **vsox** − **volminsox**

The volume of skull oxide (**vsox**) in the containment vessel is
vsox = (**gsoc** / **densoc**) − (**grampoly** / **denpoly**),

where **gsoc** (Column 2, Table 6.9.3.1-3c),
densoc is the bulk density of skull oxide content,
grampoly is the 513 g of polyethylene, and
denpoly is the density of polyethylene, 0.92 g/cm^3.

The minimum volume of skull oxide (**volminsox**) in the containment vessel is
volminsox = (**gsoc** − **grampoly** − **gramunid**) / **dnsoxtheo**,

where **gsoc** (Column 2, Table 6.9.3.1-3c),
grampoly (513 g),
gramunid (Column 12, Table 6.9.3.1-3c), and
dnsoxtheo is the theoretical density of skull oxide.

Table 6.9.3.1-3c. Canned skull oxide (SO) content for ES-3100 calculation models, assuming 513 g polyethylene present and can spacers absent.

Content	SO (g)	UO_x (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	µg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)
sk_01	11,589	8,063	4,468	28.09	6,828	4,765	417	87,518	4,105	50.58	2,596 [a]
sk_02	14,934	11,665	4,015	17.79	9,879	6,858	504	73,492	4,105	33.41	2,252 [a]
sk_03	13,821	11,876	4,893	20.62	10,058	7,028	372	52,930	3,233	32.62	1,060 [a]
sk_04	15,246	14,900	4,599	15.52	12,619	8,842	60	6,786	3,235	25.07	-227 [b]
sk_05	21,216	21,036	3,869	9.49	17,815	12,455	27	2,168	3,235	16.27	-360 [b]
sk_06	15,111	12,933	3,765	28.02	10,960	4,122	921	223,432	4,105	54.01	744 [a]
sk_07	13,155	11,666	3,989	32.68	9,886	3,712	609	164,054	4,106	61.55	367 [a]
sk_08	13,650	11,689	4,068	33.01	9,906	3,737	261	69,834	4,106	61.69	1,187 [a]
sk_09	21,300	19,865	3,801	7.43	16,816	15,673	921	58,764	3,235	12.82	1
sk_10	21,300	20,786	3,905	7.27	17,596	16,399	0	0	3,235	12.41	1

[a] Positive value specifies grams of miscellaneous neutron-absorber elements in content, modeled as water.
[b] Negative value specifies grams of excess polyethylene included in the content model.

The theoretical density of skull oxide (**dnsoxtheo**) is **dnsoxtheo** = (**ggsoc** + **guox**) / [(**ggsoc** / **dnctheo**) + (**guox** / **dnuoxtheo**)],

where **ggsoc** (Column 8, Table 6.9.3.1-3c),
guox (Column 3, Table 6.9.3.1-3c),
dnuoxtheo is the theoretical density of U_3O_8, 8.3 g/cm^3, and
dnctheo is the theoretical density of graphite, 4.2 g/cm^3.

The hydrogen to fissile uranium ratio of canned skull (Column 5, Table 6.9.3.1-3c) is **sochtox** = {[(**gmsatm** × **wtphwat**) + (**grampoly** × **wtphpoly**)] × **atwu25**} / (**gr235** × **atwth** × 100.0),

where **gmsatm** (Column 4, Table 6.9.3.1-3c)**,**
wtphwat is the weight percent hydrogen in water, 11.1913%,
grampoly (513 g),
wtphpoly is the weight percent hydrogen in polyethylene, 14.3811%,
atwu25 is the atomic weight of ^{235}U, 235.0441,
gr235 (Column 7, Table 6.9.3.1-3c), and
atwth is the atomic weight of hydrogen, 1.0078.

The amount of water in the voided region of the CV (Column 10, Table 6.9.3.1-3c) is **gwatcv** = 0.9982 × **volvcv**,

where **volvcv** is the void volume of the CV and
volvcv = (**cvarea** × **cvih**) − (**gsoc** / **densoc**),

where **cvarea** is the internal area (129.73536 cm^2) of the CV,
cvih is the internal height (78.74 cm),
gsoc (Column 2, Table 6.9.3.1-3c), and
densoc (Table 6.9.3.1-3b).

The hydrogen to fissile uranium ratio inside the containment vessel (Column 11, Table 6.9.3.1-3c) is
htox = ⟨{[(**gmsatm** + **gwatcv**) × **wtphwat**] + [**grampoly** × **wtphpoly**]}
× **atwu25**⟩ / (**gr235** × **atwth** × 100.0),

where **gmsatm** (Column 4, Table 6.9.3.1-3c),
gwatcv is the amount of water in the voided region of CV,
wtphwat is the weight percent hydrogen in water, 11.1913%,
grampoly (513 g),
wtphpoly is the weight percent hydrogen in polyethylene, 14.3811%,
atwu25 is the atomic weight of ^{235}U, 235.0441,
gr235 (Column 7, Table 6.9.3.1-3c), and
atwth is the atomic weight of hydrogen, 1.0078.

Unirradiated TRIGA reactor fuel. TRIGA fuel is uranium zirconium hydride ($UZrH_x$), an alloy of uranium metal homogeneously dispersed as fine particles in a zirconium hydride matrix. The fuel is stable because uranium hydride does not form to any considerable extent. Moreover, uranium hydride has never been detected in the photomicrographic evaluations of TRIGA fuel.

The General Atomics catalog of stock items lists ~40 TRIGA fuel elements classified into four basic types: standard element, instrumented element, fuel-follower control rod, or cluster assembly. The TRIGA element active fuel region consists of three 5-in long sections "fuel meats" of $UZrH_x$. The H/Z atom ratio "x" in $UZrH_x$ equals 1.6 in all cases except for two stock items. For these cases, x = equals 1.0 and the fissile content is < 40 g ^{235}U. The unirradiated solid form TRIGA fuel is identified as either 20 % enriched or 70 % enriched, and has dimensions and material properties specific to its design function.

The fuel diameter for the 20 % enriched TRIGA elements is either 1.44 in., 1.41 in., 1.40 in., 1.37 in., 1.34 in., or 1.31 in. The uranium composition of the fuel is 45 wt %, 30 wt %, 20 wt %, 12 wt %, and 8.5 wt %. As illustrated in Table 6.9.3.1.4-a, the TRIGA element with a maximum fissile content of 307 g ^{235}U in 1,560 g U, 45 wt% U in $UZrH_x$, and a H/Zr atom ratio of 1.6 has a computed fuel density of ~8.66 g/cm^3. The calculated number density (N_i) for each element or isotope is also given. The TRIGA fuel element with a fuel diameter of 1.44 in. contains 3,466.7 g $UZrH_x$. Further evaluation of the manufacturers data reveals that fuel density is proportional to the uranium weight fraction. Calculated density values are: 8.6597 g/cm^3 for 45 wt% U in $UZrH_x$, 6.8995 g/cm^3 for 30 wt% U in $UZrH_x$, 6.2825 g/cm^3 for 20 wt% U in $UZrH_x$, 5.9328 g/cm^3 for 12 wt% U in $UZrH_x$, and 5.7895 g/cm^3 for 8.5 wt% U in $UZrH_x$.

The active fuel diameter for 70 % enriched TRIGA fuel is 1.44 in. in both the standard element and instrumented element, and 1.31 in. in the fuel follower control rod. The uranium composition of the fuel is 8.5 wt %. The standard element and instrumented elements contain ~136 g ^{235}U in 194 g U while the fuel follower control rod contains ~113 g ^{235}U in 162 g U. As the calculation in Table 6.9.3.1.4-b illustrates, the 70 wt % enriched TRIGA fuel has a computed density of ~5.70 g/cm^3. The TRIGA fuel element with a fuel diameter of 1.44 in. contains 2,282.4 g $UZrH_x$ while the element with a fuel diameter of 1.31 in. contains 1,888.9 g $UZrH_x$.

The clad thickness is ~0.02 in. for a TRIGA fuel element with stainless steel cladding and ~0.03 in. for an element with aluminum cladding. In preparation for shipment in the ES-3100, a TRIGA fuel element is disassembled, the fuel meats are removed from the thin cladding and packed into convenience cans.

Table 6.9.3.1-4a. Calculation of constituent weight-percentage values for 20 wt % enriched uranium-zirconium hydride content in KENO V.a calculation models

Avogadro No. (N_o) =	6.0221370E+23						
U(ZrH_x)							
atom	**wt %**	**x**	**mass (g)**	**at. wt.**		**calc. N_i**	**N_iA_i**
Hydrogen	0.9554	1.6		1.00780	1.6125	4.9439E+22	4.9824E+22
Zirconium	54.0447	1		91.21960	91.2196	3.0897E+22	2.8184E+24
u-235	19.6795		307.0	235.04410			
u-238	80.3205			238.05099			
uranium	45.0000		1560.0	237.45318	75.9535	9.8830E+21	2.3468E+24
	100.0001				168.7856		
summations	100.0001					9.0219E+22	5.2150E+24
At. wt molecule							
Volume (cm^3)	400.3200						
Mass (g)	3466.66667						
density (g/cm^3)	8.65974						
den.=($\sum N_iA_i)/N_o$							8.6597

Table 6.9.3.1-4b. Calculation of constituent weight-percentage values for 70 wt % enriched uranium-zirconium hydride content in KENO V.a calculation models

Avogadro No. (N_o) =	6.0221370E+23						
U(ZrH_x)							
atom	**wt %**	**x**	**mass (g)**	**at. wt**		**calc. N_i**	**N_iA_i**
Hydrogen	1.5894	1.6		1.00780	1.6125	5.4148E+22	5.4571E+22
Zirconium	89.9107	1		91.21960	91.2196	3.3841E+22	3.0870E+24
u-235	70.1031		136.0	235.04410			
u-238	29.8969			238.05099			
uranium	8.5000		194.0	235.93508	8.6237	1.2370E+21	2.9184E+23
	100.0001				101.4558		
summations	100.0001					8.9227E+22	3.4334E+24
At. wt molecule							
Volume (cm^3)	400.3200						
Mass (g)	2282.35294						
density (g/cm^3)	5.70132						
den.=($\sum N_iA_i)/N_o$							5.7013

The TRIGA fuel may also be configured as clad fuel rods. Each clad fuel rod will be derived from a single TRIGA fuel element by removal of the stainless steel or aluminum clad extending beyond the plenum adjacent to the axial ends of the active fuel section. Each ~15-in.-long rod consists of the 3 fuel pellets and an

exterior sheath of stainless steel or aluminum clad, where the protruding clad at each end has been crimped in. The fuel rods will be packed into stainless steel or tin-plated carbon steel convenience cans, with a maximum of three fuel rods per loaded convenience can. This shipping configuration requires a minimum of two convenience cans; where only one convenience can is loaded with clad fuel rods. The loaded can is 17.5-in. tall while the empty one is 8.75-in. tall. Although can spacers are not required for criticality control, can spacers or stainless steel pads may be used to take up free volume over the 31 in. internal height of the containment vessel. The maximum quantity of fissile material per package is 408 g ^{235}U.

The clad fuel rod with 1.44-in.-diam fuel pellets contains 2,282.4-g $_{UZrHx}$ while rod with the 1.31-in.-diam fuel pellets contains 1,888.9-g $UZrH_x$. The 0.02-in.-thick sheath of stainless steel clad adds ~179 g to the mass of the active fuel for the 1.48-in.-diam standard element or instrumented element, and ~163 g to active fuel mass for the 1.35-in.-diam fuel follower control rod. Allowance for ½ in. of residual stainless steel crimped on each end of the clad fuel rod adds ~11–12-g stainless steel to these amounts. Likewise, the 0.03 in thick sheath of aluminum clad adds ~90 g to the mass of the active fuel for the 1.47-in.-diam standard element or instrumented element. Allowance for ½ in. of residual aluminum crimped on each end of the clad fuel rod adds ~6-g aluminum.

Research reactor fuel elements or fuel components are composed of U-Al, U_3O_8-Al, or UO_2-Mg. These items contain small quantities of fissile uranium typically ranging from 4.2–152-g ^{235}U. The maximum enrichment is ~93%. Components are of various solid shapes (rods, square bars, plates, or tubes) where diameters typically range from 0.18 to 4.0 in. and cross-sections typically range from 0.05 × 1.28 in. for an individual piece and 3.14 × 3.0 in. for an assembly of pieces. The active length for the various solid shapes ranges from 19.7 to 24 in.

U_3O_8-Al fuel elements are evaluated for demonstrating that research reactor related oxide contents are bounded by limits specified for TRIGA content. An aluminum-clad THAR plate (0.224 × 7.23 × 60.96 cm) contains ~101.52212 g of uranium and the enrichment is 20% ^{235}U. Table 6.9.3.1-4c presents the calculation of density values at enrichments of 20%, 70%, and 93.2% ^{235}U using plate dimensions, uranium mass, and theoretical density values of 8.3 g/cm^3 for U_3O_8 and 2.702 g/cm^3 for aluminum.

Table 6.9.3.1-4c. Calculation of constituent weight-percentage and content density values for 20 wt %, 70 wt %, and 93.2 wt % enriched uranium oxide-aluminum content in KENO V.a calculation models [a]

	Plate dimension	(cm)	Element	at. wt.	wt %	Density (g/cm^3)	Mass (g)	
	thickness	0.224	Al	26.9818	100	2.702	-	
	width	7.230	U_3O_8	variable	100	8.3	-	
	length	60.960	U	-	-	-	101.52212	

Isotope	at. wt.	wt %	Isotope	at. wt.	wt %	Isotope	at. wt.	wt %
^{235}U	235.0442	20.0	^{235}U	235.0442	70.0	^{235}U	235.0442	93.2
^{238}U	238.0510	80.0	^{238}U	238.0510	30.0	^{238}U	238.0510	6.8
U	237.4435	84.77161	U	235.9382	84.68933	U	235.2463	84.65121
O	15.9954	15.22839	O	15.9954	15.31067	O	15.9954	15.34879
U_3O_8	840.2937	100.0	U_3O_8	835.7779	100.0	U_3O_8	833.7020	100.0

Enrichment (%)	U_3O_8 (g)	Vol $_{U3O8}$ (cm^3)	Vol $_{Al}$ (cm^3)	Vol $_{Total}$ (cm^3)	Al (g)	wt % $_{U3O8}$	wt % $_{Al}$	Density (g/cm^3)
20	119.75958	14.42886	84.29707	98.72594	227.77069	34.46019	65.53981	3.52015
70	119.87593	14.44288	84.28306	98.72594	227.73282	34.48588	65.51412	3.52095
93.2	119.92992	14.44939	84.27655	98.72594	227.71524	34.49780	65.50220	3.52132

[a] Actual material at 20% enrichment, hypothetical materials at 70% and 93.2% enrichments.

A UO_2-Mg fuel element is evaluated for demonstrating that this form of research reactor related content is also bounded by limits specified for TRIGA content. An aluminum-clad EK-10 fuel rod (2.54 cm diameter and 139.7 cm length) contains ~92.35 g of uranium dioxide, 13.03 g of magnesium and 65.7 g of aluminum as cladding. The ^{235}U content is 8.05 g with a corresponding enrichment of 9.89%. Table 6.9.3.1-4d presents the calculation of density values at enrichments of 9.89%, 20%, and 93.2% ^{235}U using rod dimensions, material masses and theoretical density values of 10.96 g/cm^3 for UO_2 and 2.702 g/cm^3 for aluminum. For UO_2 content at 93.2% ^{235}U, an oxide density of 6.54 g/cm^3 is assumed consistent with bulk densities observed for product oxides with enrichments ranging from 19–100 wt % ^{235}U.

Table 6.9.3.1-4d. Calculation of constituent weight-percentage and content density values used in KENO V.a calculation models for 9.89 wt %, 20 wt %, and 93.2 wt % enriched uranium dioxide-magnesium, aluminum clad content, and for 93.2 wt % enriched uranium dioxide content [a]

		UO_2-Mg				Active	Overall	UO_2	
				Diam (cm)		0.69017	1.00000		
				Length (cm)		50.50000	55.00000		
				Vol (cm^3)		11.85982	43.19690		
		9.88 wt % ^{235}U		20 wt % ^{235}U		93.2 wt % ^{235}U		93.2 wt % ^{235}U	
	at. wt.	wt %	Mass (g)	wt %	Mass (g)	wt %	Mass (g)	wt %	Mass (g)
^{235}U	235.04420	9.88943	8.050	20.00000	16.280	93.20000	75.865	93.20000	408.000
^{238}U	238.05100	90.11057	73.350	80.00000	65.120	6.80000	5.535	6.80000	29.768
U	237.75020	88.14018	81.400	88.12668	81.400	88.02906	81.400	88.02906	437.767
O	15.99540	11.85982	10.953	11.87332	10.967	11.97094	11.069	11.97094	59.531
UO_2	269.74100		92.353		92.367		92.469		497.298
Mg	24.30480	100.00	13.030	100.00	13.030	100.00	13.030	-	-
Al	26.98180	100.00	65.670	100.00	65.670	100.00	65.670	-	-
Total			**171.053**		**171.067**		**171.169**		**497.298**
wt % U		47.58759		47.58369		47.55534		88.02906	
wt % O		6.40328		6.41096		6.46671		11.97094	
wt % Mg		7.61752		7.61690		7.61236		-	
wt % Al		38.39161		38.38846		38.36559		-	
Density (g/cm^3)		3.95984		3.96017		2.60651		6.95000	

[a] "per rod" values cited for UO_2-Mg. Actual material at 9.9% enrichment, hypothetical materials at 20% and 93.2% enrichments. Bulk values cited for UO_2.

6.9.3.2 Type 304 Stainless Steel

The metallic components of the ES-3100 package are composed of Type 304 stainless steel. These include the containment vessel, the convenience cans, the drum liner, and the drum. Type 304 stainless steel with a density of 7.9400 g/cm^3 is included as a material in the SCALE Standard Composition Library.

6.9.3.3 277-4 Neutron Absorber

Catalog No. 277-0 dry mix is a proprietary mixture for producing a heat-resistant shielding material which combines the most effective shielding components into a single homogeneous composite. The shielding composite material is designed to maximize the hydrogen content necessary for

thermalizing fast neutrons for capture in the boron constituent. Widely used in nuclear power plant applications, the heat-resistant shielding material is capable of retaining a significant portion of its shielding properties up to 230°C (450°F). The recommended operating limit is 350°F, which is well above HAC temperatures expected inside the body weldment liner inner cavity and canned spacers.

The 277-4 neutron-absorber material used in the ES-3100 is a formulation of Cat 277-0 dry mix, a boron carbide additive, and water. 277-4 is produced through a quality-controlled batch process of dry blending, wet mixing, vibration casting, and timed cure (Equipment Specification JS-YMN3-801580-A005, Appendix 1.3.5). "Loss on drying" (LOD) tests are used to measure the amount of water in the as-manufactured 277-4 casting. The as-manufactured 277-4 at 100 lb/ft^3 and 31.8 % LOD has a hydrogen concentration of 3.56 wt % and a natural boron concentration of 4.359 wt % (DAC-PKG-801624-A001, Table 5).

The ability of 277-4 to perform its function depends upon the masses of hydrogen and ^{10}B locked inside the high alumina borated cement cast into the body weldment liner inner cavity and the spacer cans. A calculated amount of boron carbide is added to Cat 277-0 dry mix for producing as-manufactured 277-4 material with a volumetric isotopic concentration >7.621 × 10^{20} at/cm^3 of ^{10}B. The additive is boron carbide (B_4C) with small amount of a frit-like compound and trace amounts of unaccounted elements (0.17 wt %). Boron carbide has a theoretical density from 2.45 to 2.52 g/cm^3. 277-4 contains a large amount of hydrated alumina, also known as aluminum trihydrate [$Al(OH)_3$]. It is a nonabrasive powder with a specific gravity of 2.42. Given that both materials are of like density and similar particle size, separation and in homogeneity of 277-4 material is not expected during the controlled vibration casting process.

Table 6.9.3.3-1 provides detailed elemental composition data derived for as-manufactured neutron-absorber material at 100 lb/ft^3 and 31.8% LOD. This material description allows for clear specification of reduced boron and water contents required in the evaluation of NCT and HAC. As shown in Table 6.9.3.3-1, both the water and boron components are extracted from the material specification for the neutron absorber, and the constituent weight percents are recalculated accordingly (green box). 277-4 is specified in KENO V.a as three arbitrary materials: **arbmnpmx** with a density of 1.02276 g/cm^3, **arbmnph2o** with a density of 0.509253 g/cm^3, and **arbmboron** with a density of 6.98257E-02 g/cm^3. Model densities for 277-4 inside the body weldment liner inner cavity are reduced by a factor of 0.966893 to account for a material gap at the top of the liner. This material description allows for clear specification of reduced boron and water contents required in the evaluation of NCT and HAC.

The testing of 277-4 reveals that the material will dehydrate at elevated temperatures. Test specimens were dried at 250°F for 168 hours to reach the NCT state, and weight measurements were taken. These specimens where subsequently heated to 320°F for 4 hours to reach the HAC state, and weight measurements were again taken. The compositions of 277-4 at NCT and HAC states were derived by adjustment of the formulation specification for measured losses taking into account the statistical variations in the data. Conservation of mass for nonvolatile materials was observed in the derivation of material specifications based upon testing. Given that hydrogen must be present for the neutron absorber to be effective, conservative material specifications were derived for minimum hydrogen content and minimum material density.

Tables 6.9.3.3-2 and 6.9.3.3-3 respectively provide NCT and HAC composition data for as-manufactured 277-4 material at minimum density and hydrogen content. Respectively, Tables 6.9.3.3-4 and 6.9.3.3-5 provide NCT and HAC composition data or as-manufactured neutron-absorber material at minimum density and boron content. Because the amount of ^{10}B present in the neutron-absorber material is near saturation, a change in the hydrogen concentration has a major effect on the neutron multiplication factor, while a change in the amount of boron has a minor effect.

The neutron-absorbing material used in the ES-3100 Shipping Package will perform as analyzed. The analysis of 277-4 with criticality calculations is adequate in lieu of neutron transmission testing for the demonstration of acceptable performance by experimental means. Criticality calculations show boron content is adequate and k_{eff} is not dependent on absolute (microscopic) homogeneity. Geometry characteristics of the ES-3100 system preclude the need for uniformity in boron areal density as a prerequisite for criticality safety control. The neutron-absorbing material will be fabricated under strict quality control and accepted for use under an NQA-1 compliant quality assurance (QA) program. A QA-approved mixing process provides a method for creating an exact mix for the neutron absorber during ES-3100 fabrication. An important part of this QA-approved process is a 277-4 material verification and acceptance testing program. The following discussion elaborates on these key points:

The analysis of 277-4 with criticality calculations is adequate in lieu of neutron transmission testing for the demonstration of acceptable performance. Early on in the licensing process, BoroBond 4 ™ was selected as the neutron-absorber material for use in the ES-3100 package. The decision to use BoroBond 4 ™ in the ES-3100 was made because of favorable experience with its use in the Highly Enriched Uranium Materials Facility Rackable Can Storage Box (RCSB). From an economic standpoint, however, BoroBond 4 ™ proved not to be a viable option for the small quantities needed for the ES-3100 project. 277-4 neutron-absorber material, which has very similar nuclear material properties to BoroBond 4 ™, was then selected as an alternative.

Both the RCSB and the ES-3100 are fast systems in the normal condition when the HEU fissile material is essentially unmoderated. A key factor for an effective neutron absorber is that hydrogen should be present for moderation, and it should be interspersed with ^{10}B, thus promoting neutron capture. The potential for neutron streaming through an absorber is significant when a hydrogenous moderator is absent, as in the case of an aluminum boron-carbide matrix (a Boral alloy).

BoroBond 4 is a ceramicrete material with slightly greater than 4 wt % boron carbide (B_4C). The boron carbide powder is micro encapsulated by the crystalline matrix of the ceramic; therefore, leaching out the boron is not feasible. In BoroBond 4, 100 wt % of the B_4C has a particle size <500 µm; 90 wt % of the other constituents range from <164 µm to <36 µm. Given the differences in particle size, the potential for separation in the mixing process is real.

Some of the questions regarding the use of 277-4 as a neutron poison in the ES-3100 were previously addressed regarding the use of BoroBond 4 in the RCSB. Radiography was performed on BoroBond 4 samples ranging in thickness from 1.0 to 1.5 in. Inspections revealed little or no visual differences, indicating uniformity of the BoroBond 4. For 277-4 where the B_4C grit is on the order of 100 µm, the potential for separation is reduced.

Table 6.9.3.3-1. Calculation of constituent weight-percentage values used in KENO V.a calculation models for as-manufactured 277-4 at minimum acceptable density and boron content

			arbmboron	arbmnpmx	arbmnph2o			**arbmboron**	**arbmnpmx**	**arbmnph2o**
31.8% LOD	At. wt	lb/ft^3	lb/ft^3	lb/ft^3	lb/ft^3		**NID**	**wt %**	**wt %**	**wt %**
H	1.0078	3.5579			3.5579	H	1001			11.1913%
B10	10.0129	0.7911	0.7911			B10	5010	18.1482%		
B11	11.0093	3.5680	3.5680			B11	5011	81.8518%		
C	12.0000	1.2251		1.2251		C	6012		1.9187%	
N	14.0031	0.0090		0.0090		N	7014		0.0141%	
O	15.9949	55.9620		27.7281	28.2339	O	8016		43.4275%	88.8087%
Na	22.9895	0.0750		0.0750		Na	11023		0.1175%	
Mg	24.3051	0.2156		0.2156		Mg	12000		0.3377%	
Al	26.9818	24.9306		24.9306		Al	13027		39.0461%	
Si	28.0853	1.5752		1.5752		Si	14000		2.4671%	
S	32.0636	0.1969		0.1969		S	16000		0.3084%	
Ca	40.0803	7.5553		7.5553		Ca	20000		11.8331%	
Fe	55.8447	0.3383		0.3383		Fe	24000		0.5298%	
Totals		100.0000	4.3591	63.8491	31.7918			100.00%	100.00%	100.00%
H_2O	18.0105									
density (g/cm^3)		1.601838E+00	6.982572E-02	1.022759E+00	5.092532E-01	spacer density (g/cm^3)	1.601838E+00	6.98257E-02	1.02276E+00	5.09253E-01
						liner density (g/cm^3)	1.548806E+00	6.75140E-02	9.88899E-01	4.92393E-01
						liner den. multiplier	0.966893			

Source: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 5.

Table 6.9.3.3-2. Calculation of constituent weight-percentage values used in KENO V.a calculation models for NCT as-manufactured 277-4 at minimum density and hydrogen content

			arbmboron	arbmnpmx	arbmnph2o			**arbmboron**	**arbmnpmx**	**arbmnph2o**
	At. wt	lb/ft^3	lb/ft^3	lb/ft^3	lb/ft^3		**NID**	**wt %**	**wt %**	**wt %**
H	1.0078	2.6840			2.6840	H	1001			11.1913%
B10	10.0129	0.8282	0.8282			B10	5010	18.1479%		
B11	11.0093	3.7354	3.7354			B11	5011	81.8520%		
C	12.0000	1.2826		1.2826		C	6012		1.9189%	
N	14.0031	0.0094		0.0094		N	7014		0.0141%	
O	15.9949	50.3252		29.0262		O	8016		43.4251%	
O	15.9949				21.2990	O	8016			88.8087%
Na	22.9895	0.0785		0.0785		Na	11023		0.1174%	
Mg	24.3051	0.2258		0.2258		Mg	12000		0.3378%	
Al	26.9818	26.1004		26.1004		Al	13027		39.0479%	
Si	28.0853	1.6491		1.6491		Si	14000		2.4672%	
S	32.0636	0.2061		0.2061		S	16000		0.3083%	
Ca	40.0803	7.9098		7.9098		Ca	20000		11.8336%	
Fe	55.8447	0.3541		0.3541		Fe	24000		0.5298%	
Totals		95.3886	4.5636	66.8420	23.9830			100.00%	100.00%	100.00%
H_2O	18.0105									
density (g/cm^3)		1.527971E+00	7.310148E-02	1.070700E+00	3.841692E-01	spacer density (g/cm^3)	1.527971E+00	7.31015E-02	1.07070E+00	3.84169E-01
						liner density (g/cm^3)	1.477385E+00	7.06813E-02	1.03525E+00	3.71451E-01
						liner den. multiplier	0.966893			

Source: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 11.

Table 6.9.3.3-3. Calculation of constituent weight-percentage values used in KENO V.a calculation models for HAC as-manufactured 277-4 at minimum density and hydrogen content

			arbmboron	arbmnpmx	arbmnph2o			**arbmboron**	**arbmnpmx**	**arbmnph2o**
	At. wt	lb/ft^3	lb/ft^3	lb/ft^3	lb/ft^3		**NID**	**wt %**	**wt %**	**wt %**
H	1.0078	2.6758			2.6758	H	1001			11.1913%
B10	10.0129	0.8282	0.8282			N10	5010	18.1479%		
B11	11.0093	3.7354	3.7354			N11	5011	81.8520%		
C	12.0000	1.2826		1.2826		V	6012		1.9188%	
N	14.0031	0.0094		0.0094		N	7014		0.0141%	
O	15.9949	50.2605		29.0265		O	8016		43.4254%	
O	15.9949				21.2340	O	8016			88.8087%
Na	22.9895	0.0785		0.0785		Na	11023		0.1174%	
Mg	24.3051	0.2258		0.2258		,g	12000		0.3378%	
Al	26.9818	26.1004		26.1004		Al	13027		39.0477%	
Si	28.0853	1.6491		1.6491		Si	14000		2.4671%	
S	32.0636	0.2061		0.2061		S	16000		0.3083%	
Ca	40.0803	7.9098		7.9098		Ca	20000		11.8335%	
Fe	55.8447	0.3541		0.3541		Fe	24000		0.5298%	
Totals		95.3157	4.5636	66.8423	23.9098			100.00%	100.00%	100.00%
H_2O	18.0105									
density (g/cm^3)		1.52680E+00	7.31015E-02	1.07071E+00	3.82995E-01	spacer density (g/cm^3)	1.52680E+00	7.31015E-02	1.07071E+00	3.82995E-01
						liner density (g/cm^3)	1.47626E+00	7.06813E-02	1.03526E+00	3.70316E-01
						liner den. multiplier	0.966893			

Source: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 12.

Table 6.9.3.3-4. Calculation of constituent weight-percentage values used in KENO V.a calculation models for NCT as-manufactured 277-4 at minimum density and boron content

			arbmboron	arbmnpmx	arbmnph2o
	At. wt	lb/ft^3	lb/ft^3	lb/ft^3	lb/ft^3
H	1.0078	2.9617			2.9617
B10	10.0129	0.7911	0.7911		
B11	11.0093	3.5680	3.5680		
C	12.0000	1.2251		1.2251	
N	14.0031	0.0090		0.0090	
O	15.9949	51.2291		27.7264	
O	15.9949				23.5027
Na	22.9895	0.0750		0.0750	
Mg	24.3051	0.2156		0.2156	
Al	26.9818	24.9306		24.9306	
Si	28.0853	1.5752		1.5752	
S	32.0636	0.1969		0.1969	
Ca	40.0803	7.5553		7.5553	
Fe	55.8447	0.3383		0.3383	
Totals		94.6709	4.3591	63.8474	26.4644
H_2O	18.0105				
density (g/cm^3)		1.516474E+00	6.982572E-02	1.022731E+00	4.239172E-01

		arbmboron	arbmnpmx	arbmnph2o
	NID	**wt %**	**wt %**	**wt %**
H	1001			11.1913%
B10	5010	18.1482%		
B11	5011	81.8517%		
C	6012		1.9188%	
N	7014		0.0141%	
O	8016		43.4260%	
O	8016			88.8087%
Na	11023		0.1175%	
Mg	12000		0.3377%	
Al	13027		39.0472%	
Si	14000		2.4671%	
S	16000		0.3084%	
Ca	20000		11.8334%	
Fe	24000		0.5299%	
		100.00%	100.00%	100.00%
spacer density (g/cm^3)	1.516474E+00	6.98257E-02	1.02273E+00	4.23917E-01
liner density (g/cm^3)	1.466269E+00	6.75140E-02	9.88872E-01	4.09883E-01
liner den. multiplier	0.966893			

Source: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 13.

Table 6.9.3.3-5. Calculation of constituent weight-percentage values used in KENO V.a calculation models for HAC as-manufactured 277-4 at minimum density and boron content

			arbmboron	arbmnpmx	arbmnph2o			arbmboron	arbmnpmx	arbmnph2o
	At. wt	lb/ft^3	lb/ft^3	lb/ft^3	lb/ft^3		NID	wt %	wt %	wt %
H	1.0078	2.9524			2.9524	H	1001			11.1913%
B10	10.0129	0.7911	0.7911			B10	5010	18.1482%		
B11	11.0093	3.5680	3.5680			B11	5011	81.8517%		
C	12.0000	1.2251		1.2251		C	6012		1.9188%	
N	14.0031	0.0090		0.0090		N	7014		0.0141%	
O	15.9949	51.1551		27.7262		O	8016		43.4258%	
O	15.9949				23.4289	O	8016			88.8087%
Na	22.9895	0.0750		0.0750		Na	11023		0.1175%	
Mg	24.3051	0.2156		0.2156		Mg	12000		0.3377%	
Al	26.9818	24.9306		24.9306		Al	13027		39.0473%	
Si	28.0853	1.5752		1.5752		Si	14000		2.4671%	
S	32.0636	0.1969		0.1969		S	16000		0.3084%	
Ca	40.0803	7.5553		7.5553		Ca	20000		11.8334%	
Fe	55.8447	0.3383		0.3383		Fe	24000		0.5299%	
Totals		94.5876	4.3591	63.8472	26.3813			100.00%	100.00%	100.00%
H_2O	18.0105									
density (g/cm^3)		1.515140E+00	6.982572E-02	1.022728E+00	4.225861E-01	spacer density (g/cm^3)	1.515140E+00	6.98257E-02	1.02273E+00	4.22586E-01
						liner density (g/cm^3)	1.464979E+00	6.75140E-02	9.88869E-01	4.08596E-01
						liner den. multiplier	0.966893			

Source: G. A. Byington, *Mixing Weights and Elemental Composition of 277-4 Neutron Poison Used in the ES-3100*, DAC-PKG-801624-A001, BWXT Y-12, Y-12 National Security Complex, Jan. 25, 2006, Table 14.

Measurements from neutron transmission tests on BoroBond 4 ™ for determination of areal density indicated greater boron content than was physically present. This is due to the presence of elements besides the aluminum and boron (principally hydrogen, oxygen and other low and intermediate-Z elements). Given the similarity of 277-4 to BoroBond 4 ™ (a ceramic-cement composite shielding material, with a similar elemental composition, more uniform particle size, and the same boron content), the 75% credit for boron content applied in the ES-3100 criticality calculations is an adequate enough correction for the efficiency of the material.

Criticality calculations show boron content is adequate and k_{eff} is not dependent on absolute (microscopic) homogeneity. The boron concentration calculations presented here model an infinite array of ES-3100 packages with the boron concentration of Cat 277-4 uniformly varied inside the body weldment inner liner. While the Cat 277-4 described herein is an earlier formulation of the neutron-absorber material, the behavior characteristics being demonstrated for Cat 277-4 apply to the revised formulation, 277-4.

Credit for only 75% of the boron is taken in the specification of Cat 277-4. Each package in the array contains 2.774 kg of ^{235}U in broken metal form uniformly distributed inside the containment vessel. The presence of just the hydrogenous cement matrix in the inner liner reduces k_{eff} to 1.132 from a value of 1.35 without the cement matrix. As an initial 1 wt % natural boron is added to the high alumina cement system (Table 6.9.3.3-6), the calculated k_{eff} based on 75% of the boron present drops significantly. Cat 277-4 with 4.2284 wt % natural boron in the minimum cast density of 100 lb/ft^3 (1.60 g/cc) has an acceptable mixture concentration, generating a k_{eff} of 0.88. The saturation value for boron content is reached at ~8 wt %. This near doubling of the boron content results in ~4% decrease in k_{eff} to an asymptotic value of ~0.85.

The density of Cat 277-4 is the sum of constituent densities: the boron density, the base-material density, and the water density. In the calculation model, the density of water in Cat 277-4 is 0.48210 g/cm^3 (not shown in Table 6.9.3.3-6). Canned spacers are omitted from the calculation model. Credit for only 75% of the boron is taken in each parametric calculation. The volume of the 277-4 in the body weldment inner liner cavity is 1.32708×10^4 cm^3.

Table 6.9.3.3-6. Effect of boron concentration on array neutron multiplication

100%B (wt %)	Boron density (g/cm^3)	Base material density (g/cm^3)	NP277-4 mass (g)	Case name	$k_{eff} \pm 2\sigma$ (@75% B)
0.01	0.00016	1.11775	2.12326E+04	nbiabm_kvsb_1	1.13199 +/- 0.00138
0.1	0.0016	1.11631	2.12279E+04	nbiabm_kvsb_2	1.07944 +/- 0.00145
1	0.016	1.10191	2.11801E+04	nbiabm_kvsb_3	0.95564 +/- 0.00129
2	0.032	1.08591	2.11270E+04	nbiabm_kvsb_4	0.91708 +/- 0.00135
3	0.048	1.06991	2.10739E+04	nbiabm_kvsb_5	0.89396 +/- 0.00117
4.2284	0.068614	1.04930	2.10056E+04	nbiabm_kvsb_6	0.87985 +/- 0.00145
6	9.6000E-02	1.02191	2.09147E+04	nbiabm_kvsb_7	0.86029 +/- 0.00151
8	1.2800E-01	0.98991	2.08085E+04	nbiabm_kvsb_8	0.84769 +/- 0.00150
10	0.16	0.95791	2.07024E+04	nbiabm_kvsb_9	0.84086 +/- 0.00142

NUREG 1609 recommended that only 75% of the minimum boron density be credited in criticality evaluation in order to address the issue of non-homogeneity of 10B in the neutron-absorber material. The boron non-homogenity calculations presented here model an infinite array of ES-3100

packages with the boron concentration of Cat 277-4 varying along the vertical height of the body weldment inner liner. However, the total amount of boron in each package is fixed. Each package in the array contains 2.774 kg of 235U in broken metal form uniformly distributed inside the containment vessel. Two sets of calculations are evaluated with this model to address the effects of boron distribution in the ES-3100 inner liner.

In one set of cases, the inner cavity is divided vertically into three equal-volume regions. The density in one region is increased to 95% of the minimum boron density, while the boron density in the other two regions is decreased to 65%, thus preserving the amount of neutron-absorber material in the package. In the other set of cases, the inner cavity is divided vertically into four equal volume regions, but two regions are combined. This creates two quarter-sized regions and one half-size region. The density in the half-size region is increased to 95% of the minimum boron density, while the density in the quarter-sized regions is decreased to 55%, thus preserving the amount of neutron absorber in the package. In both sets of calculations, the high-density region was shifted upward in the package to examine the effect of boron distribution.

As shown in Figs. 6.9.3.3-2 and 6.9.3.3-3, the effect of non-homogeneity of boron in the ES-3100 liner on k_{eff} is not statistically significant. The "65% - 95% - 65%" nonhomogeneous boron distribution represents a relative standard deviation of 23.1% in boron concentration. Given the controls on method of manufacture and installation of the neutron-absorber material, these calculated conditions bound the expected physical distribution of boron with a large degree of conservatism.

Geometry characteristics of the ES-3100 system preclude the need for uniformity in boron areal density as a prerequisite for criticality safety control. The U.S. Nuclear Regulatory Commission provides crucial guidance in SFST-ISG-15 for controlling areal density in a geometry configuration where one-dimensional effects are significant, such as a distributed source separated by thin Boral sheets (aluminum and boron carbide) which range in thickness from 0.075 to 0.4 in. In this example, Boral aluminum sheets are placed between fissile fuel rods just a few inches away and only become efficient when the low-enriched fissile material is placed in a sea of hydrogenous moderator. The cylindrical thickness of the ES-3100 cast neutron-absorber material (Cat 277-4) is 1.12 in., which is about three times thicker than the largest Boral sheet. Its purpose in the ES-3100 is to provide criticality safety control for arrays of packages.

In the ES-3100, the proposed fissile mass loads are separated by at least one drum diameter (19.36 in.). Drawing M2E801580A031 in Appendix 1.3.7 shows the cross-section view of the many different layers of materials that are between the fissile mass loads in adjacent packages in an array. The direct neutron transport path between dispersed fissile material (assuming a neutron passes through the following thickness of materials at a normal angle to the closest neighboring package) is:

- fissile material,
- 0.100 in. Type 304 stainless-steel containment vessel wall,
- air gap,
- 0.06 in. Type 304 stainless-steel inner liner wall,
- 1.12 in. of 277-4 neutron-absorber material,
- 0.06 in. Type 304 stainless-steel outer liner wall,
- 4.77 in. of Kaolite,
- 0.06 in. Type 304 stainless-steel outer drum wall, and
- air gap,

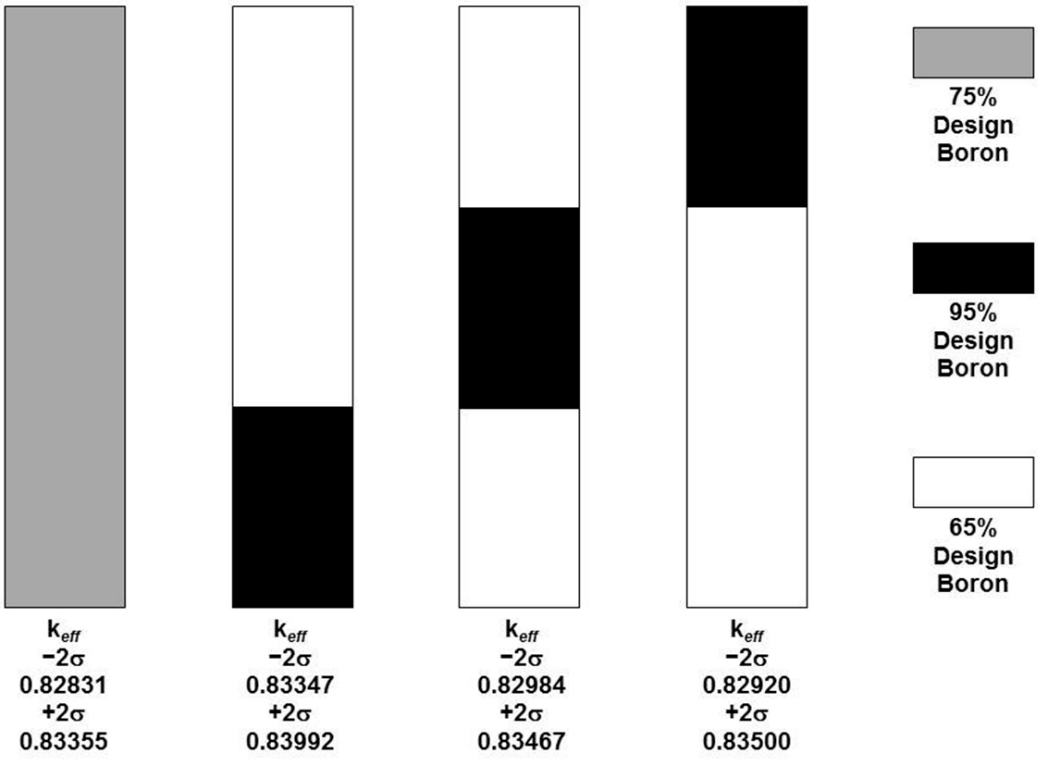


Fig. 6.9.3.3-2. Three equal-region models for evaluation of non-homogeneity in the boron distribution.

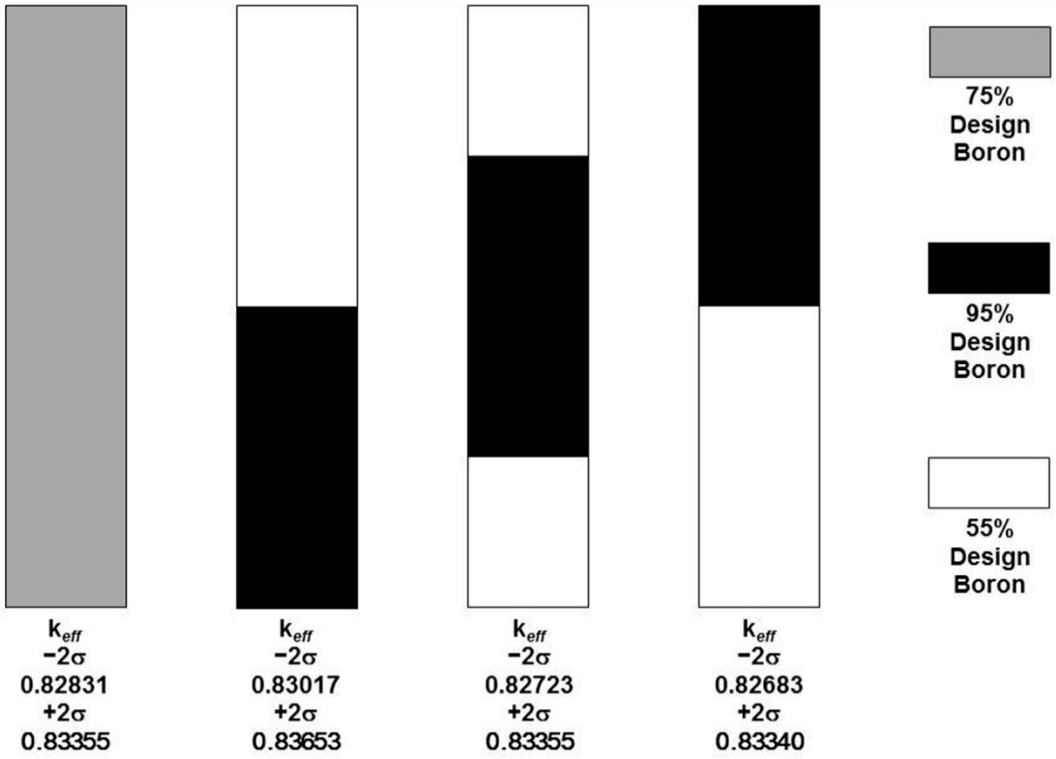


Fig. 6.9.3.3-3. Non-uniform region model for evaluation of non-homogeneity in the boron distribution.

followed by the reverse:

- 0.06 in. stainless-steel outer drum wall,
- 4.77 in. of Kaolite,
- 0.06 in. Type 304 stainless-steel outer liner wall,
- 1.12 in. of 277-4 neutron-absorber material,
- 0.06 in. Type 304 stainless-steel inner liner wall,
- air gap,
- 0.100 in. Type 304 stainless-steel containment vessel wall, and
- back into a fissile material.

At the shortest distance between fissile materials, neutrons travel through the 1.12 in. (2.8448 cm) of 277-4 neutron-absorber material and 0.28 in. (0.7112 cm) of Type 304 stainless steel at least twice, with the high probability of several neutron scattering collisions along the way. Thus, the mean free path in the package is much smaller than the separation between the fissile material of adjacent packages.

In contrast to a Boral sheet application, the neutron-absorber component of the ES-3100 package physically represents a significant fraction of the total container volume and is large in comparison to the potential fissile material volume. Furthermore, the neutron-absorber component consists of boron dispersed throughout a hydraulic cement matrix with a high neutron scattering potential. The net result is that sensitivity to angular and spatial variations in the areal density of ^{10}B in the neutron-absorber volume is eliminated.

The calculation model for a 277-4 canned spacer was developed based on available information at the time of the initial design. The dimensions of the 277-4 filler are 4.13 in. for the diameter and 1.4 in. for the height with a resultant volume of 307.34 cm^3. Based on a density of 95.3886 lb/ft^3 (1.527971 g/cm^3), the amount of 277-4 represented in the calculation model is 469.61 g. As shown on Drawing M2E801580A043 (Appendix 1.3.7), the outer diameter of the stainless-steel can is 4.13 ± 0.09 in. and the height for the 277-4 filler is 1.37 ± 0.06 in. The wall thickness for the 30 gauge stainless steel is 0.012 in. The actual minimum volume of the 277-4 filler is 271.93 cm^3 based on this acceptance criteria. For cast material having a nominal density of 105 lb/ft^3 (1.68193 g/cm^3), the actual minimum amount of 277-4 present in a canned spacer is 457.36 g. An excess 12.25 g of neutron poison in the calculation model on which criticality safety is based is insignificant. Nevertheless, results of additional calculations are presented for demonstrating this fact.

A set of Cases **hciabmt12** establishing loading limits for broken metal were selected from Table 6.9.6-11. These cases based on the nominal 277-4 canned spacer were rerun using SCALE5 and are identified in Table 6.9.6-11d as reference Cases **5hciabmt12**. The corresponding cases for revised calculation model with 277-4 canned spacer sized per the minimal acceptance criteria are identified in Table 6.9.6-11d as Cases **5_401by131**. The minimum dimensions of the 277-4 filler in these cases are 4.01 in. for the diameter and 1.31 in. for the height; the amount of amount of 277-4 represented is 415 g. A statistically significant difference between case results for a configuration with the nominal canned spacer and one with the minimum-sized spacer occurs if the absolute value of the quantity "$\mathbf{(\Delta k_{eff}+2\sigma)/\sigma}$" is >3. As shown in Table 6.9.6-11d, the differences are statistically insignificant; therefore, loadings limits are adequate for content configurations with the canned spacer sized per the minimum acceptance criteria.

The neutron-absorbing material will be fabricated under strict quality control and accepted for use under an NQA-1 compliant QA program. The original equipment specification for the production of 277-4 neutron-absorber material used a proprietary mixture from the Thermo Electron Corporation that combined high alumina cement and a boron grit (Cat 277-4). The manufacturing process for the neutron

absorber was revised in order to obtain details necessary for material characterization and to achieve process control for ensuring consistency of absorber material among lots.

A two-part system of dry-blend components is now employed rather than relying on a single base material (a premixed powder of high alumina cement and boron grit). The vendor's proprietary high-alumina cement without boron grit (Cat 277-0) is mixed with boron carbide by the ES-3100 manufacturer under strict quality controls. A single batch is mixed on a per package basis. The boron carbide used in this process is strictly controlled. Boron carbide is specified as Type 1 material per ASTM C 750, "Nuclear-Grade Boron Carbide Powder." The particle size is controlled in accordance with JS-YMN5-801580-A003, Sect. 3.3.1.2.

The revised formulation designated "277-4" is produced through a quality-controlled batch process of dry blending, wet mixing, vibration casting, and timed cure (JS-YMN3-801580-A005, Appendix 1.3.5). The plan is to control the purity, boron carbide particle size, chemistry, measurements, weights, mixing, recording, casting, and testing using one batch per each shipping package (and its two companion spacer cans). A design analysis calculation shows all of the calculations used in mixing and determines (from the minimum acceptable chemical purities) the volumetric densities in g/cm^3 and an areal density in g/cm^3 of ^{10}B (DAC-PKG-801624-A001). These values will prove the acceptability of the mixing specifications.

An important part of this approach is a QA-approved 277-4 material verification and acceptance testing program. The applicant plans on performing 100% acceptance testing on the criticality safety significant properties of density, ^{10}B interaction (neutron absorption), and hydrogen content. The acceptance density shall be the as cast density in the drum to 105−5+10 lb/ft^3 and shall be determined as shown in Appendix 1.3.5. To test the other properties, two companion sample cans shall be cast from each batch used to cast a shipping container (the manufacturer will cast a fresh batch for each shipping container). The companion sample cans shall also have their density verified. The ^{10}B interaction will be tested in the manner described in Appendix A of the 277-4 specification (Appendix 1.3.5). Initially, a set of 277-4–certified cans will be cast using the proposed casting specification with the QA plan described previously. Then, on a companion sample can for each batch pour, a prompt gamma-ray neutron activation analysis (PGNAA) test will be used to neutronically test the ^{10}B for absorption. To pass the PGNAA test, the sample can results must be within the results obtained for the 277-4 certified standards, in units of Average Net Count rate (ANC/second) ±3 standard deviations. The second companion sample can will be used to test for hydrogen content using an LOD test as described in Appendix 1.3.5. Upon successful completion of the density, PGNAA, and LOD testing, the ES-3100 neutron-absorber material will be accepted for use.

6.9.3.4 Kaolite 1600

Kaolite 1600, manufactured by Thermal Ceramics of Augusta, Georgia [telephone number (404) 796-4200], is a super-lightweight, low thermal conductivity, castable material designed for backup insulation up to 1600°F. The material is obtained as a dry powder with the chemical composition given in Table 6.9.3.4-1. The powder is mixed with water in a water-to-powder ratio of 14.5 qt per 20-lb bag. The mixture is poured into the drum body weldment or top plug, vibrated to eliminate voids, and then dried and fired to form the finished product (Y/EN-5984). The density of the fired material is ~25 lb/ft^3. It is assumed that the wet mixture contains the maximum water possible. This value (14.5 qt per 20 lb) is therefore used to determine the maximum water content of the fired product,

$$S.G._{max} = \frac{14.5\ qt}{20\ lb\ dry} \times \frac{25\ lb}{ft^3} \times \frac{0.946\ L}{1\ qt} \times \frac{998.2\ g}{L} \times \frac{35.32\ ft^3}{10^6\ cm^3} = \frac{0.6045\ g}{cm^3}$$

Table 6.9.3.4-1. Kaolite 1600 chemical composition, percent fired basis

Component	Weight percent	Component	Weight percent
Al_2O_3	9.6	CaO	30.7
SiO_2	36.7	MgO	13.1
Fe_2O_3	6.7	Na_2O	2.0
TiO_2	1.2		

Tables 6.9.3.4-2 and 6.9.3.4-3 provide detailed information regarding the weight measurements taken during the casting of Kaolite 1600 for the production of a series of drum body weldment and top plug parts for a similar package (the CNS Model ES-2100). The mean values for the amount of Kaolite and water present after baking are 107.08 lb of Kaolite and 4.8 lb of water in the drum body weldment, and 16.99 lb of Kaolite and 0.58 lb of water in the top plug. An ES-2100 package contains, on the average, 124.07 lb (56,276.91 g) of Kaolite and 5.38 lb (2,440.32 g) of water. Given that the average volume is 5.72 ft^3, the average density of Kaolite is 22.63 lb/ft^3 (0.3625 g/cm^3).

The volume of the Kaolite region in the KENO models is 1.63417×5 cm^3. For NCT, the density of Kaolite is 0.34438 g/cm^3, and the density of water is 0.01493 g/cm^3. The data in Tables 6.9.3.4-2 and 6.9.3.4-3 indicate that the Kaolite may have as little as 1.90 lb (861.82 g) of water after baking (Part Serial Number 97) such that the corresponding density of water is 0.00527 g/cm^3. For the water-flooded HAC, the amount of water is assumed not to exceed the amount present before baking. The package would contain on the average 186.10 lb (84,413.1 g) of water such that the corresponding density is 0.51655 g/cm^3. The full range of NCT and HAC conditions would be covered by a variation of water in the Kaolite from 0 g/cm^3 to 0.51655 g/cm^3 in a calculation model.

The Kaolite components of ES-3100 shipping package had not been manufactured at the time this criticality safety evaluation was performed. Given the lack of production data for ES-3100 Kaolite, a material specification (mass and density) was derived from data for ES-2100 production units. This specification, denoted “as-manufactured” (AM) Kaolite, was used for the ES-3100 criticality calculations. This ES-2100 shipping package is similar in design to the ES-3100 currently being evaluated.

The Kaolite production process was re-evaluated and improved following the production of ES-3100 units (Y/DW-1890). Test samples were produced. These were classified into three groups: high density, medium density, and low density. The predominate number of samples fell into the medium density category (22.04 lb/ft^3), representing the expected, improved Kaolite production process (Y/DW-1890, Table 5). A material specification for use in criticality calculations was derived from the medium density “test sample” (TS) Kaolite data. However, the TS data are based on small sample volumes, whereas the AM data represents the entire package. Taking into consideration both the potential for scaling error and the uncertainty of how representative the test samples are of the manufactured ES-2100 units, the criticality safety packaging analysts chose to utilize the material specification derived from AM data rather than TS data in the criticality calculations for the ES-3100 safety analysis report for packaging.

Table 6.9.3.4-2. Fabrication data, before and after baking the drum body weldment parts of the ES-2100 shipping package

Part Serial Number	Clean and empty (lb)	Filled with water (lb)	Before baking (lb)	After baking (lb)	Density after baking (lb/ft^3)	Water conditions (lb)	Volume (ft^3)	Before baking			After baking		
								Kaolite and water (lb)	Kaolite (lb)	Water (lb)	Kaolite and water (lb)	Kaolite (lb)	Water (lb)
97	87.5	393.5	356.5	197.0	22.29	306.00	4.91	269.00	107.60	161.40	109.50	107.60	1.90
98	87.5	393.5	356.5	198.5	22.60	306.00	4.91	269.00	107.60	161.40	111.00	107.60	3.40
54	87.5	395.0	356.5	199.0	22.59	307.50	4.94	269.00	107.60	161.40	111.50	107.60	3.90
87	87.5	394.0	353.5	196.5	22.16	306.50	4.92	266.00	106.40	159.60	109.00	106.40	2.60
2	88.0	394.0	360.0	202.5	23.31	306.00	4.91	272.00	108.80	163.20	114.50	108.80	5.70
4	88.0	395.5	360.0	203.0	23.30	307.50	4.94	272.00	108.80	163.20	115.00	108.80	6.20
42	88.0	394.5	356.5	199.5	22.66	306.50	4.92	268.50	107.40	161.10	111.50	107.40	4.10
43	88.0	396.0	357.5	198.0	22.25	308.00	4.94	269.50	107.80	161.70	110.00	107.80	2.20
94	87.0	393.5	361.5	205.0	23.99	306.50	4.92	274.50	109.80	164.70	118.00	109.80	8.20
35	88.0	394.5	363.5	208.0	24.39	306.50	4.92	275.50	110.20	165.30	120.00	110.20	9.80
3	87.0	393.0	364.0	206.0	24.23	306.00	4.91	277.00	110.80	166.20	119.00	110.80	8.20
44	88.0	394.0	356.5	204.5	23.72	306.00	4.91	268.50	107.40	161.10	116.50	107.40	9.10
32	88.0	396.0	355.0	198.5	22.35	308.00	4.94	267.00	106.80	160.20	110.50	106.80	3.70
33	87.5	394.0	351.0	197.5	22.36	306.50	4.92	263.50	105.40	158.10	110.00	105.40	4.60
58	87.5	394.5	351.5	196.5	22.12	307.00	4.93	264.00	105.60	158.40	109.00	105.60	3.40
4	87.5	394.0	343.0	192.5	21.34	306.50	4.92	255.50	102.20	153.30	105.00	102.20	2.80
22	87.5	394.5	352.0	196.0	22.02	307.00	4.93	264.50	105.80	158.70	108.50	105.80	2.70
27	88.0	395.5	352.5	196.5	21.98	307.50	4.94	264.50	105.80	158.70	108.50	105.80	2.70
28	87.5	394.5	350.5	199.0	22.63	307.00	4.93	263.00	105.20	157.80	111.50	105.20	6.30
30	87.5	395.0	352.0	200.0	22.79	307.50	4.94	264.50	105.80	158.70	112.50	105.80	6.70
27	88.0	395.5	352.5	196.5	21.98	307.50	4.94	264.50	105.80	158.70	108.50	105.80	2.70
Mean	87.67	394.50	355.36	199.55	22.72	306.83	4.93	267.69	107.08	160.61	111.88	107.08	4.80
Std. dev.					0.8132						100%	95.71%	4.29%
Computed on means					22.72	306.83	4.93	267.69	107.08	160.61	111.88	107.08	4.80

Table 6.9.3.4-3. Fabrication data, before and after baking the top plug parts of the ES-2100 shipping package

Part Serial Number	Clean and empty (lb)	Filled with water (lb)	Before baking (lb)	After baking (lb)	Density after baking (lb/ft^3)	Water conditions (lb)	Volume (ft^3)	Before baking			After baking		
								Kaolite and water (lb)	Kaolite (lb)	Water (lb)	Kaolite and water (lb)	Kaolite (lb)	Water (lb)
97	10.5	60.0	53.5	28.5	22.65	49.50	0.79	43.00	17.20	25.80	18.00	17.20	0.80
83	10.5	59.0	50.5	27.0	50.50	27.00	50.50	27.00	16.00	24.00	16.00	24.00	16.00
86	10.5	60.0	50.5	27.5	21.40	49.50	0.79	40.00	16.00	24.00	17.00	16.00	1.00
87	10.5	59.0	53.0	28.5	23.12	48.50	0.78	42.50	17.00	25.50	18.00	17.00	1.00
28	11.0	59.0	53.0	28.5	22.71	48.00	0.77	42.00	16.80	25.20	17.50	16.80	0.70
23	10.5	59.5	52.5	28.0	22.25	49.00	0.79	42.00	16.80	25.20	17.50	16.80	0.70
24	10.5	59.0	53.5	28.5	23.12	48.50	0.78	43.00	17.20	25.80	18.00	17.20	0.80
25	10.5	58.5	54.0	29.0	24.01	48.00	0.77	43.50	17.40	26.10	18.50	17.40	1.10
26	10.5	59.0	54.0	29.0	23.76	48.50	0.78	43.50	17.40	26.10	18.50	17.40	1.10
27	10.5	60.0	54.5	29.0	23.28	49.50	0.79	44.00	17.60	26.40	18.50	17.60	0.90
0	10.5	60.0	52.0	27.0	20.77	49.50	0.79	41.50	16.60	24.90	16.50	16.60	-0.10a
20	10.5	60.0	53.5	28.0	22.03	49.50	0.79	43.00	17.20	25.80	17.50	17.20	0.30
22	10.5	60.0	54.0	28.5	22.65	49.50	0.79	43.50	17.40	26.10	18.00	17.40	0.60
21	10.5	61.0	53.0	28.0	21.59	50.50	0.81	42.50	17.00	25.50	17.50	17.00	0.50
19	10.5	60.0	53.0	27.5	21.40	49.50	0.79	42.50	17.00	25.50	17.00	17.00	0.00
11	10.5	60.0	52.5	28.0	22.03	49.50	0.79	42.00	16.80	25.20	17.50	16.80	0.70
14	10.5	60.0	52.5	27.5	21.40	49.50	0.79	42.00	16.80	25.20	17.00	16.80	0.20
15	10.5	60.5	54.0	28.0	21.81	50.00	0.80	43.50	17.40	26.10	17.50	17.40	0.10
16	10.5	59.0	52.0	27.5	21.84	48.50	0.78	41.50	16.60	24.90	17.00	16.60	0.40
17	10.5	60.5	54.5	28.5	22.43	50.00	0.80	44.00	17.60	26.40	18.00	17.60	0.40
Mean	10.53	59.70	53.00	28.10	23.74	48.10	3.28	42.48	16.99	25.49	17.58	16.99	0.59
Std. dev.					6.3565						100%	96.67%	3.33%
Computed on means					22.27	49.18	0.79	42.48	16.99	25.49	17.58	16.99	0.59

[a] No explanation is given for the negative amount of water in Part 0. Also, the smaller percentage of water present in the top plug compared with to the drum body weldment is attributed to the larger surface-to-volume ratio, which results in better drying of the parts.

A set of criticality calculations was performed for each of the packaging material specifications (i.e., the TS and the AM Kaolite) using three package water contents to represent the range of NCT and HAC. Y-12 statisticians were asked to determine whether or not the observed differences in neutronic performance are statistically significant for a package modeled with the TS specification versus one modeled with the AM specification. The purpose of this discussion is to summarize this comparison (DAC-FS-900000-A014) and draw conclusions.

Criticality Calculations. Each case is rerun using a different starting random number in order to produce computed k_{eff} values that are statistically independent. Table 6.9.3.4-4 presents the random starting number, the mean value (k_{eff}) and corresponding standard error (s_i) computed for 10 individual runs of each case.

Three sets of criticality calculations were run for both the AM Kaolite and TS Kaolite. One set of calculations is for dry Kaolite (i.e., low water content, IS = 1E-04 sp gr water); another set is for normal moisture Kaolite (i.e., NCT water content); and the third set is for flooded Kaolite (i.e., high water content, IS = 1.0 sp gr water). These conditions span the range of NCT and HAC addressed in the criticality evaluation. An infinite array of packages was evaluated in order to eliminate any biases arising from spectral leakage effects in the reflector of the finite array. Each package was modeled having 36 kg of 100% enriched uranium in the form of 3.24-in.-diam cylinder content. The k_{eff} values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data.

Statistical evaluation. A review of KENO V.a calculation results was made to determine if a statistically significant difference exists between the mean k_{eff} for the TS Kaolite specification and the AM Kaolite material specifications used in the criticality evaluation of the ES-3100 shipping package. Case results were classified into three groups (i.e., low water content, medium water content, or high water content) depending on the amount of water present in the ES-3100 shipping package. The symbol "I" is used to specify the group. The mean difference and standard deviation for each of the three (3) sets of pair-wise differences was defined as follows:

(a) $d_i = (k_{effBi} - k_{effAi})/n$ and

(b) $s_{di} = \sqrt{\left[\left[n\Sigma d_i^{\,2} - (\Sigma d_i)^{\,2} \right] / n(n-1) \right]}$ (conservatively defined for the t-test appropriate for small sample sizes)

where A_i denotes the TS by group classification, B_i the AM by group classification, and n the sample size of ten (10). It is reasonable to assume that the paired differences have been randomly selected from a normally distributed population of paired differences with mean μ_d and standard deviation σ_d. Therefore, the sampling distribution of

$$(d - \mu_d) / (s_d/\sqrt{n})$$

is a *t*-distribution having n-1 degrees of freedom.

Table 6.9.3.4-4. Data for the statistical evaluation of "as-manufactured"and "test sample" Kaolite

As-manufactured Kaolite				Test sample Kaolite			
Case name	**Random number**	**k_{eff}**	**s_i**	**Case name**	**Random number**	**k_{eff}**	**s_i**
Group 1 – Low water content							
esrandnum_01_01_in	109E77866CF	1.00274	0.00138	mdrandnum_01_01_in	109E77866CF	1.00170	0.00125
esrandnum_01_02_in	16AA4A58735	1.00224	0.00120	mdrandnum_01_02_in	16AA4A58735	1.00416	0.00116
esrandnum_01_03_in	1814171B652	1.00121	0.00107	mdrandnum_01_03_in	1814171B652	1.00208	0.00125
esrandnum_01_04_in	1A423B9472C	1.00367	0.00118	mdrandnum_01_04_in	1A423B9472C	1.00271	0.00131
esrandnum_01_05_in	20E876D8224	1.00290	0.00133	mdrandnum_01_05_in	20E876D8224	1.00406	0.00125
esrandnum_01_06_in	3F6E65CA744	1.00266	0.00137	mdrandnum_01_06_in	3F6E65CA744	1.00418	0.00124
esrandnum_01_07_in	479D21DB750	1.00393	0.00108	mdrandnum_01_07_in	479D21DB750	1.00193	0.00133
esrandnum_01_08_in	55D4371D3A2	1.00313	0.00113	mdrandnum_01_08_in	55D4371D3A2	1.00196	0.00105
esrandnum_01_09_in	6E1A14672B8	1.00343	0.00119	mdrandnum_01_09_in	6E1A14672B8	1.00503	0.00118
esrandnum_01_10_in	77A0308C0E4	1.00229	0.00113	mdrandnum_01_10_in	77A0308C0E4	1.00358	0.00108
Group 2 – NCT medium density							
esrandnum_06_01_in	109E77866CF	0.99025	0.00119	mdrandnum_06_01_in	109E77866CF	0.98323	0.00118
esrandnum_06_02_in	16AA4A58735	0.98863	0.00128	mdrandnum_06_02_in	16AA4A58735	0.98630	0.00108
esrandnum_06_03_in	1814171B652	0.98811	0.00120	mdrandnum_06_03_in	1814171B652	0.98328	0.00125
esrandnum_06_04_in	1A423B9472C	0.98933	0.00114	mdrandnum_06_04_in	1A423B9472C	0.98487	0.00112
esrandnum_06_05_in	20E876D8224	0.98869	0.00103	mdrandnum_06_05_in	20E876D8224	0.98559	0.00109
esrandnum_06_06_in	3F6E65CA744	0.98854	0.00117	mdrandnum_06_06_in	3F6E65CA744	0.98412	0.00106
esrandnum_06_07_in	479D21DB750	0.98900	0.00119	mdrandnum_06_07_in	479D21DB750	0.98395	0.00118
esrandnum_06_08_in	55D4371D3A2	0.98844	0.00113	mdrandnum_06_08_in	55D4371D3A2	0.98546	0.00114
esrandnum_06_09_in	6E1A14672B8	0.99007	0.00126	mdrandnum_06_09_in	6E1A14672B8	0.98424	0.00121
esrandnum_06_10_in	77A0308C0E4	0.99028	0.00122	mdrandnum_06_10_in	77A0308C0E4	0.98465	0.00118
Group 3 – High water content							
esrandnum_09_01_in	109E77866CF	0.92872	0.00118	mdrandnum_09_01_in	109E77866CF	0.92800	0.00123
esrandnum_09_02_in	16AA4A58735	0.92800	0.00110	mdrandnum_09_02_in	16AA4A58735	0.92817	0.00107
esrandnum_09_03_in	1814171B652	0.92844	0.00118	mdrandnum_09_03_in	1814171B652	0.92770	0.00115
esrandnum_09_04_in	1A423B9472C	0.92780	0.00123	mdrandnum_09_04_in	1A423B9472C	0.92763	0.00126
esrandnum_09_05_in	20E876D8224	0.92783	0.00134	mdrandnum_09_05_in	20E876D8224	0.92584	0.00105
esrandnum_09_06_in	3F6E65CA744	0.92809	0.00128	mdrandnum_09_06_in	3F6E65CA744	0.92853	0.00112
esrandnum_09_07_in	479D21DB750	0.92725	0.00111	mdrandnum_09_07_in	479D21DB750	0.92682	0.00111
esrandnum_09_08_in	55D4371D3A2	0.92622	0.00126	mdrandnum_09_08_in	55D4371D3A2	0.92706	0.00116
esrandnum_09_09_in	6E1A14672B8	0.92925	0.00132	mdrandnum_09_09_in	6E1A14672B8	0.92733	0.00110
esrandnum_09_10_in	77A0308C0E4	0.92757	0.00114	mdrandnum_09_10_in	77A0308C0E4	0.92886	0.00132

The evaluation of the mean differences (d_i) for the 10 sets of cases is accomplished through hypothesis testing, a statistical tool used to provide evidence that a difference exists or does not exist. The ti values are 0.70, 10.0 and 0.95 for dry Kaolite, for NCT Kaolite, and for flooded Kaolite, respectively. A value of 3.25 is obtained from the standard table for critical values for the t distribution, from which the decision to accept or reject the null hypothesis H0 is made with a Type I error probability (α) of 0.01. For t <3.25, the Ho hypothesis is not rejected. Acceptance of the null hypothesis is the result of insufficient evidence to reject it. Thus, it can be concluded that the mean estimate of the difference of the AM Kaolite is not significantly different from the mean of the TS Kaolite for both dry and flooded Kaolite. For t >3.25, the Ho hypothesis is rejected. Therefore, it can be concluded that the mean estimate of the difference of the AM Kaolite is significantly different from the mean of the TS Kaolite for the normal moisture Kaolite. The mean k_{eff} for AM Kaolite is significantly greater than the mean k_{eff} of the TS Kaolite; therefore, the use of the AM specification in the ES-3100 criticality calculations is conservative and bounding. Details of the statistical evaluation are documented in Reference DAC-FS-900000-A014.

6.9.3.5 Water

Water is used in various regions of the models to simulate HAC as an interstitial moderator and as a reflector. When used at full density, the density of water is 0.9982 g/cm^3 (NUREG/CR-0200, Rev. 6).

6.9.3.6 Calculation of Equivalent Water Mass for Polyethylene

In the calculation models for evaluation of NCT, water may be substituted for the polyethylene composition of bags present in the package. Based on hydrogen density, 1285.14 g of water are equivalent to 1000 g of polyethylene for nuclear criticality safety calculations. The equivalent water mass is calculated as follows:

$$1 \text{ kg polyethylene} = \frac{1000 \text{ g}}{0.92 \text{ g/cm}^3} = 1087.0197 \text{ cm}^3$$

$$\text{H number density} = \frac{(0.92)\,(4)\,(6.02252 \times 10^{23})}{(28.0312)\,(10^{24})} = 7.906502 \times 10^{-2} \text{ at/bn-cm}$$

$$\text{H in 1 kg} = (1087.0197 \text{ cm}^3)\,(7.906502 \times 10^{-2}) = 85.945234 \text{ at-cm}^2/\text{bn}$$

Hydrogen in 1 kg of polyethylene [$(CH_2)_2$, molecular weight = 28.0312; density = 0.92]:

Grams of water [H_2O, molecular weight = 18.0110; density = 0.9982] with hydrogen content equivalent to 1 kg of polyethylene:

$$\text{equivalent g of } H_2O = \frac{(85.945234)\,(18.0110)\,(10^{24})}{(2)\,(6.02252 \times 10^{23})} = 1285.1427 \text{ g}$$

Appendix 6.9.4

Qualification of a Neutron-absorber Material for the ES-3100

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Appendix 6.9.4

Qualification of a Neutron-absorber Material for the ES-3100

6.9.4.1 Introduction

277-4 is a formulation of Thermo Electron Corporation's Cat. 277-0, a boron carbide additive and water. 277-4 is a neutron radiation shielding product and is one of several materials in its class that have been evaluated as a candidate neutron-absorber system for a variety of nuclear criticality safety applications by the Y-12 National Security Complex (Y-12). This class of materials is characterized as a dispersion of $^{nat}B_4C$ particulate[1] throughout a hardened hydraulic cement or binder, resulting in a high-hydrogen, borated material system. It offers many advantages for typical Y-12 applications over other classes of materials such as borated aluminum because a neutron moderator and neutron absorber are both integral to the solid material system itself. The separate addition of another neutron moderating material such as water or polyethylene is not required in order for it to function effectively.

Computational methods of analysis in simple geometry permit direct comparison of neutron-absorber system performance for nuclear criticality safety applications. The measure of comparison is the neutron interaction potential between two parallel 0.745-cm-thick slabs of infinite extent of ^{235}U metal at a density of 18.81 g/cm^3. The slabs are separated by a variable thickness of material and reflected by a 60-cm thickness of the same material (Fig. 6.9.4.1-1). Each material is modeled as an idealized homogeneous mixture of elements based on nominal density and constituent proportions (Table 6.9.4.1-1). The result is expressed in terms of calculated k_{eff} [2] as influenced by the thickness of the candidate material between the two parallel slabs (see Fig. 6.9.4.1-2).

The least effective neutron-absorber material systems are those with low hydrogen content and low neutron absorption cross section (e.g., ordinary concrete). The performance of concrete that contains $^{nat}B_4C$ particulate (e.g., borated concrete) is improved, but it is still hindered by its low hydrogen content. This is a function of the proportion and type of cement in the typical concrete mixture (i.e., a low proportion of lime- and silica-based Portland cement). Ordinary water is also included for comparison because of its high hydrogen content, but its performance is also limited by a low total mass density and low neutron absorption cross section.

As expected, materials with high hydrogen content and high boron content (e.g., 277-4, borated ceramics, and borated polymers) are predicted to be the most effective neutron-absorber systems. Although the mechanical and thermal properties of such systems can vary significantly, their nuclear properties are dictated almost exclusively by the relative proportion and content of ^{10}B and H and the total mass density of the material system. These things being equal, the nuclear performance of any material in this class (i.e., 277-4, borated ceramics, and borated polymers) is representative of the others.

[1] 277-4 is an improved variant of the Cat 277 product ca. 2000 which was originally formulated as a dispersion of ^{nat}Borosilicate glass granules rather than the current practice of using $^{nat}B_4C$ particulate.

[2] SCALE 4.4a, CSAS25 code sequence for KENO V.a with the 238-group ENDF B-IV neutron cross-section library on the Y-12 Safety Analysis Engineering Hewlett-Packard J5600 workstation (CMODB).

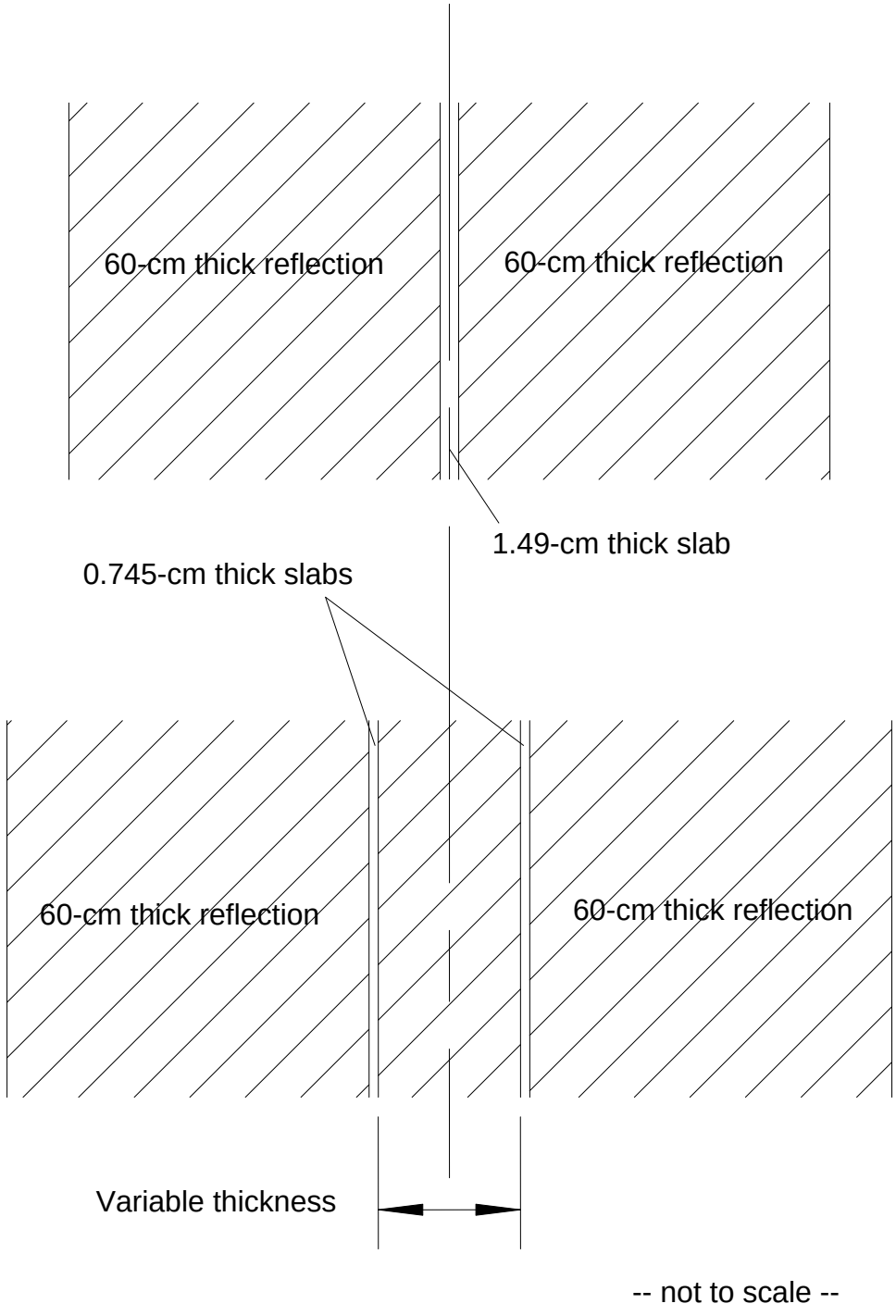


Fig. 6.9.4.1-1. Physical model of parallel ^{235}U metal slabs of infinite extent reflected and separated by various candidate neutron-absorber materials.

Table 6.9.4.1-1. Nominal elemental and isotopic compositions of idealized material models for comparison of various neutron absorbers (atoms/barn·cm)

	Ordinary concrete A 2.147 g/cm^3	Ordinary concrete B 2.299 g/cm^3	Water 0.9982 g/cm^3	Borated concrete 2.563 g/cm^3	Cat 277a 1.68 g/cm^3	Borated ceramic 1.91 g/cm^3	Borated polymer 1.717 g/cm^3	^{235}U metal 18.81 g/cm^3
H	4.2581E-03	8.5010E-03	6.6751E-02	4.2900E-03	3.3800E-02	2.7200E-02	5.7600E-02	
B-10				1.7600E-04	2.8400E-04	2.6500E-03	9.4600E-04	
B-11				6.8100E-04	1.1800E-03	1.1000E-02	3.9200E-03	
C	1.1348E-02	2.0217E-02		9.0000E-04		4.2600E-03	2.3500E-02	
N							1.3800E-03	
O	4.0370E-02	3.5511E-02	3.3376E-02	4.2400E-02	3.7100E-02	3.2900E-02	2.5900E-02	
Na	7.9356E-05	1.6299E-05		6.7100E-05	2.6000E-04	7.9200E-05		
Mg	5.0111E-03	1.8602E-03		2.3000E-04	2.0800E-04	2.3300E-03		
Al	3.7660E-04	5.5580E-04		2.2900E-03	8.9700E-03	1.7400E-03	7.7000E-03	
Si	1.9382E-03	1.7000E-03		1.1800E-02	7.6700E-04	3.2300E-03		
P						2.1200E-03		
S	1.0013E-04			9.6300E-05	6.0000E-05	7.7800E-05		
Cl	1.9074E-05							
K	3.1231E-04	4.0300E-05		3.1600E-04		2.3100E-03		
Ca	7.3008E-03	1.1101E-02		3.1200E-03	2.2300E-03	2.4600E-04		
Ti	4.0183E-05					7.0800E-05		
Mn	1.2050E-05			1.4000E-04				
Fe	1.2954E-04	1.9301E-04		4.6200E-03	4.8900E-05	5.2000E-04		
U-235								4.8200E-02

[a] The ^{10}B content of this material model for Cat 277 is based on its ca. 2000 formulation using crushed borosilicate glass rather than the current practice of using $^{nat}B_4C$ particulate. This particular formulation is roughly equivalent to ~2% $^{nat}B_4C$ particulate (i.e., equivalent ^{10}B content, by weight). For otherwise identical H and B-10 content, this difference is unimportant relative to its nuclear performance as an idealized homogeneous mixture of elements. However, the current use of more than 5% $^{nat}B_4C$ particulate (by weight) is preferred due to reasons relating to the method of preparation, chemical reaction, and placement of 277-4 and uniformity of ^{10}B distribution in the cured product. As with all the materials in this class, the amount of H and ^{10}B in the finished product is determined by the relative proportions of its major constituents, which are tailored to the requirements of the specific application.

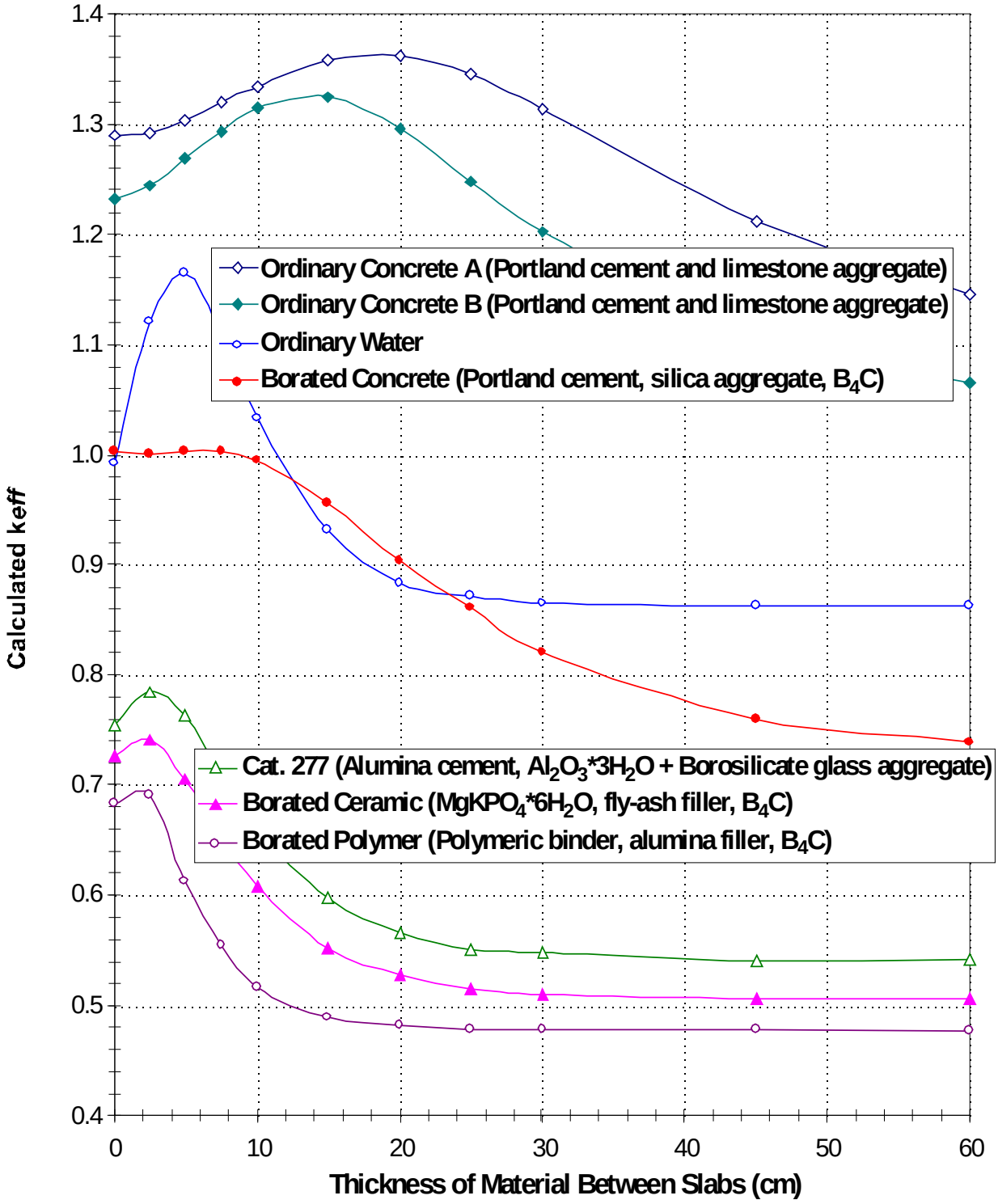


Fig. 6.9.4.1-2. The effect of various materials on neutron interaction between parallel slabs of ^{235}U metal of infinite extent.

6.9.4.2 Performance Testing

To investigate the performance of this class of neutron-absorbing materials further, Y-12 has studied neutron radiography and neutron transmission measurements on several samples of a borated ceramic. Like 277-4, the borated ceramic is also a dispersion of $^{nat}B_4C$ particulate throughout a hardened hydraulic crystalline solid material matrix for which the binder phase is $MgKPO_4 \cdot 6H_2O$ rather than the hydrates of CaO and Al_2O_3. In fact, the more finely divided $^{nat}B_4C$ particulate specified for 277-4 is a slight advantage over the modestly coarser particulate in the borated ceramic. As shown below in Table 6.9.4.2-1, the relative proportion and content of H and ^{10}B and their total mass density are very similar. The small differences between the nuclear properties of their associated low- and intermediate-Z elements (i.e., oxides of Mg, Al, P, K, and Ca) are negligible. Thus, performance and the most significant factors affecting performance are nearly identical for both materials, so the results of neutron radiography and neutron transmission for the borated ceramic samples are judged applicable to 277-4 specimens of similar dimension.

Table 6.9.4.2-1. Comparison of nominal values for 277-4 and borated ceramic samples subjected to neutron radiography and neutron transmission testing.

Attribute	Cat 277 original formulation ca. 2000	277-4 ES-3100 formulation as cured	Borated ceramic samples for testing
Principal binder phase(s)	Hydrates of CaO and Al_2O_3	Hydrates of CaO and Al_2O_3	$MgKPO_4 \cdot 6H_2O$
Neutron absorber	^{nat}Borosilicate glass granules	$^{nat}B_4C$ particulate	$^{nat}B_4C$ particulate
Particle Size	90 wt % <2360 μm 65 wt % <1180 μm 40 wt % <600 μm 15 wt % <102 μm 0 wt % <150 μm	100 wt % <102 μm	100 wt % <559 μm 90 wt % <356 μm 40 wt % <254 μm 3 wt % <122 μm 0 wt % <63 μm
Filler Material(s)	$Al_2O_3 \cdot 3H_2O$	$Al_2O_3 \cdot 3H_2O$	Class F Coal Fly-ash
Total Mass Density	1.68 g/cm^3	1.60 g/cm^3	1.91 g/cm^3
Total H_2O content	0.51 g/cm^3	0.51 g/cm^3	0.49 g/cm^3
Total ^{10}B content	0.005 g/cm^3	0.013 g/cm^3	0.012 g/cm^3

Samples were prepared from sectioned pieces of a single specimen from a vertically oriented mold measuring 10 × 10 × ~30 cm tall, as illustrated in Fig. 6.9.4.2-1 (nominally 4 × 4 × 12 in. tall). One specimen was prepared by the normal method of mixing and preparation for the borated ceramic material. Sectioning the first specimen resulted in two thick samples designated “1 of 2” and “2 of 2” which each measured 10-cm wide by ~30-cm long by ~2.4-cm thick (nominally 1-in. thick). A second specimen was prepared by abnormal methods intended to produce non-homogeneity (i.e., poorly mixed using retardants followed by excessive and extended vibration of the mold after installation). Sectioning this specimen resulted in two thin samples designated “062d1bc” and “062d1bd” which each measured 10-cm wide by ~30-cm long by ~1.2-cm thick (nominally 0.5-in. thick). The samples were delivered to the Breazeale Nuclear Reactor Building at Pennsylvania State University for inspection. Upon completion of inspection for all four samples as received, a thick sample “1 of 2” and a thin sample “062d1bc” were dehydrated by heating to 140°C to eliminate interference by hydrogen, and all four samples were tested again.

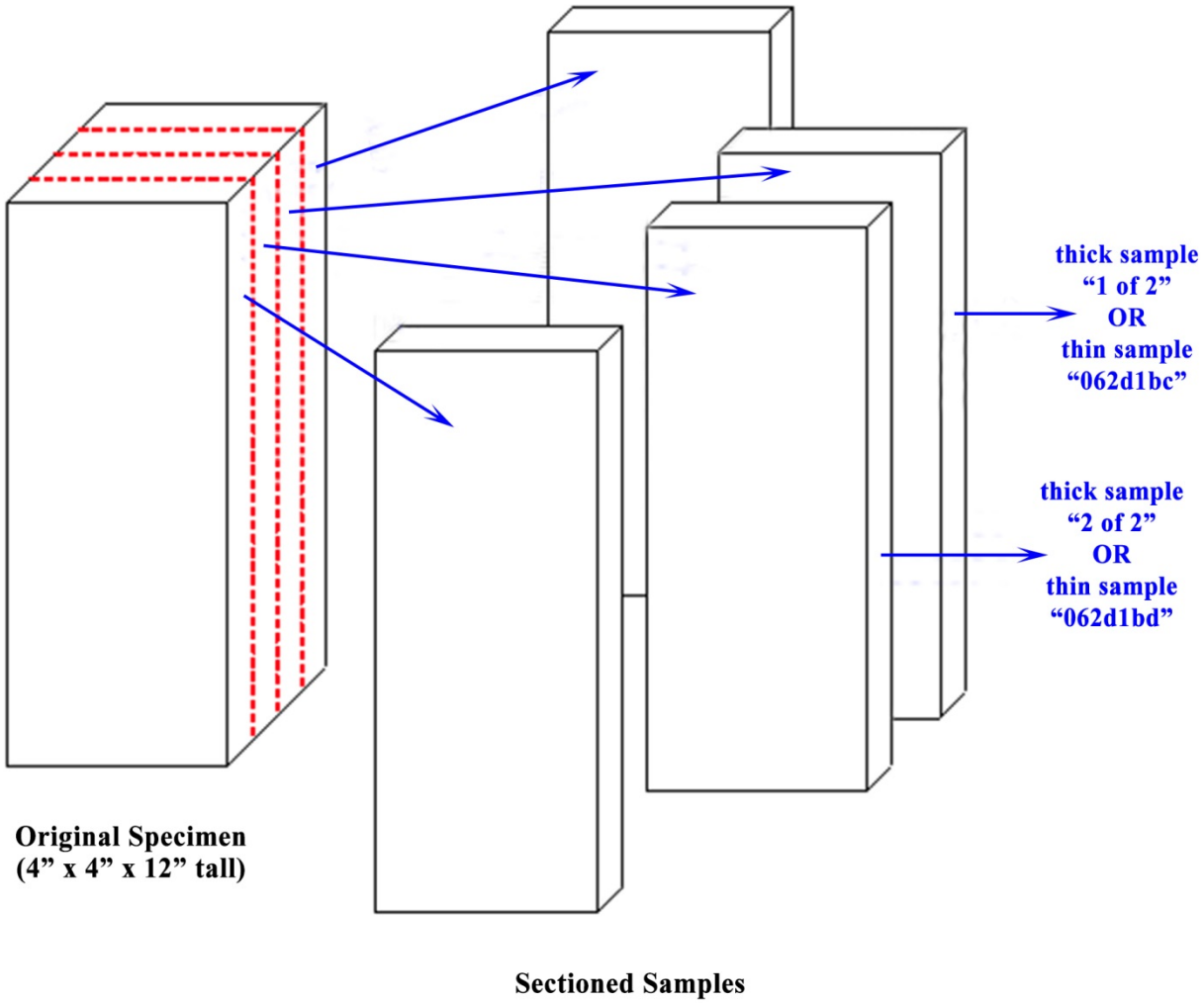


Fig. 6.9.4.2-1. Illustration of sectioning plan for borated ceramic samples for neutron radiography and neutron transmission measurements.

All four samples were qualitatively inspected for visual defects and subjected to neutron radiographic inspection. The inspections were intended to identify any variations in image luminance, which would indicate a variation in homogeneity and density. Neutron transmission measurements were calibrated to results for thin ZrB_2 reference coupons sandwiched with thick aluminum metal. The ^{10}B areal densities of the thin reference coupons ranged from 5.32 mg/cm^2 to 57.04 mg/cm^2 over a total ZrB_2 + Al reference thickness of 24.21–24.98 mm. By comparison, the thick samples contain an idealized ^{10}B areal density of 28.8 mg/cm^2 (i.e., 0.012 g/cm^3 over a 2.4-cm thickness), and the thin samples contain an idealized ^{10}B areal density of 14.4 mg/cm^2 (i.e., 0.012 g/cm^3 over a 1.2-cm thickness).

Radiographic examination of both thick samples "1 of 2" and "2 of 2" indicated uniformity of composition and density (see Fig. 6.9.4.2-2). Even after dehydration of thick sample "1 of 2," radioscopic examination indicated uniformity of composition and density. Initial neutron transmission results for both thick samples "1 of 2" and "2 of 2" indicated that neutron transmission was very low. In fact, the interference due to the hydrogen content implies an equivalent ^{10}B areal density measurement of ~67 ± 4 mg/cm^2. This is more than twice the actual physical value of 28.8 mg/cm^2. Only after thick sample of "1 of 2" is dehydrated and tested again do the results of neutron transmission measurements more accurately reflect the actual physical ^{10}B content. In fact, the average measured value of 27.419 mg/cm^2 at eleven points along the long axis of the dehydrated sample "1 of 2" is more than 95% of the actual physical value of 28.8 mg/cm^2 and varies no more than a few percent from one end to the other (see Tables 6.9.4.2-2 and 6.9.4.2-3).

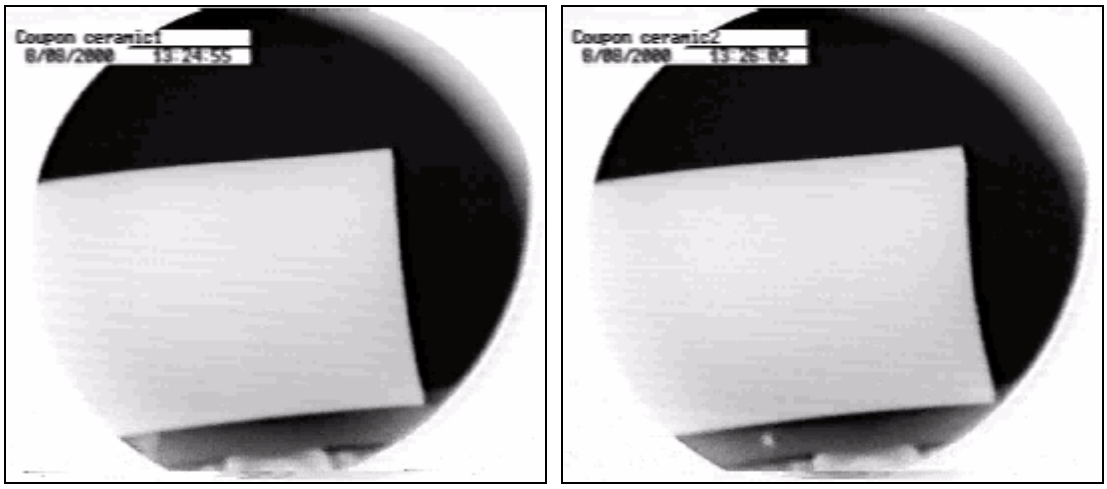


Fig. 6.9.4.2-2. Radiographic images of thick samples "1 of 2" (left) and "2 of 2" (right) indicating uniformity of composition and density.

Table 6.9.4.2-2. Results of neutron transmission measurements of thick samples

	Equivalent ^{10}B areal density (mg/cm^2)		
	End	**Center**	**End**
sample "1 of 2"	66.419	68.673	71.003
sample "2 of 2"	65.0	68.25	69.708
sample "1 of 2" (dehydrated)	27.586	27.191	28.555
sample "2 of 2" (re-test)	63.687	65.966	65.572

Table 6.9.4.2-3. Neutron transmission measurements of thick sample "1 of 2" after dehydration

Point of measurement (uniform intervals from one end to the other)	Equivalent ^{10}B areal density (mg/cm^2)	Deviation from average (%)
1	27.586	+0.6 %
2	26.909	-1.9 %
3	27.039	-1.4 %
4	27.358	-0.2 %
5	27.286	-0.5 %
6	27.191	-0.8 %
7	27.375	-0.2 %
8	27.179	-0.8 %
9	27.236	-0.7 %
10	27.897	-0.9 %
11	28.555	+4.1 %
Average	**27.419**	

Radiographic examination of both thin samples "062d1bc" and "062d1bd" indicates areas of nonuniformity and spots of lower neutron attenuation, along with greater dissimilarity between the samples themselves (see Fig. 6.9.4.2-3). Many of these areas and spots remained evident by radiographic examination even after dehydration of thin sample "062d1bc" and are attributed to physical voids revealed during visual inspection. Again, initial neutron transmission measurements implied a greater-than-actual equivalent ^{10}B areal density due to the interference of hydrogen (i.e., measured values averaged ~23.3 mg $^{10}B/cm^2$ rather than the actual value of 14.4 mg $^{10}B/cm^2$).

Measurements repeated after dehydration of sample "062d1bc" more correctly estimate the equivalent ^{10}B areal density to be ~11.1 mg/cm^2, which is ~77% of the actual physical ^{10}B content. Again, the relative values vary only a few percent from one end of the sample to the other (see Table 6.9.4.2-4). However, the measured values of a dehydrated sample in this case are known to be biased low. First, the total thicknesses of the ZrB_2 + Al reference coupons for calibration were ~24.21 to 24.98-mm compared to the 1.2-cm thickness of "062d1bc." Second, the total mass density of the sample is ~1.4 to 1.5 g/cm^3 after dehydration compared to an Al mass density of ~2.7 g/cm^3 for the ZrB_2 + Al reference coupons. This indicates that even the performance of the thin samples (i.e., 1.2-cm thickness) exhibiting non-uniformity of composition and density is only marginally reduced from that of the idealized, homogeneous material model with respect to neutron absorber efficiency.

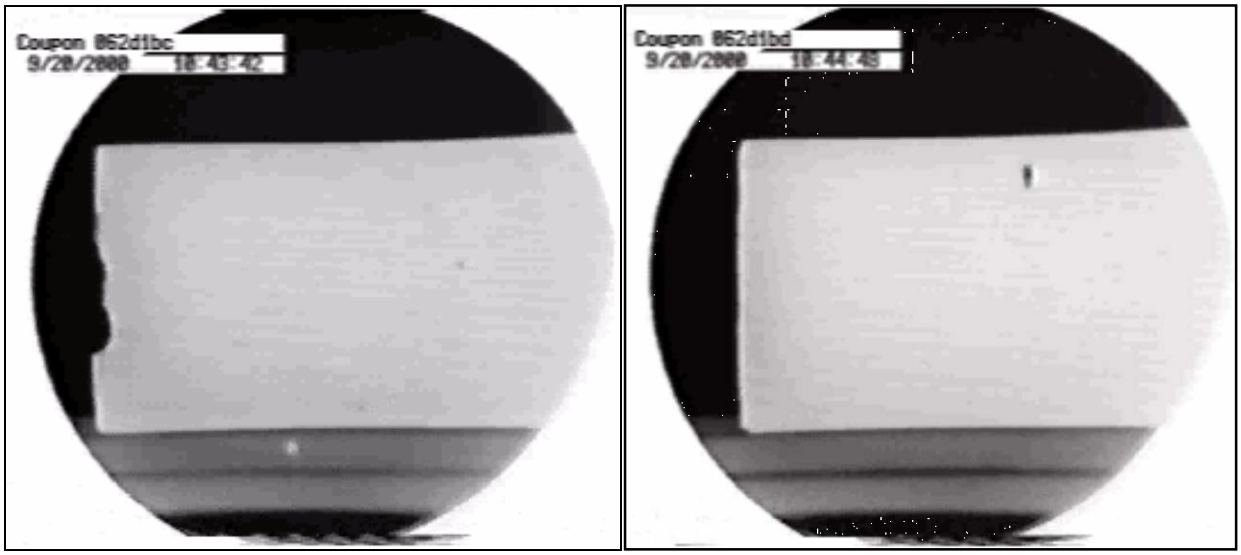


Fig. 6.9.4.2-3. Radiographic images of thin samples "062d1bc" (left) and "062d1bd" (right) indicating non-uniformity of composition and density and dissimilarity of samples.

Table 6.9.4.2-4. Neutron transmission results for dehydrated thin sample "062d1bc" and re-test of thin sample "062d1bd"

Position of measurement (see Fig. 6.9.4.2-4)	Minimum equivalent ^{10}B areal density (mg/cm^2)			
	Dehydrated thin sample "062d1bc"		Re-test of thin sample "062d1bd"	
	Line A	Line B	Line A	Line B
1	12.227	11.781	25.909	25.154
2	11.776	11.462	24.390	25.344
3	11.388	11.252	24.257	24.645
4	10.554	10.462	25.341	24.885
5	10.432	10.528	24.646	25.483
6	10.754	11.728	25.450	25.712
7	10.396	11.534	25.761	23.063
8	11.166	10.221	24.522	25.257
9	10.875	10.459	23.113	23.882
10	11.051	10.676	25.270	23.724
11	11.258	11.214	24.922	25.355
Combined average	**11.1**		**24.8**	

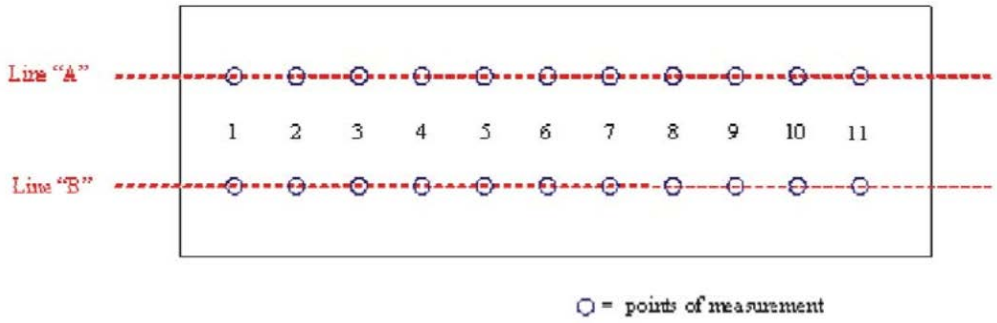


Fig. 6.9.4.2-4. Illustration of measurement plan for neutron transmission measurements of thin samples "062d1bc" and "062d1bd."

6.9.4.2.3 Conclusions

Provided that 277-4 is prepared in a controlled manner to ensure the proper specification and proportioning of batch constituents, thorough mixing of the wet slurry, and correct placement and installation to prevent large physical voids, a credible technical justification exists to credit no less than 75% of the $^{nat}B_4C$ particulate and its other constituents, by weight, as an idealized homogeneous mixture for nuclear criticality safety analysis of the ES-3100. There is no evidence of non-homogeneity, neutron self-shielding effects, or neutron streaming effects in borated hydraulic cement or ceramic material systems for thicknesses of 2.4-cm or more. The qualification of 277-4 for use in the design and construction of the ES-3100 described herein is based on sound nuclear engineering principles and direct application of performance test results for such material systems.

Appendix 6.9.5

Miscellaneous Information and Data

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Appendix 6.9.5

Miscellaneous Information and Data

Table 6.9.5.1 provides the atomic weights of the elements and isotopes of the materials used in this criticality safety evaluation. Atomic weights and isotopic weight percents of the naturally occurring materials are those taken from the Materials Information Processor in the SCALE Standard Composition Library.

Table 6.9.5.2 provides the molecular weights and weight percents of the corresponding elements and isotopes of the various compounds. The weight percents shown in this table are the input to KENO V.a (NUREG/CR-0200, Rev. 6).

Table 6.9.5.3 provides equations for determining atomic densities. These equations were derived based on the assumption that all constituents in the mixture are volume additive. Although these equations with their corresponding subscripts are for mixtures of elements, isotopes, or both, all except Equation (2) can be applied to compounds if the user substitutes certain subscript notations and meaning changes. For example, in Equations (1a) and (1b), the atomic weight becomes the molecular weight and the subscript "m" for mixture changes to the subscript "c" for compound. Likewise, in Equations (3a) and (3b), the atomic weight becomes the molecular weight, and the atom fraction (n_i) becomes the stoichiometric proportion of the elements making up the molecule. In Equations (3)–(5), the atom fraction (n_i) becomes the stoichiometric proportion (the element number subscript in the molecular formula), whose sum does not equal unity. Equation (2) is applicable only to the theoretical density of mixtures; it does not apply to the density of compounds.

Table 6.9.5.1. Atomic weights

Element or isotope	Atomic weight
H	1.0078
C	12.0000
O	15.9954
N	14.0033
Na	22.9895
Mg	24.3051
Al	26.9818
Si	28.0853
Ca	40.0803
Ti	47.8789
Cr	51.9957
Mn	54.9380
Fe	55.8447
Ni	58.6868
Zr	91.2196
^{235}U	235.0442
^{238}U	238.0510

Table 6.9.5.2. Molecular weights

Compound		Molecular or atomic weight	Weight percent in compound	Stoichiometric composition
Kaolite 1600™				
	Alumina	-	9.6	Al_2O_3
	Al	26.9818	52.92507	
	O	15.9954	47.07493	
	Silica	-	36.7	SiO_2
	Si	28.0853	46.74349	
	O	15.9954	53.25651	
	Ferric Oxide	-	6.7	Fe_2O_3
	Fe	55.8447	69.94330	
	O	15.9954	30.05670	
	Titanium Oxide	-	1.2	TiO_2
	Ti	47.8789	59.95084	
	O	15.9954	40.04916	
	Calcium Oxide	-	30.7	CaO
	Ca	40.0803	71.47009	
	O	15.9954	28.52991	
	Magnesium Oxide	-	13.1	MgO
	Mg	24.3051	60.30359	
	O	15.9954	39.69641	
	Alkalies	-	2.0	Na_2O
	Na	22.9895	74.18575	
	O	15.9954	25.81425	

Table 6.9.5.3. Useful equations

$$N_m = \rho_m N_o / A_m \quad (1a)$$

$$N_i = w_i \rho_m N_o / A_i \quad (1b)$$

$$\rho_m = 1/\Sigma w_i/\rho_i \quad (2)$$

$$A_m = 1/\Sigma w_i/A_i \quad (3a)$$

$$= \Sigma n_i A_i \quad (3b)$$

$$w_i = m_i/m_m \quad (4a)$$

$$= n_i A_i/\Sigma n_i A_i \quad (4b)$$

$$n_i = N_i/N_m \quad (5a)$$

$$= (w_i/A_i)/\Sigma(w_i/A_i) \quad (5b)$$

where

N_o = 0.602252×10^{24} (atoms/mol) Avogadro's number,
N = atom density (atoms/cm^3), $N_m = \Sigma N_i$,
ρ = density (g/cm^3),
A = atomic mass (g-mol),
w = weight fraction, $\Sigma w_i = 1$,
n = atom fraction, $\Sigma n_i = 1$,
subscript "m" = of the mixture,
subscript "i" = i^{th} component of the mixture,
(atoms/cm^3)$(1/10^{24})$ = atoms/barn-cm.

Appendix 6.9.6

Abridged Summary Tables of Criticality Calculation Results

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Appendix 6.9.6

Abridged Summary Tables of Criticality Calculation Results

This appendix contains the summary tables for calculation results identified in Sects. 6.4, 6.5, 6.6, and 6.7 of this document. The CV calculation model is a modification of the water-reflected, single-unit package calculation model where the packaging regions external to the containment vessel are replaced with full density water. The index is as follows:

Cylinder Content

Table 6.9.6-1 Results for the 3.24-in.-diam cylinder HEU content in CV calculation model.

Table 6.9.6-2 Results for the 3.24-in.-diam cylinder HEU content in bare and water reflected package calculation models.

Table 6.9.6-3 Results for the 3.24-in.-diam cylinder HEU content in package calculation models.

Table 6.9.6-3b Results for spacing of 3.24 in.-diameter cylinder HEU metal content in CV calculation model.

Table 6.9.6-3c Results for spacing of 3.24 in.-diameter cylinder HEU metal content in packaging calculation model.

Square Bar Content

Table 6.9.6-4 Results for the 2.29-in square bar HEU content in CV calculation model.

Table 6.9.6-5 Results for the 2.29-in square bar HEU content in packaging calculation model.

Cylinder Content

Table 6.9.6-6 Results for the 4.25-in.-diam cylinder HEU content in CV calculation model.

Table 6.9.6-7 Results for the 4.25-in.-diam cylinder HEU content in packaging calculation models.

Slugs Content

Table 6.9.6-8 Results for 1.5-in.-diam × 2.0-in.-tall slug HEU metal content in CV calculation model.

Table 6.9.6-9 Results for the 1.5-in.-diam × 2.0-in.-tall slug HEU metal content in packaging calculation model.

Broken Metal Content

Table 6.9.6-10 Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

Table 6.9.6-11 Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

Table 6.9.6-11b Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models

Table 6.9.6-11c Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models

Table 6.9.6-11d Comparison of results for the 277-4 canned spacer under the nominal and the minimal acceptance criteria for HEU broken metal content in ES-3100 HAC packaging calculation models

HEU Product Oxide Content

Table 6.9.6-12 Results for HEU oxide content in CV calculation model.

Table 6.9.6-13 Results for HEU product oxide content at 6.54 g/cm^3 in single-unit packaging calculation model.

Table 6.9.6-13a Results for HEU oxide content in single-unit packaging calculation model.

Table 6.9.6-13b Results for HEU oxide content in array packaging calculation model.

UNX Crystal Content

Table 6.9.6-14 Results for UNX crystal content in CV calculation model.

Table 6.9.6-15 Results for UNX crystal content in packaging calculation model.

Table 6.9.6-16 Results for leakage of UNX crystal content out of containment vessel.

HEU Skull Oxide Content

Table 6.9.6-17 Results for skull oxide (SO) content in CV calculation model.

Table 6.9.6-18a NCT results for SO content in packaging calculation model.

Table 6.9.6-18b HAC results for SO content in packaging calculation model.

Unirradiated TRIGA Reactor Fuel Element Content

Table 6.9.6-19a Results for $UZrH_x$ content in CV calculation model.

Table 6.9.6-19b Results for $UZrH_x$ content spacing in CV calculation model.

Table 6.9.6-19c Results for $UZrH_x$ content uranium weight fraction in CV calculation model.

Table 6.9.6-20a Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model.

Table 6.9.6-20b Results for $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model.

Table 6.9.6-20c Results for 1.31 in. smaller diameter $UZrH_x$ at 70.1 wt % ^{235}U content in packaging calculation model.

Table 6.9.6-20d Results for 1.31 in. smaller diameter $UZrH_x$ at 19.7 wt % ^{235}U content in packaging calculation model.

Air Transport Content

Table 6.9.6-21 Results for solid HEU metal content for air transportation.

Table 6.9.6-22a Results for TRIGA ($UZrH_x$) fuel element content at 19.7 wt % ^{235}U for air transportation.

Table 6.9.6-22b Results for TRIGA ($UZrH_x$) fuel element content at 70.1 wt % ^{235}U for air transportation.

Table 6.9.6-22c Results for research reactor fuel (U_3O_8-Al) content for air transportation.

Table 6.9.6-22d Results for research reactor fuel (UO_2-Mg) content for air transportation.

Table 6.9.6-23 Results for HEU broken metal content for air transport.

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Table 6.9.6-1. Results for 3.24 in.-diameter cylinder HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
flooded containment vessel, reflected									
no can spacers (np thickness = 0.0 in.)									
cvcrcyt11_36_1_1	0.0	36000	36000	0	0.00	1.0E-20	0.90460	0.00107	0.90673
cvcrcyt11_36_1_6	0.0	36000	36000	829	0.60	1.0E-01	0.90726	0.00124	0.90973
cvcrcyt11_36_1_7	0.0	36000	36000	1657	1.20	2.0E-01	0.91182	0.00120	0.91422
cvcrcyt11_36_1_8	0.0	36000	36000	2486	1.80	3.0E-01	0.91690	0.00139	0.91967
cvcrcyt11_36_1_9	0.0	36000	36000	3315	2.40	4.0E-01	0.92263	0.00119	0.92500
cvcrcyt11_36_1_10	0.0	36000	36000	4143	3.00	5.0E-01	0.92840	0.00115	0.93071
cvcrcyt11_36_1_11	0.0	36000	36000	4972	3.60	6.0E-01	0.93827	0.00112	0.94050
cvcrcyt11_36_1_12	0.0	36000	36000	5801	4.21	7.0E-01	0.94633	0.00127	0.94886
cvcrcyt11_36_1_13	0.0	36000	36000	6629	4.81	8.0E-01	0.95397	0.00120	0.95636
cvcrcyt11_36_1_14	0.0	36000	36000	7458	5.41	9.0E-01	0.96276	0.00137	0.96551
cvcrcyt11_36_1_15	0.0	36000	36000	8287	6.01	1.0E+00	0.97121	0.00125	0.97371
cvcrcyt11_36_1	0.0	36000	36000	8287	6.01	1.0E+00	0.97121	0.00125	0.97371
cvcrcyt11_35_1	0.0	35000	35000	8340	6.22	1.0E+00	0.96937	0.00120	0.97177
cvcrcyt11_34_1	0.0	34000	34000	8393	6.44	1.0E+00	0.96886	0.00120	0.97126
cvcrcyt11_33_1	0.0	33000	33000	8446	6.68	1.0E+00	0.96531	0.00111	0.96754
cvcrcyt11_32_1	0.0	32000	32000	8499	6.93	1.0E+00	0.96360	0.00120	0.96600
cvcrcyt11_31_1	0.0	31000	31000	8552	7.20	1.0E+00	0.95960	0.00122	0.96205
cvcrcyt11_30_1	0.0	30000	30000	8605	7.49	1.0E+00	0.95842	0.00128	0.96097
cvcrcyt11_29_1	0.0	29000	29000	8658	7.79	1.0E+00	0.95488	0.00115	0.95717
cvcrcyt11_28_1	0.0	28000	28000	8711	8.12	1.0E+00	0.95409	0.00118	0.95645
cvcrcyt11_27_1	0.0	27000	27000	8764	8.47	1.0E+00	0.94797	0.00113	0.95023
cvcrcyt11_26_1	0.0	26000	26000	8817	8.85	1.0E+00	0.94376	0.00124	0.94623

Table 6.9.6-1. Results for 3.24 in.-diameter cylinder HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrcyt11_25_1	0.0	25000	25000	8870	9.26	1.0E+00	0.94075	0.00141	0.94357
cvcrcyt11_24_1	0.0	24000	24000	8923	9.70	1.0E+00	0.93510	0.00133	0.93776
cvcrcyt11_23_1	0.0	23000	23000	8977	10.19	1.0E+00	0.93038	0.00130	0.93298
cvcrcyt11_22_1	0.0	22000	22000	9030	10.71	1.0E+00	0.92658	0.00106	0.92870
cvcrcyt11_21_1	0.0	21000	21000	9083	11.29	1.0E+00	0.92046	0.00118	0.92282
cvcrcyt11_20_1	0.0	20000	20000	9136	11.92	1.0E+00	0.91168	0.00125	0.91418
cvcrcyt11_19_1	0.0	19000	19000	9189	12.62	1.0E+00	0.90618	0.00128	0.90874
cvcrcyt11_18_1	0.0	18000	18000	9242	13.40	1.0E+00	0.89978	0.00124	0.90226
with can spacers (np thickness=1.4 in.)									
cvcrcyt11_36_2_1	1.4	36000	36000	0	0.00	1.0E-20	0.83041	0.00103	0.83248
cvcrcyt11_36_2_6	1.4	36000	36000	767	0.56	1.0E-01	0.82885	0.00106	0.83096
cvcrcyt11_36_2_7	1.4	36000	36000	1535	1.11	2.0E-01	0.83022	0.00104	0.83230
cvcrcyt11_36_2_8	1.4	36000	36000	2302	1.67	3.0E-01	0.83492	0.00104	0.83699
cvcrcyt11_36_2_9	1.4	36000	36000	3069	2.23	4.0E-01	0.84066	0.00123	0.84311
cvcrcyt11_36_2_10	1.4	36000	36000	3837	2.78	5.0E-01	0.84789	0.00102	0.84993
cvcrcyt11_36_2_11	1.4	36000	36000	4604	3.34	6.0E-01	0.85423	0.00101	0.85624
cvcrcyt11_36_2_12	1.4	36000	36000	5371	3.89	7.0E-01	0.86190	0.00106	0.86403
cvcrcyt11_36_2_13	1.4	36000	36000	6139	4.45	8.0E-01	0.86687	0.00118	0.86923
cvcrcyt11_36_2_14	1.4	36000	36000	6906	5.01	9.0E-01	0.87589	0.00113	0.87816
cvcrcyt11_36_2_15	1.4	36000	36000	7673	5.56	1.0E+00	0.88436	0.00111	0.88657
cvcrcyt11_36_2	1.4	36000	36000	7673	5.56	1.0E+00	0.88436	0.00111	0.88657
cvcrcyt11_35_2	1.4	35000	35000	7726	5.76	1.0E+00	0.88274	0.00108	0.88491
cvcrcyt11_34_2	1.4	34000	34000	7779	5.97	1.0E+00	0.87740	0.00119	0.87977
cvcrcyt11_33_2	1.4	33000	33000	7832	6.19	1.0E+00	0.87234	0.00112	0.87459

Table 6.9.6-1. Results for 3.24 in.-diameter cylinder HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrcyt11_32_2	1.4	32000	32000	7885	6.43	1.0E+00	0.86817	0.00108	0.87033
cvcrcyt11_31_2	1.4	31000	31000	7938	6.68	1.0E+00	0.86047	0.00124	0.86295
cvcrcyt11_30_2	1.4	30000	30000	7992	6.95	1.0E+00	0.85525	0.00117	0.85760
flooded containment vessel, reflected, no can spacers (np thickness = 0.0 in.)									
no polyethylene									
cvcrcyt11_21_1	0.0	21000	21000	9083	11.29	1.0E+00	0.92046	0.00118	0.92282
500 g polyethylene									
cvcrpcyt11_21_1	0.0	21000	21000	8540	11.41	1.0E+00	0.90599	0.00107	0.90814
dry containment vessel, reflected, no can spacers (np thickness = 0.0 in.)									
500 g polyethylene									
cvdcrpcyt11_21_1	0.0	21000	21000	0	0.80	1.0E+00	0.84505	0.00105	0.84716

Table 6.9.6-2. Results for 3.24 in.-diameter cylinder HEU metal content in bare and water reflected packaging calculation models

case name	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	nlf	k_{eff}	σ	$k_{eff}+2\sigma$	case name	nlf	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded CV, single package bare										**content in flooded CV, single package reflected**				
no can spacers (np thickness = 0.0 in.)										**no can spacers (np thickness = 0.0 in.)**				
ncsbcyt11_36_1_1	36000	36000	8287	6.01	1.0E-20	0.4744	0.90856	0.00115	0.91087	ncsrcyt11_36_1_1	0.0021	0.91542	0.00120	0.91782
ncsbcyt11_36_1_2	36000	36000	8287	6.01	1.0E-05	0.4749	0.90825	0.00100	0.91026	ncsrcyt11_36_1_2	0.0021	0.91477	0.00123	0.91724
ncsbcyt11_36_1_3	36000	36000	8287	6.01	1.0E-04	0.4747	0.90817	0.00121	0.91059	ncsrcyt11_36_1_3	0.0022	0.91550	0.00111	0.91772
ncsbcyt11_36_1_4	36000	36000	8287	6.01	1.0E-03	0.4744	0.90926	0.00134	0.91194	ncsrcyt11_36_1_4	0.0022	0.91636	0.00117	0.91869
ncsbcyt11_36_1_5	36000	36000	8287	6.01	1.0E-02	0.4730	0.90883	0.00108	0.91100	ncsrcyt11_36_1_5	0.0022	0.91537	0.00109	0.91755
ncsbcyt11_36_1_6	36000	36000	8287	6.01	1.0E-01	0.4510	0.91550	0.00112	0.91774	ncsrcyt11_36_1_6	0.0019	0.92121	0.00133	0.92386

Table 6.9.6-2. Results for 3.24 in.-diameter cylinder HEU metal content in bare and water reflected packaging calculation models

case name	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	nlf	k_{eff}	σ	$k_{eff}+2\sigma$	case name	nlf	k_{eff}	σ	$k_{eff}+2\sigma$
ncsbcyt11_36_1_8	36000	36000	8287	6.01	3.0E-01	0.3899	0.92546	0.00134	0.92814	ncsrcyt11_36_1_8	0.0016	0.92807	0.00112	0.93032
ncsbcyt11_36_1_15	36000	36000	8287	6.01	1.0E+00	0.1823	0.95215	0.00119	0.95454	ncsrcyt11_36_1_15	0.0007	0.95213	0.00129	0.95472
ncsbcyt11_36_1_15	36000	36000	8287	6.01	1.0E+00	0.1823	0.95215	0.00119	0.95454	ncsrcyt11_36_1_15	0.0007	0.95213	0.00129	0.95472
ncsbcyt11_35_1_15	35000	35000	8340	6.22	1.0E+00	0.1838	0.94834	0.00122	0.95077	ncsrcyt11_35_1_15	0.0008	0.94870	0.00107	0.95083
ncsbcyt11_34_1_15	34000	34000	8393	6.44	1.0E+00	0.1842	0.94748	0.00113	0.94975	ncsrcyt11_34_1_15	0.0008	0.94742	0.00124	0.94990
ncsbcyt11_33_1_15	33000	33000	8446	6.68	1.0E+00	0.1853	0.94613	0.00118	0.94850	ncsrcyt11_33_1_15	0.0008	0.94478	0.00119	0.94716
ncsbcyt11_32_1_15	32000	32000	8499	6.93	1.0E+00	0.1863	0.94237	0.00106	0.94448	ncsrcyt11_32_1_15	0.0007	0.94247	0.00111	0.94468
ncsbcyt11_31_1_15	31000	31000	8552	7.20	1.0E+00	0.1867	0.94052	0.00106	0.94264	ncsrcyt11_31_1_15	0.0008	0.94091	0.00107	0.94306
ncsbcyt11_30_1_15	30000	30000	8605	7.49	1.0E+00	0.1882	0.93819	0.00110	0.94039	ncsrcyt11_30_1_15	0.0007	0.94139	0.00137	0.94412
ncsbcyt11_29_1_15	29000	29000	8658	7.79	1.0E+00	0.1894	0.93483	0.00104	0.93692	ncsrcyt11_29_1_15	0.0007	0.93406	0.00108	0.93622
ncsbcyt11_28_1_15	28000	28000	8711	8.12	1.0E+00	0.1894	0.93339	0.00102	0.93543	ncsrcyt11_28_1_15	0.0008	0.93012	0.00124	0.93261
ncsbcyt11_27_1_15	27000	27000	8764	8.47	1.0E+00	0.1911	0.92636	0.00112	0.92860	ncsrcyt11_27_1_15	0.0008	0.92820	0.00122	0.93064
ncsbcyt11_26_1_15	26000	26000	8817	8.85	1.0E+00	0.1919	0.92366	0.00115	0.92597	ncsrcyt11_26_1_15	0.0008	0.92396	0.00141	0.92679
ncsbcyt11_25_1_15	25000	25000	8870	9.26	1.0E+00	0.1928	0.92122	0.00122	0.92366	ncsrcyt11_25_1_15	0.0008	0.91761	0.00102	0.91966
ncsbcyt11_24_1_15	24000	24000	8923	9.70	1.0E+00	0.1948	0.91432	0.00108	0.91648	ncsrcyt11_24_1_15	0.0008	0.91466	0.00107	0.91680
ncsbcyt11_23_1_15	23000	23000	8977	10.19	1.0E+00	0.1965	0.91055	0.00130	0.91314	ncsrcyt11_23_1_15	0.0008	0.91172	0.00116	0.91403
ncsbcyt11_22_1_15	22000	22000	9030	10.71	1.0E+00	0.1969	0.90695	0.00121	0.90936	ncsrcyt11_22_1_15	0.0008	0.90680	0.00153	0.90986
ncsbcyt11_21_1_15	21000	21000	9083	11.29	1.0E+00	0.1984	0.90241	0.00124	0.90490	ncsrcyt11_21_1_15	0.0009	0.90125	0.00113	0.90352
ncsbcyt11_20_1_15	20000	20000	9136	11.92	1.0E+00	0.2007	0.89477	0.00125	0.89726	ncsrcyt11_20_1_15	0.0009	0.89481	0.00109	0.89698
ncsbcyt11_19_1_15	19000	19000	9189	12.62	1.0E+00	0.2026	0.88819	0.00113	0.89044	ncsrcyt11_19_1_15	0.0008	0.88857	0.00136	0.89129
ncsbcyt11_18_1_15	18000	18000	9242	13.40	1.0E+00	0.2037	0.88255	0.00126	0.88507	ncsrcyt11_18_1_15	0.0008	0.88157	0.00127	0.88410
with can spacers (np thickness = 1.4 in.)										**with can spacers (np thickness = 1.4 in.)**				
ncsbcyt11_36_2_1	36000	36000	7673	5.56	1.0E-20	0.4882	0.83390	0.00106	0.83603	ncsrcyt11_36_2_1	0.0022	0.83904	0.00110	0.84125
ncsbcyt11_36_2_2	36000	36000	7673	5.56	1.0E-05	0.4879	0.83481	0.00142	0.83764	ncsrcyt11_36_2_2	0.0021	0.84122	0.00110	0.84342

Table 6.9.6-2. Results for 3.24 in.-diameter cylinder HEU metal content in bare and water reflected packaging calculation models

case name	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	nlf	k_{eff}	σ	$k_{eff}+2\sigma$	case name	nlf	k_{eff}	σ	$k_{eff}+2\sigma$
ncsbcyt11_36_2_3	36000	36000	7673	5.56	1.0E-04	0.4883	0.83383	0.00100	0.83583	ncsrcyt11_36_2_3	0.0022	0.84013	0.00106	0.84225
ncsbcyt11_36_2_4	36000	36000	7673	5.56	1.0E-03	0.4880	0.83530	0.00126	0.83783	ncsrcyt11_36_2_4	0.0022	0.84001	0.00112	0.84224
ncsbcyt11_36_2_5	36000	36000	7673	5.56	1.0E-02	0.4861	0.83461	0.00120	0.83702	ncsrcyt11_36_2_5	0.0021	0.84128	0.00115	0.84359
ncsbcyt11_36_2_6	36000	36000	7673	5.56	1.0E-01	0.4642	0.83979	0.00110	0.84199	ncsrcyt11_36_2_6	0.0020	0.84524	0.00116	0.84755
ncsbcyt11_36_2_8	36000	36000	7673	5.56	3.0E-01	0.4000	0.84736	0.00123	0.84982	ncsrcyt11_36_2_8	0.0016	0.84947	0.00103	0.85153
ncsbcyt11_36_2_15	36000	36000	7673	5.56	1.0E+00	0.1881	0.87048	0.00109	0.87266	ncsrcyt11_36_2_15	0.0008	0.87062	0.00122	0.87305
ncsbcyt11_36_2_15	36000	36000	7673	5.56	1.0E+00	0.1881	0.87048	0.00109	0.87266	ncsrcyt11_36_2_15	0.0008	0.87062	0.00122	0.87305
ncsbcyt11_35_2_15	35000	35000	7726	5.76	1.0E+00	0.1879	0.86609	0.00114	0.86836	ncsrcyt11_35_2_15	0.0007	0.86649	0.00118	0.86886
ncsbcyt11_34_2_15	34000	34000	7779	5.97	1.0E+00	0.1885	0.86151	0.00103	0.86358	ncsrcyt11_34_2_15	0.0008	0.86038	0.00129	0.86296
ncsbcyt11_33_2_15	33000	33000	7832	6.19	1.0E+00	0.1901	0.85729	0.00099	0.85927	ncsrcyt11_33_2_15	0.0007	0.85903	0.00106	0.86115
ncsbcyt11_32_2_15	32000	32000	7885	6.43	1.0E+00	0.1908	0.85350	0.00116	0.85582	ncsrcyt11_32_2_15	0.0007	0.85357	0.00108	0.85573
ncsbcyt11_31_2_15	31000	31000	7938	6.68	1.0E+00	0.1922	0.84914	0.00108	0.85129	ncsrcyt11_31_2_15	0.0008	0.84895	0.00123	0.85142
ncsbcyt11_30_2_15	30000	30000	7992	6.95	1.0E+00	0.1913	0.84250	0.00100	0.84450	ncsrcyt11_30_2_15	0.0008	0.84343	0.00114	0.84572

Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, single package reflected													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
ncsrcyt11_36_1_1	0.0	36000	36000	8287	6.01	1.0E-20	0.91542	0.00120	0.91782	hcsrcyt12_36_1_1	0.91636	0.00117	0.91869
ncsrcyt11_36_1_2	0.0	36000	36000	8287	6.01	1.0E-05	0.91477	0.00123	0.91724	hcsrcyt12_36_1_2	0.91593	0.00138	0.91869

Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrcyt11_36_1_3	0.0	36000	36000	8287	6.01	1.0E-04	0.91550	0.00111	0.91772	hcsrcyt12_36_1_3	0.91660	0.00134	0.91929
ncsrcyt11_36_1_4	0.0	36000	36000	8287	6.01	1.0E-03	0.91636	0.00117	0.91869	hcsrcyt12_36_1_4	0.91565	0.00122	0.91810
ncsrcyt11_36_1_5	0.0	36000	36000	8287	6.01	1.0E-02	0.91537	0.00109	0.91755	hcsrcyt12_36_1_5	0.91489	0.00120	0.91729
ncsrcyt11_36_1_6	0.0	36000	36000	8287	6.01	1.0E-01	0.92121	0.00133	0.92386	hcsrcyt12_36_1_6	0.92198	0.00104	0.92407
ncsrcyt11_36_1_8	0.0	36000	36000	8287	6.01	3.0E-01	0.92807	0.00112	0.93032	hcsrcyt12_36_1_8	0.92950	0.00125	0.93201
ncsrcyt11_36_1_15	0.0	36000	36000	8287	6.01	1.0E+00	0.95213	0.00129	0.95472	hcsrcyt12_36_1_15	0.95112	0.00120	0.95353
ncsrcyt11_36_1_15	0.0	36000	36000	8287	6.01	1.0E+00	0.95213	0.00129	0.95472	hcsrcyt12_36_1_15	0.95112	0.00120	0.95353
ncsrcyt11_35_1_15	0.0	35000	35000	8340	6.22	1.0E+00	0.94870	0.00107	0.95083	hcsrcyt12_35_1_15	0.94915	0.00120	0.95155
ncsrcyt11_34_1_15	0.0	34000	34000	8393	6.44	1.0E+00	0.94742	0.00124	0.94990	hcsrcyt12_34_1_15	0.94863	0.00113	0.95088
ncsrcyt11_33_1_15	0.0	33000	33000	8446	6.68	1.0E+00	0.94478	0.00119	0.94716	hcsrcyt12_33_1_15	0.94610	0.00123	0.94856
ncsrcyt11_32_1_15	0.0	32000	32000	8499	6.93	1.0E+00	0.94247	0.00111	0.94468	hcsrcyt12_32_1_15	0.94528	0.00141	0.94810
ncsrcyt11_31_1_15	0.0	31000	31000	8552	7.20	1.0E+00	0.94091	0.00107	0.94306	hcsrcyt12_31_1_15	0.94090	0.00107	0.94304
ncsrcyt11_30_1_15	0.0	30000	30000	8605	7.49	1.0E+00	0.94139	0.00137	0.94412	hcsrcyt12_30_1_15	0.94035	0.00120	0.94275
ncsrcyt11_29_1_15	0.0	29000	29000	8658	7.79	1.0E+00	0.93406	0.00108	0.93622	hcsrcyt12_29_1_15	0.93540	0.00112	0.93765
ncsrcyt11_28_1_15	0.0	28000	28000	8711	8.12	1.0E+00	0.93012	0.00124	0.93261	hcsrcyt12_28_1_15	0.93239	0.00118	0.93475
ncsrcyt11_27_1_15	0.0	27000	27000	8764	8.47	1.0E+00	0.92820	0.00122	0.93064	hcsrcyt12_27_1_15	0.93043	0.00144	0.93331
ncsrcyt11_26_1_15	0.0	26000	26000	8817	8.85	1.0E+00	0.92396	0.00141	0.92679	hcsrcyt12_26_1_15	0.92632	0.00119	0.92870
ncsrcyt11_25_1_15	0.0	25000	25000	8870	9.26	1.0E+00	0.91761	0.00102	0.91966	hcsrcyt12_25_1_15	0.92218	0.00109	0.92436
ncsrcyt11_24_1_15	0.0	24000	24000	8923	9.70	1.0E+00	0.91466	0.00107	0.91680	hcsrcyt12_24_1_15	0.91688	0.00117	0.91922
ncsrcyt11_23_1_15	0.0	23000	23000	8977	10.19	1.0E+00	0.91172	0.00116	0.91403	hcsrcyt12_23_1_15	0.91134	0.00119	0.91371
ncsrcyt11_22_1_15	0.0	22000	22000	9030	10.71	1.0E+00	0.90680	0.00153	0.90986	hcsrcyt12_22_1_15	0.90850	0.00113	0.91077
ncsrcyt11_21_1_15	0.0	21000	21000	9083	11.29	1.0E+00	0.90125	0.00113	0.90352	hcsrcyt12_21_1_15	0.90188	0.00124	0.90437
ncsrcyt11_20_1_15	0.0	20000	20000	9136	11.92	1.0E+00	0.89481	0.00109	0.89698	hcsrcyt12_20_1_15	0.89612	0.00115	0.89842

Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrcyt11_19_1_15	0.0	19000	19000	9189	12.62	1.0E+00	0.88857	0.00136	0.89129	hcsrcyt12_19_1_15	0.89080	0.00122	0.89323
ncsrcyt11_18_1_15	0.0	18000	18000	9242	13.40	1.0E+00	0.88157	0.00127	0.88410	hcsrcyt12_18_1_15	0.88276	0.00128	0.88532
with can spacers (np thickness = 1.4 in.)													
ncsrcyt11_36_2_1	1.4	36000	36000	7673	5.56	1.0E-20	0.83904	0.00110	0.84125	hcsrcyt12_36_2_1	0.84250	0.00103	0.84456
ncsrcyt11_36_2_2	1.4	36000	36000	7673	5.56	1.0E-05	0.84122	0.00110	0.84342	hcsrcyt12_36_2_2	0.84146	0.00118	0.84382
ncsrcyt11_36_2_3	1.4	36000	36000	7673	5.56	1.0E-04	0.84013	0.00106	0.84225	hcsrcyt12_36_2_3	0.84182	0.00105	0.84392
ncsrcyt11_36_2_4	1.4	36000	36000	7673	5.56	1.0E-03	0.84001	0.00112	0.84224	hcsrcyt12_36_2_4	0.83975	0.00103	0.84181
ncsrcyt11_36_2_5	1.4	36000	36000	7673	5.56	1.0E-02	0.84128	0.00115	0.84359	hcsrcyt12_36_2_5	0.84070	0.00129	0.84328
ncsrcyt11_36_2_6	1.4	36000	36000	7673	5.56	1.0E-01	0.84524	0.00116	0.84755	hcsrcyt12_36_2_6	0.84484	0.00127	0.84738
ncsrcyt11_36_2_8	1.4	36000	36000	7673	5.56	3.0E-01	0.84947	0.00103	0.85153	hcsrcyt12_36_2_8	0.85159	0.00102	0.85364
ncsrcyt11_36_2_15	1.4	36000	36000	7673	5.56	1.0E+00	0.87062	0.00122	0.87305	hcsrcyt12_36_2_15	0.87110	0.00117	0.87344
ncsrcyt11_36_2_15	1.4	36000	36000	7673	5.56	1.0E+00	0.87062	0.00122	0.87305	hcsrcyt12_36_2_15	0.87110	0.00117	0.87344
ncsrcyt11_35_2_15	1.4	35000	35000	7726	5.76	1.0E+00	0.86649	0.00118	0.86886	hcsrcyt12_35_2_15	0.86666	0.00110	0.86886
ncsrcyt11_34_2_15	1.4	34000	34000	7779	5.97	1.0E+00	0.86038	0.00129	0.86296	hcsrcyt12_34_2_15	0.86109	0.00117	0.86343
ncsrcyt11_33_2_15	1.4	33000	33000	7832	6.19	1.0E+00	0.85903	0.00106	0.86115	hcsrcyt12_33_2_15	0.86022	0.00123	0.86267
ncsrcyt11_32_2_15	1.4	32000	32000	7885	6.43	1.0E+00	0.85357	0.00108	0.85573	hcsrcyt12_32_2_15	0.85544	0.00096	0.85736
ncsrcyt11_31_2_15	1.4	31000	31000	7938	6.68	1.0E+00	0.84895	0.00123	0.85142	hcsrcyt12_31_2_15	0.84745	0.00105	0.84956
ncsrcyt11_30_2_15	1.4	30000	30000	7992	6.95	1.0E+00	0.84343	0.00114	0.84572	hcsrcyt12_30_2_15	0.84390	0.00112	0.84615
content in flooded containment vessel, array packaging model for CSI=0.0													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
nciacyt11_36_1_1	0.0	36000	36000	8287	6.01	1.0E-20	1.02410	0.00125	1.02660	hciacyt12_36_1_1	1.02427	0.00120	1.02667
nciacyt11_36_1_2	0.0	36000	36000	8287	6.01	1.0E-05	1.02380	0.00124	1.02628	hciacyt12_36_1_2	1.02384	0.00130	1.02644
nciacyt11_36_1_3	0.0	36000	36000	8287	6.01	1.0E-04	1.02208	0.00111	1.02430	hciacyt12_36_1_3	1.02390	0.00135	1.02660

Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciacyt11_36_1_4	0.0	36000	36000	8287	6.01	1.0E-03	1.02276	0.00134	1.02545	hciacyt12_36_1_4	1.02441	0.00122	1.02684
nciacyt11_36_1_5	0.0	36000	36000	8287	6.01	1.0E-02	1.01749	0.00124	1.01997	hciacyt12_36_1_5	1.01867	0.00114	1.02094
nciacyt11_36_1_6	0.0	36000	36000	8287	6.01	1.0E-01	0.98560	0.00118	0.98797	hciacyt12_36_1_6	0.98825	0.00112	0.99048
nciacyt11_36_1_8	0.0	36000	36000	8287	6.01	3.0E-01	0.96228	0.00116	0.96461	hciacyt12_36_1_8	0.96519	0.00122	0.96763
nciacyt11_36_1_15	0.0	36000	36000	8287	6.01	1.0E+00	0.96088	0.00119	0.96326	hciacyt12_36_1_15	0.96417	0.00119	0.96655
nciacyt11_36_1_3	0.0	36000	36000	8287	6.01	1.0E-04	1.02208	0.00111	1.02430	hciacyt12_36_1_3	1.02390	0.00135	1.02660
nciacyt11_35_1_3	0.0	35000	35000	8340	6.22	1.0E-04	1.01930	0.00118	1.02166	hciacyt12_35_1_3	1.01912	0.00127	1.02165
nciacyt11_34_1_3	0.0	34000	34000	8393	6.44	1.0E-04	1.01654	0.00130	1.01914	hciacyt12_34_1_3	1.01860	0.00104	1.02068
nciacyt11_33_1_3	0.0	33000	33000	8446	6.68	1.0E-04	1.01121	0.00116	1.01353	hciacyt12_33_1_3	1.01077	0.00142	1.01361
nciacyt11_32_1_3	0.0	32000	32000	8499	6.93	1.0E-04	1.00876	0.00134	1.01144	hciacyt12_32_1_3	1.00943	0.00114	1.01171
nciacyt11_31_1_3	0.0	31000	31000	8552	7.20	1.0E-04	1.00544	0.00116	1.00777	hciacyt12_31_1_3	1.00148	0.00102	1.00353
nciacyt11_30_1_3	0.0	30000	30000	8605	7.49	1.0E-04	0.99921	0.00131	1.00182	hciacyt12_30_1_3	0.99963	0.00138	1.00238
nciacyt11_29_1_3	0.0	29000	29000	8658	7.79	1.0E-04	0.99494	0.00121	0.99736	hciacyt12_29_1_3	0.99453	0.00117	0.99687
nciacyt11_28_1_3	0.0	28000	28000	8711	8.12	1.0E-04	0.98905	0.00124	0.99152	hciacyt12_28_1_3	0.99159	0.00123	0.99405
nciacyt11_27_1_3	0.0	27000	27000	8764	8.47	1.0E-04	0.98520	0.00115	0.98750	hciacyt12_27_1_3	0.98720	0.00122	0.98963
nciacyt11_26_1_3	0.0	26000	26000	8817	8.85	1.0E-04	0.97887	0.00117	0.98120	hciacyt12_26_1_3	0.97870	0.00130	0.98129
nciacyt11_25_1_3	0.0	25000	25000	8870	9.26	1.0E-04	0.97441	0.00118	0.97676	hciacyt12_25_1_3	0.97501	0.00106	0.97713
nciacyt11_24_1_3	0.0	24000	24000	8923	9.70	1.0E-04	0.96997	0.00115	0.97228	hciacyt12_24_1_3	0.96945	0.00122	0.97188
nciacyt11_23_1_3	0.0	23000	23000	8977	10.19	1.0E-04	0.96203	0.00122	0.96447	hciacyt12_23_1_3	0.96228	0.00121	0.96469
nciacyt11_22_1_3	0.0	22000	22000	9030	10.71	1.0E-04	0.95256	0.00110	0.95475	hciacyt12_22_1_3	0.95313	0.00138	0.95589
nciacyt11_21_1_3	0.0	21000	21000	9083	11.29	1.0E-04	0.94755	0.00114	0.94982	hciacyt12_21_1_3	0.94735	0.00121	0.94976
nciacyt11_20_1_3	0.0	20000	20000	9136	11.92	1.0E-04	0.93967	0.00124	0.94215	hciacyt12_20_1_3	0.94131	0.00113	0.94357
nciacyt11_19_1_3	0.0	19000	19000	9189	12.62	1.0E-04	0.93107	0.00113	0.93334	hciacyt12_19_1_3	0.92967	0.00120	0.93207
nciacyt11_18_1_3	0.0	18000	18000	9242	13.40	1.0E-04	0.92165	0.00100	0.92366	hciacyt12_18_1_3	0.92083	0.00110	0.92302

Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciacyt11_15_1_3	0.0	15000	15000	9401	16.36	1.0E-04	0.88925	0.00111	0.89146	hciacyt12_15_1_3	0.88802	0.00116	0.89034
nciacyt11_12_1_3	0.0	12000	12000	9560	20.79	1.0E-04	0.84430	0.00103	0.84636	hciacyt12_12_1_3	0.84558	0.00110	0.84777
nciacyt11_9_1_3	0.0	9000	9000	9719	28.19	1.0E-04	0.78552	0.00116	0.78784	hciacyt12_9_1_3	0.78464	0.00132	0.78728
nciacyt11_6_1_3	0.0	6000	6000	9879	42.97	1.0E-04	0.69176	0.00119	0.69414	hciacyt12_6_1_3	0.69169	0.00122	0.69413
nciacyt11_3_1_3	0.0	3000	3000	10038	87.33	1.0E-04	0.53217	0.00084	0.53385	hciacyt12_3_1_3	0.53298	0.00091	0.53481
with can spacers (np thickness = 1.4 in.)													
nciacyt11_36_2_1	1.4	36000	36000	7673	5.56	1.0E-20	0.95474	0.00109	0.95693	hciacyt12_36_2_1	0.95429	0.00106	0.95641
nciacyt11_36_2_2	1.4	36000	36000	7673	5.56	1.0E-05	0.95402	0.00119	0.95640	hciacyt12_36_2_2	0.95522	0.00105	0.95732
nciacyt11_36_2_3	1.4	36000	36000	7673	5.56	1.0E-04	0.95362	0.00105	0.95571	hciacyt12_36_2_3	0.95319	0.00139	0.95596
nciacyt11_36_2_4	1.4	36000	36000	7673	5.56	1.0E-03	0.95222	0.00128	0.95478	hciacyt12_36_2_4	0.95333	0.00116	0.95564
nciacyt11_36_2_5	1.4	36000	36000	7673	5.56	1.0E-02	0.94649	0.00110	0.94869	hciacyt12_36_2_5	0.94837	0.00124	0.95084
nciacyt11_36_2_6	1.4	36000	36000	7673	5.56	1.0E-01	0.91268	0.00128	0.91524	hciacyt12_36_2_6	0.91591	0.00121	0.91834
nciacyt11_36_2_8	1.4	36000	36000	7673	5.56	3.0E-01	0.88453	0.00140	0.88733	hciacyt12_36_2_8	0.89062	0.00119	0.89300
nciacyt11_36_2_15	1.4	36000	36000	7673	5.56	1.0E+00	0.87822	0.00106	0.88034	hciacyt12_36_2_15	0.88152	0.00135	0.88423
nciacyt11_36_2_3	1.4	36000	36000	7673	5.56	1.0E-04	0.95362	0.00105	0.95571	hciacyt12_36_2_3	0.95319	0.00139	0.95596
nciacyt11_35_2_3	1.4	35000	35000	7726	5.76	1.0E-04	0.94906	0.00125	0.95156	hciacyt12_35_2_3	0.94788	0.00129	0.95046
nciacyt11_34_2_3	1.4	34000	34000	7779	5.97	1.0E-04	0.94393	0.00136	0.94664	hciacyt12_34_2_3	0.94428	0.00130	0.94687
nciacyt11_33_2_3	1.4	33000	33000	7832	6.19	1.0E-04	0.93703	0.00114	0.93930	hciacyt12_33_2_3	0.93708	0.00122	0.93952
nciacyt11_32_2_3	1.4	32000	32000	7885	6.43	1.0E-04	0.92940	0.00125	0.93191	hciacyt12_32_2_3	0.93065	0.00109	0.93283
nciacyt11_31_2_3	1.4	31000	31000	7938	6.68	1.0E-04	0.92483	0.00119	0.92721	hciacyt12_31_2_3	0.92625	0.00125	0.92874
nciacyt11_30_2_3	1.4	30000	30000	7992	6.95	1.0E-04	0.91737	0.00106	0.91949	hciacyt12_30_2_3	0.91983	0.00107	0.92198
nciacyt11_29_2_3	1.4	29000	29000	8045	7.24	1.0E-04	0.91253	0.00116	0.91484	hciacyt12_29_2_3	0.91204	0.00107	0.91419
nciacyt11_28_2_3	1.4	28000	28000	8098	7.55	1.0E-04	0.90504	0.00117	0.90737	hciacyt12_28_2_3	0.90515	0.00100	0.90716
nciacyt11_27_2_3	1.4	27000	27000	8151	7.88	1.0E-04	0.89967	0.00121	0.90208	hciacyt12_27_2_3	0.89749	0.00097	0.89942

Table 6.9.6-3. Results for 3.24 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciacyt11_26_2_3	1.4	26000	26000	8204	8.24	1.0E-04	0.89129	0.00107	0.89343	hciacyt12_26_2_3	0.88997	0.00124	0.89246
nciacyt11_25_2_3	1.4	25000	25000	8257	8.62	1.0E-04	0.88183	0.00104	0.88391	hciacyt12_25_2_3	0.88253	0.00129	0.88511
nciacyt11_24_2_3	1.4	24000	24000	8310	9.04	1.0E-04	0.87406	0.00117	0.87640	hciacyt12_24_2_3	0.87448	0.00117	0.87681
nciacyt11_23_2_3	1.4	23000	23000	8363	9.49	1.0E-04	0.86345	0.00109	0.86564	hciacyt12_23_2_3	0.86388	0.00119	0.86626
nciacyt11_22_2_3	1.4	22000	22000	8416	9.98	1.0E-04	0.85413	0.00107	0.85627	hciacyt12_22_2_3	0.85333	0.00109	0.85551
nciacyt11_21_2_3	1.4	21000	21000	8469	10.53	1.0E-04	0.84424	0.00109	0.84642	hciacyt12_21_2_3	0.84414	0.00111	0.84636
nciacyt11_20_2_3	1.4	20000	20000	8522	11.12	1.0E-04	0.83545	0.00106	0.83756	hciacyt12_20_2_3	0.83388	0.00099	0.83585
nciacyt11_19_2_3	1.4	19000	19000	8575	11.78	1.0E-04	0.82051	0.00130	0.82311	hciacyt12_19_2_3	0.82263	0.00109	0.82480
nciacyt11_18_2_3	1.4	18000	18000	8628	12.51	1.0E-04	0.81105	0.00122	0.81350	hciacyt12_18_2_3	0.81076	0.00113	0.81301
nciacyt11_15_2_3	1.4	15000	15000	8787	15.29	1.0E-04	0.76734	0.00107	0.76948	hciacyt12_15_2_3	0.76757	0.00102	0.76960
nciacyt11_12_2_3	1.4	12000	12000	8947	19.46	1.0E-04	0.71377	0.00097	0.71571	hciacyt12_12_2_3	0.71466	0.00102	0.71669
nciacyt11_9_2_3	1.4	9000	9000	9106	26.41	1.0E-04	0.64515	0.00110	0.64734	hciacyt12_9_2_3	0.64486	0.00103	0.64692
nciacyt11_6_2_3	1.4	6000	6000	9265	40.30	1.0E-04	0.54772	0.00094	0.54960	hciacyt12_6_2_3	0.54697	0.00098	0.54893
nciacyt11_3_2_3	1.4	3000	3000	9424	81.99	1.0E-04	0.39773	0.00080	0.39933	hciacyt12_3_2_3	0.39723	0.00087	0.39896

Table 6.9.6-3b. Results for spacing of 3.24 in.-diameter cylinder HEU metal content in CV calculation model

case name	np (in.)	^{235}U (g)	H_2O (g)	h/x	separation (cm)	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, reflected									
NCT									
separation is the distance between the 3.24 in.-diameter cylinders (an additional 1.4 in. is provided by the can spacer)									
cvcrcyat11_1_2	1.4	30000	7992	6.95	0.000	1.0E+00	0.85525	0.00117	0.85760
cvcrcyat11_2_2	1.4	30000	7992	6.95	0.254	1.0E+00	0.85568	0.00100	0.85768

Table 6.9.6-3b. Results for spacing of 3.24 in.-diameter cylinder HEU metal content in CV calculation model

case name	np (in.)	^{235}U (g)	H_2O (g)	h/x	separation (cm)	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrcyat11_3_2	1.4	30000	7992	6.95	0.762	1.0E+00	0.85058	0.00110	0.85278
cvcrcyat11_4_2	1.4	30000	7992	6.95	1.270	1.0E+00	0.84834	0.00124	0.85082
cvcrcyat11_5_2	1.4	30000	7992	6.95	1.778	1.0E+00	0.84241	0.00123	0.84488
cvcrcyat11_6_2	1.4	30000	7992	6.95	2.286	1.0E+00	0.83866	0.00099	0.84063
cvcrcyat11_7_2	1.4	30000	7992	6.95	2.794	1.0E+00	0.83549	0.00117	0.83782
cvcrcyat11_8_2	1.4	30000	7992	6.95	3.302	1.0E+00	0.83213	0.00126	0.83465
cvcrcyat11_9_2	1.4	30000	7992	6.95	3.810	1.0E+00	0.82984	0.00125	0.83233
cvcrcyat11_10_2	1.4	30000	7992	6.95	4.318	1.0E+00	0.82777	0.00105	0.82986
cvcrcyat11_11_2	1.4	30000	7992	6.95	4.826	1.0E+00	0.82499	0.00116	0.82731
cvcrcyat11_12_2	1.4	30000	7992	6.95	12.230	1.0E+00	0.80870	0.00121	0.81113

Table 6.9.6-3c. Results for spacing of 3.24 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	^{235}U (g)	H_2O (g)	h/x	separation (cm)	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, single package reflected									
NCT									
separation is the distance between the 3.24 in.-diameter cylinders (an additional 1.4 in. is provided by the canned spacer)									
ncsrcyat11_1_2_15	1.4	30000	7992	6.95	0.000	1.0E+00	0.84343	0.00114	0.84572
ncsrcyat11_2_2_15	1.4	30000	7992	6.95	0.254	1.0E+00	0.84249	0.00111	0.84472
ncsrcyat11_3_2_15	1.4	30000	7992	6.95	0.762	1.0E+00	0.83638	0.00103	0.83845
ncsrcyat11_4_2_15	1.4	30000	7992	6.95	1.270	1.0E+00	0.83416	0.00110	0.83636
ncsrcyat11_5_2_15	1.4	30000	7992	6.95	1.778	1.0E+00	0.82786	0.00128	0.83043
ncsrcyat11_6_2_15	1.4	30000	7992	6.95	2.286	1.0E+00	0.82516	0.00113	0.82743

Table 6.9.6-3c. Results for spacing of 3.24 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	^{235}U (g)	H_2O (g)	h/x	separation (cm)	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrcyat11_7_2_15	1.4	30000	7992	6.95	2.794	1.0E+00	0.82161	0.00116	0.82393
ncsrcyat11_8_2_15	1.4	30000	7992	6.95	3.302	1.0E+00	0.82004	0.00114	0.82232
ncsrcyat11_9_2_15	1.4	30000	7992	6.95	3.810	1.0E+00	0.81641	0.00101	0.81843
ncsrcyat11_10_2_15	1.4	30000	7992	6.95	4.318	1.0E+00	0.81362	0.00109	0.81581
ncsrcyat11_11_2_15	1.4	30000	7992	6.95	4.826	1.0E+00	0.81218	0.00104	0.81426
ncsrcyat11_12_2_15	1.4	30000	7992	6.95	12.230	1.0E+00	0.79592	0.00100	0.79793

Table 6.9.6-4. Results for 2.29 in.-square bar HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
flooded containment vessel, reflected									
no can spacers (np thickness = 0.0 in.)									
cvcrsqt11_36_1	0.0	36000	36000	8287	6.01	1.0E+00	0.87614	0.00128	0.87869
cvcrsqt11_35_1	0.0	35000	35000	8340	6.22	1.0E+00	0.87560	0.00111	0.87781
cvcrsqt11_34_1	0.0	34000	34000	8393	6.44	1.0E+00	0.87541	0.00126	0.87794
cvcrsqt11_33_1	0.0	33000	33000	8446	6.68	1.0E+00	0.87396	0.00108	0.87612
cvcrsqt11_32_1	0.0	32000	32000	8499	6.93	1.0E+00	0.87319	0.00119	0.87556
cvcrsqt11_31_1	0.0	31000	31000	8552	7.20	1.0E+00	0.86993	0.00116	0.87225
cvcrsqt11_30_1	0.0	30000	30000	8605	7.49	1.0E+00	0.87046	0.00120	0.87286
cvcrsqt11_29_1	0.0	29000	29000	8658	7.79	1.0E+00	0.86852	0.00107	0.87067
cvcrsqt11_28_1	0.0	28000	28000	8711	8.12	1.0E+00	0.86740	0.00113	0.86966
cvcrsqt11_27_1	0.0	27000	27000	8764	8.47	1.0E+00	0.86366	0.00116	0.86597
cvcrsqt11_26_1	0.0	26000	26000	8817	8.85	1.0E+00	0.86498	0.00138	0.86773

Table 6.9.6-4. Results for 2.29 in.-square bar HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsqt11_25_1	0.0	25000	25000	8870	9.26	1.0E+00	0.86077	0.00121	0.86319
cvcrsqt11_24_1	0.0	24000	24000	8923	9.70	1.0E+00	0.85955	0.00138	0.86231
cvcrsqt11_23_1	0.0	23000	23000	8977	10.19	1.0E+00	0.85604	0.00106	0.85816
cvcrsqt11_22_1	0.0	22000	22000	9030	10.71	1.0E+00	0.85211	0.00103	0.85417
cvcrsqt11_21_1	0.0	21000	21000	9083	11.29	1.0E+00	0.84970	0.00118	0.85206
cvcrsqt11_20_1	0.0	20000	20000	9136	11.92	1.0E+00	0.84694	0.00119	0.84931
cvcrsqt11_19_1	0.0	19000	19000	9189	12.62	1.0E+00	0.84285	0.00109	0.84503
cvcrsqt11_18_1	0.0	18000	18000	9242	13.40	1.0E+00	0.83888	0.00115	0.84117
with can spacers (np thickness=1.4 in.)									
cvcrsqt11_36_2	1.4	36000	36000	7673	5.56	1.0E+00	0.82217	0.00098	0.82414
cvcrsqt11_35_2	1.4	35000	35000	7726	5.76	1.0E+00	0.81622	0.00130	0.81881
cvcrsqt11_34_2	1.4	34000	34000	7779	5.97	1.0E+00	0.81548	0.00103	0.81755
cvcrsqt11_33_2	1.4	33000	33000	7832	6.19	1.0E+00	0.81272	0.00118	0.81508
cvcrsqt11_32_2	1.4	32000	32000	7885	6.43	1.0E+00	0.80782	0.00120	0.81022
cvcrsqt11_31_2	1.4	31000	31000	7938	6.68	1.0E+00	0.80495	0.00109	0.80712
cvcrsqt11_30_2	1.4	30000	30000	7992	6.95	1.0E+00	0.80163	0.00117	0.80397

Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, single package reflected													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
ncsrsqt11_36_1_1	0.0	36000	36000	8287	6.01	1.0E-20	0.82940	0.00124	0.83189	hcsrsqt12_36_1_1	0.83133	0.00125	0.83384
ncsrsqt11_36_1_2	0.0	36000	36000	8287	6.01	1.0E-05	0.83107	0.00107	0.83320	hcsrsqt12_36_1_2	0.83168	0.00121	0.83409
ncsrsqt11_36_1_3	0.0	36000	36000	8287	6.01	1.0E-04	0.83051	0.00120	0.83292	hcsrsqt12_36_1_3	0.83088	0.00103	0.83293
ncsrsqt11_36_1_4	0.0	36000	36000	8287	6.01	1.0E-03	0.82981	0.00116	0.83213	hcsrsqt12_36_1_4	0.83030	0.00122	0.83273
ncsrsqt11_36_1_5	0.0	36000	36000	8287	6.01	1.0E-02	0.82859	0.00123	0.83105	hcsrsqt12_36_1_5	0.83244	0.00126	0.83496
ncsrsqt11_36_1_6	0.0	36000	36000	8287	6.01	1.0E-01	0.83608	0.00123	0.83853	hcsrsqt12_36_1_6	0.83502	0.00119	0.83739
ncsrsqt11_36_1_8	0.0	36000	36000	8287	6.01	3.0E-01	0.84146	0.00118	0.84382	hcsrsqt12_36_1_8	0.84236	0.00115	0.84465
ncsrsqt11_36_1_15	0.0	36000	36000	8287	6.01	1.0E+00	0.86253	0.00131	0.86516	hcsrsqt12_36_1_15	0.86198	0.00112	0.86422
ncsrsqt11_36_1_15	0.0	36000	36000	8287	6.01	1.0E+00	0.86253	0.00131	0.86516	hcsrsqt12_36_1_15	0.86198	0.00112	0.86422
ncsrsqt11_35_1_15	0.0	35000	35000	8340	6.22	1.0E+00	0.86041	0.00112	0.86265	hcsrsqt12_35_1_15	0.86067	0.00121	0.86309
ncsrsqt11_34_1_15	0.0	34000	34000	8393	6.44	1.0E+00	0.85820	0.00129	0.86078	hcsrsqt12_34_1_15	0.85896	0.00102	0.86101
ncsrsqt11_33_1_15	0.0	33000	33000	8446	6.68	1.0E+00	0.85708	0.00106	0.85920	hcsrsqt12_33_1_15	0.86064	0.00110	0.86285
ncsrsqt11_32_1_15	0.0	32000	32000	8499	6.93	1.0E+00	0.85769	0.00107	0.85983	hcsrsqt12_32_1_15	0.85800	0.00110	0.86020
ncsrsqt11_31_1_15	0.0	31000	31000	8552	7.20	1.0E+00	0.85495	0.00127	0.85749	hcsrsqt12_31_1_15	0.85333	0.00123	0.85580
ncsrsqt11_30_1_15	0.0	30000	30000	8605	7.49	1.0E+00	0.85270	0.00120	0.85510	hcsrsqt12_30_1_15	0.85520	0.00132	0.85784
ncsrsqt11_29_1_15	0.0	29000	29000	8658	7.79	1.0E+00	0.85067	0.00119	0.85305	hcsrsqt12_29_1_15	0.85348	0.00114	0.85575
ncsrsqt11_28_1_15	0.0	28000	28000	8711	8.12	1.0E+00	0.85223	0.00111	0.85446	hcsrsqt12_28_1_15	0.85043	0.00101	0.85246
ncsrsqt11_27_1_15	0.0	27000	27000	8764	8.47	1.0E+00	0.84973	0.00121	0.85214	hcsrsqt12_27_1_15	0.85029	0.00111	0.85250
ncsrsqt11_26_1_15	0.0	26000	26000	8817	8.85	1.0E+00	0.84838	0.00127	0.85091	hcsrsqt12_26_1_15	0.84829	0.00115	0.85058
ncsrsqt11_25_1_15	0.0	25000	25000	8870	9.26	1.0E+00	0.84598	0.00113	0.84824	hcsrsqt12_25_1_15	0.84583	0.00105	0.84792
ncsrsqt11_24_1_15	0.0	24000	24000	8923	9.70	1.0E+00	0.84390	0.00111	0.84611	hcsrsqt12_24_1_15	0.84296	0.00112	0.84521

Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrsqt11_23_1_15	0.0	23000	23000	8977	10.19	1.0E+00	0.84101	0.00108	0.84317	hcsrsqt12_23_1_15	0.84241	0.00129	0.84499
ncsrsqt11_22_1_15	0.0	22000	22000	9030	10.71	1.0E+00	0.83888	0.00112	0.84111	hcsrsqt12_22_1_15	0.83951	0.00107	0.84164
ncsrsqt11_21_1_15	0.0	21000	21000	9083	11.29	1.0E+00	0.83473	0.00112	0.83696	hcsrsqt12_21_1_15	0.83577	0.00128	0.83832
ncsrsqt11_20_1_15	0.0	20000	20000	9136	11.92	1.0E+00	0.83029	0.00110	0.83250	hcsrsqt12_20_1_15	0.83094	0.00103	0.83300
ncsrsqt11_19_1_15	0.0	19000	19000	9189	12.62	1.0E+00	0.82676	0.00107	0.82889	hcsrsqt12_19_1_15	0.82652	0.00113	0.82879
ncsrsqt11_18_1_15	0.0	18000	18000	9242	13.40	1.0E+00	0.82247	0.00121	0.82489	hcsrsqt12_18_1_15	0.82440	0.00112	0.82664
with can spacers (np thickness = 1.4 in.)													
ncsrsqt11_36_2_1	1.4	36000	36000	7673	5.56	1.0E-20	0.78167	0.00104	0.78375	hcsrsqt12_36_2_1	0.78308	0.00128	0.78563
ncsrsqt11_36_2_2	1.4	36000	36000	7673	5.56	1.0E-05	0.78210	0.00112	0.78434	hcsrsqt12_36_2_2	0.78549	0.00112	0.78772
ncsrsqt11_36_2_3	1.4	36000	36000	7673	5.56	1.0E-04	0.78209	0.00104	0.78417	hcsrsqt12_36_2_3	0.78508	0.00119	0.78746
ncsrsqt11_36_2_4	1.4	36000	36000	7673	5.56	1.0E-03	0.78414	0.00111	0.78636	hcsrsqt12_36_2_4	0.78484	0.00121	0.78727
ncsrsqt11_36_2_5	1.4	36000	36000	7673	5.56	1.0E-02	0.78141	0.00137	0.78415	hcsrsqt12_36_2_5	0.78362	0.00114	0.78591
ncsrsqt11_36_2_6	1.4	36000	36000	7673	5.56	1.0E-01	0.78591	0.00113	0.78818	hcsrsqt12_36_2_6	0.78757	0.00108	0.78972
ncsrsqt11_36_2_8	1.4	36000	36000	7673	5.56	3.0E-01	0.79206	0.00130	0.79466	hcsrsqt12_36_2_8	0.79070	0.00128	0.79327
ncsrsqt11_36_2_15	1.4	36000	36000	7673	5.56	1.0E+00	0.80894	0.00103	0.81101	hcsrsqt12_36_2_15	0.80856	0.00110	0.81077
ncsrsqt11_36_2_15	1.4	36000	36000	7673	5.56	1.0E+00	0.80894	0.00103	0.81101	hcsrsqt12_36_2_15	0.80856	0.00110	0.81077
ncsrsqt11_35_2_15	1.4	35000	35000	7726	5.76	1.0E+00	0.80583	0.00113	0.80808	hcsrsqt12_35_2_15	0.80522	0.00112	0.80747
ncsrsqt11_34_2_15	1.4	34000	34000	7779	5.97	1.0E+00	0.80341	0.00125	0.80591	hcsrsqt12_34_2_15	0.80255	0.00107	0.80469
ncsrsqt11_33_2_15	1.4	33000	33000	7832	6.19	1.0E+00	0.80213	0.00108	0.80429	hcsrsqt12_33_2_15	0.79972	0.00096	0.80164
ncsrsqt11_32_2_15	1.4	32000	32000	7885	6.43	1.0E+00	0.79784	0.00124	0.80032	hcsrsqt12_32_2_15	0.79750	0.00118	0.79985
ncsrsqt11_31_2_15	1.4	31000	31000	7938	6.68	1.0E+00	0.79226	0.00107	0.79440	hcsrsqt12_31_2_15	0.79447	0.00099	0.79646
ncsrsqt11_30_2_15	1.4	30000	30000	7992	6.95	1.0E+00	0.79192	0.00110	0.79412	hcsrsqt12_30_2_15	0.79053	0.00108	0.79268

Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, array packaging model for CSI=0.0													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
nciasqt11_36_1_3	0.0	36000	36000	8287	6.01	1.0E-04	0.93786	0.00112	0.94011	hciasqt12_36_1_3	0.93760	0.00119	0.93998
nciasqt11_35_1_3	0.0	35000	35000	8340	6.22	1.0E-04	0.93414	0.00107	0.93629	hciasqt12_35_1_3	0.93524	0.00130	0.93785
nciasqt11_34_1_3	0.0	34000	34000	8393	6.44	1.0E-04	0.93004	0.00116	0.93235	hciasqt12_34_1_3	0.92962	0.00116	0.93195
nciasqt11_33_1_3	0.0	33000	33000	8446	6.68	1.0E-04	0.92897	0.00121	0.93139	hciasqt12_33_1_3	0.92744	0.00120	0.92984
nciasqt11_32_1_3	0.0	32000	32000	8499	6.93	1.0E-04	0.92703	0.00119	0.92942	hciasqt12_32_1_3	0.92854	0.00110	0.93073
nciasqt11_31_1_3	0.0	31000	31000	8552	7.20	1.0E-04	0.92403	0.00109	0.92621	hciasqt12_31_1_3	0.92290	0.00105	0.92499
nciasqt11_30_1_3	0.0	30000	30000	8605	7.49	1.0E-04	0.91959	0.00114	0.92188	hciasqt12_30_1_3	0.91960	0.00125	0.92211
nciasqt11_29_1_3	0.0	29000	29000	8658	7.79	1.0E-04	0.91544	0.00122	0.91787	hciasqt12_29_1_3	0.91645	0.00138	0.91922
nciasqt11_28_1_3	0.0	28000	28000	8711	8.12	1.0E-04	0.91153	0.00123	0.91399	hciasqt12_28_1_3	0.91477	0.00122	0.91722
nciasqt11_27_1_3	0.0	27000	27000	8764	8.47	1.0E-04	0.90851	0.00099	0.91050	hciasqt12_27_1_3	0.91066	0.00119	0.91305
nciasqt11_26_1_3	0.0	26000	26000	8817	8.85	1.0E-04	0.90835	0.00125	0.91084	hciasqt12_26_1_3	0.90452	0.00124	0.90699
nciasqt11_25_1_3	0.0	25000	25000	8870	9.26	1.0E-04	0.90272	0.00115	0.90501	hciasqt12_25_1_3	0.90142	0.00116	0.90374
nciasqt11_24_1_3	0.0	24000	24000	8923	9.70	1.0E-04	0.89930	0.00123	0.90177	hciasqt12_24_1_3	0.89640	0.00120	0.89881
nciasqt11_23_1_3	0.0	23000	23000	8977	10.19	1.0E-04	0.89380	0.00120	0.89619	hciasqt12_23_1_3	0.89613	0.00135	0.89882
nciasqt11_22_1_3	0.0	22000	22000	9030	10.71	1.0E-04	0.88934	0.00105	0.89144	hciasqt12_22_1_3	0.88839	0.00106	0.89051
nciasqt11_21_1_3	0.0	21000	21000	9083	11.29	1.0E-04	0.88358	0.00109	0.88576	hciasqt12_21_1_3	0.88413	0.00118	0.88649
nciasqt11_20_1_3	0.0	20000	20000	9136	11.92	1.0E-04	0.87812	0.00123	0.88058	hciasqt12_20_1_3	0.87811	0.00124	0.88058
nciasqt11_19_1_3	0.0	19000	19000	9189	12.62	1.0E-04	0.87206	0.00108	0.87423	hciasqt12_19_1_3	0.87171	0.00118	0.87408
nciasqt11_18_1_3	0.0	18000	18000	9242	13.40	1.0E-04	0.86772	0.00140	0.87052	hciasqt12_18_1_3	0.86555	0.00119	0.86794
nciasqt11_15_1_3	0.0	15000	15000	9401	16.36	1.0E-04	0.84518	0.00119	0.84756	hciasqt12_15_1_3	0.84416	0.00102	0.84620
nciasqt11_12_1_3	0.0	12000	12000	9560	20.79	1.0E-04	0.81425	0.00113	0.81651	hciasqt12_12_1_3	0.81332	0.00101	0.81534
nciasqt11_9_1_3	0.0	9000	9000	9719	28.19	1.0E-04	0.76947	0.00115	0.77178	hciasqt12_9_1_3	0.77066	0.00107	0.77280

Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciasqt11_6_1_3	0.0	6000	6000	9879	42.97	1.0E-04	0.69668	0.00099	0.69866	hciasqt12_6_1_3	0.69648	0.00101	0.69850
nciasqt11_3_1_3	0.0	3000	3000	10038	87.33	1.0E-04	0.55857	0.00089	0.56036	hciasqt12_3_1_3	0.55806	0.00092	0.55989
with can spacers (np thickness = 1.4 in.)													
nciasqt11_36_2_3	1.4	36000	36000	7673	5.56	1.0E-04	0.89382	0.00114	0.89610	hciasqt12_36_2_3	0.89230	0.00114	0.89458
nciasqt11_35_2_3	1.4	35000	35000	7726	5.76	1.0E-04	0.88604	0.00105	0.88813	hciasqt12_35_2_3	0.88890	0.00130	0.89150
nciasqt11_34_2_3	1.4	34000	34000	7779	5.97	1.0E-04	0.88480	0.00105	0.88690	hciasqt12_34_2_3	0.88544	0.00139	0.88822
nciasqt11_33_2_3	1.4	33000	33000	7832	6.19	1.0E-04	0.87854	0.00118	0.88090	hciasqt12_33_2_3	0.87897	0.00106	0.88110
nciasqt11_32_2_3	1.4	32000	32000	7885	6.43	1.0E-04	0.87561	0.00104	0.87768	hciasqt12_32_2_3	0.87638	0.00121	0.87880
nciasqt11_31_2_3	1.4	31000	31000	7938	6.68	1.0E-04	0.86867	0.00123	0.87114	hciasqt12_31_2_3	0.87222	0.00105	0.87432
nciasqt11_30_2_3	1.4	30000	30000	7992	6.95	1.0E-04	0.86347	0.00122	0.86590	hciasqt12_30_2_3	0.86614	0.00121	0.86855
nciasqt11_29_2_3	1.4	29000	29000	8045	7.24	1.0E-04	0.85781	0.00109	0.86000	hciasqt12_29_2_3	0.85842	0.00113	0.86068
nciasqt11_28_2_3	1.4	28000	28000	8098	7.55	1.0E-04	0.85401	0.00119	0.85640	hciasqt12_28_2_3	0.85399	0.00116	0.85630
nciasqt11_27_2_3	1.4	27000	27000	8151	7.88	1.0E-04	0.84755	0.00127	0.85009	hciasqt12_27_2_3	0.84935	0.00125	0.85184
nciasqt11_26_2_3	1.4	26000	26000	8204	8.24	1.0E-04	0.84285	0.00119	0.84522	hciasqt12_26_2_3	0.84287	0.00106	0.84500
nciasqt11_25_2_3	1.4	25000	25000	8257	8.62	1.0E-04	0.83719	0.00124	0.83967	hciasqt12_25_2_3	0.83683	0.00113	0.83910
nciasqt11_24_2_3	1.4	24000	24000	8310	9.04	1.0E-04	0.82927	0.00102	0.83132	hciasqt12_24_2_3	0.83192	0.00111	0.83414
nciasqt11_23_2_3	1.4	23000	23000	8363	9.49	1.0E-04	0.82375	0.00132	0.82638	hciasqt12_23_2_3	0.82315	0.00124	0.82562
nciasqt11_22_2_3	1.4	22000	22000	8416	9.98	1.0E-04	0.81735	0.00107	0.81950	hciasqt12_22_2_3	0.81490	0.00105	0.81700
nciasqt11_21_2_3	1.4	21000	21000	8469	10.53	1.0E-04	0.80580	0.00118	0.80817	hciasqt12_21_2_3	0.81021	0.00121	0.81263
nciasqt11_20_2_3	1.4	20000	20000	8522	11.12	1.0E-04	0.79977	0.00110	0.80197	hciasqt12_20_2_3	0.80091	0.00116	0.80324
nciasqt11_19_2_3	1.4	19000	19000	8575	11.78	1.0E-04	0.79125	0.00109	0.79343	hciasqt12_19_2_3	0.79175	0.00113	0.79400
nciasqt11_18_2_3	1.4	18000	18000	8628	12.51	1.0E-04	0.78165	0.00110	0.78386	hciasqt12_18_2_3	0.78285	0.00110	0.78505
nciasqt11_15_2_3	1.4	15000	15000	8787	15.29	1.0E-04	0.74822	0.00105	0.75032	hciasqt12_15_2_3	0.74548	0.00107	0.74762
nciasqt11_12_2_3	1.4	12000	12000	8947	19.46	1.0E-04	0.70519	0.00106	0.70732	hciasqt12_12_2_3	0.70419	0.00105	0.70628
nciasqt11_9_2_3	1.4	9000	9000	9106	26.41	1.0E-04	0.64473	0.00106	0.64685	hciasqt12_9_2_3	0.64451	0.00101	0.64653

Table 6.9.6-5. Results for 2.29 in.-square bar HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciasqt11_6_2_3	1.4	6000	6000	9265	40.30	1.0E-04	0.55778	0.00097	0.55972	hciasqt12_6_2_3	0.55888	0.00098	0.56084
nciasqt11_3_2_3	1.4	3000	3000	9424	81.99	1.0E-04	0.41347	0.00085	0.41517	hciasqt12_3_2_3	0.41398	0.00074	0.41545

Table 6.9.6-6. Results for 4.25 in.-diameter cylinder HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
flooded containment vessel, reflected									
no can spacers (np thickness = 0.0 in.)									
cvcrcyct11_36_1	0.0	36000	36000	8287	6.01	1.0E+00	1.06320	0.00115	1.06549
cvcrcyct11_35_1	0.0	35000	35000	8340	6.22	1.0E+00	1.06114	0.00121	1.06356
cvcrcyct11_34_1	0.0	34000	34000	8393	6.44	1.0E+00	1.05675	0.00122	1.05919
cvcrcyct11_33_1	0.0	33000	33000	8446	6.68	1.0E+00	1.04990	0.00112	1.05214
cvcrcyct11_32_1	0.0	32000	32000	8499	6.93	1.0E+00	1.04469	0.00123	1.04714
cvcrcyct11_31_1	0.0	31000	31000	8552	7.20	1.0E+00	1.04101	0.00104	1.04310
cvcrcyct11_30_1	0.0	30000	30000	8605	7.49	1.0E+00	1.03487	0.00117	1.03722
cvcrcyct11_29_1	0.0	29000	29000	8658	7.79	1.0E+00	1.02817	0.00115	1.03046
cvcrcyct11_28_1	0.0	28000	28000	8711	8.12	1.0E+00	1.02183	0.00125	1.02433
cvcrcyct11_27_1	0.0	27000	27000	8764	8.47	1.0E+00	1.01524	0.00109	1.01742
cvcrcyct11_26_1	0.0	26000	26000	8817	8.85	1.0E+00	1.00971	0.00116	1.01203
cvcrcyct11_25_1	0.0	25000	25000	8870	9.26	1.0E+00	1.00149	0.00136	1.00420
cvcrcyct11_24_1	0.0	24000	24000	8923	9.70	1.0E+00	0.99327	0.00137	0.99600
cvcrcyct11_23_1	0.0	23000	23000	8977	10.19	1.0E+00	0.98432	0.00124	0.98680
cvcrcyct11_22_1	0.0	22000	22000	9030	10.71	1.0E+00	0.97759	0.00112	0.97984

Table 6.9.6-6. Results for 4.25 in.-diameter cylinder HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrcyct11_21_1	0.0	21000	21000	9083	11.29	1.0E+00	0.96672	0.00116	0.96904
cvcrcyct11_20_1	0.0	20000	20000	9136	11.92	1.0E+00	0.95743	0.00128	0.95999
cvcrcyct11_19_1	0.0	19000	19000	9189	12.62	1.0E+00	0.94629	0.00118	0.94866
cvcrcyct11_18_1	0.0	18000	18000	9242	13.40	1.0E+00	0.93349	0.00114	0.93576
cvcrcyct11_17_1	0.0	17000	17000	9295	14.27	1.0E+00	0.91942	0.00105	0.92152
cvcrcyct11_16_1	0.0	16000	16000	9348	15.25	1.0E+00	0.90458	0.00120	0.90699
cvcrcyct11_15_1	0.0	15000	15000	9401	16.36	1.0E+00	0.88788	0.00107	0.89002
with can spacers (np thickness=1.4 in.)									
cvcrcyct11_36_2	1.4	36000	36000	7673	5.56	1.0E+00	0.94321	0.00111	0.94543
cvcrcyct11_35_2	1.4	35000	35000	7726	5.76	1.0E+00	0.93828	0.00114	0.94056
cvcrcyct11_34_2	1.4	34000	34000	7779	5.97	1.0E+00	0.93114	0.00129	0.93372
cvcrcyct11_33_2	1.4	33000	33000	7832	6.19	1.0E+00	0.92558	0.00124	0.92805
cvcrcyct11_32_2	1.4	32000	32000	7885	6.43	1.0E+00	0.91799	0.00111	0.92021
cvcrcyct11_31_2	1.4	31000	31000	7938	6.68	1.0E+00	0.91146	0.00114	0.91375
cvcrcyct11_30_2	1.4	30000	30000	7992	6.95	1.0E+00	0.90499	0.00117	0.90734

Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, single package reflected													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
ncsrcyct11_36_1_1	0.0	36000	36000	8286.7	6.01	1.0E-20	0.98628	0.00107	0.98841	hcsrcyct12_36_1_1	0.98723	0.00126	0.98975
ncsrcyct11_36_1_2	0.0	36000	36000	8286.7	6.01	1.0E-05	0.98712	0.00138	0.98988	hcsrcyct12_36_1_2	0.98582	0.00120	0.98823
ncsrcyct11_36_1_3	0.0	36000	36000	8287	6.01	1.0E-04	0.98624	0.00119	0.98861	hcsrcyct12_36_1_3	0.98691	0.00113	0.98917
ncsrcyct11_36_1_4	0.0	36000	36000	8287	6.01	1.0E-03	0.98433	0.00102	0.98637	hcsrcyct12_36_1_4	0.98537	0.00111	0.98759
ncsrcyct11_36_1_5	0.0	36000	36000	8287	6.01	1.0E-02	0.98646	0.00103	0.98852	hcsrcyct12_36_1_5	0.98809	0.00110	0.99028
ncsrcyct11_36_1_6	0.0	36000	36000	8287	6.01	1.0E-01	0.99092	0.00127	0.99346	hcsrcyct12_36_1_6	0.99096	0.00099	0.99295
ncsrcyct11_36_1_8	0.0	36000	36000	8287	6.01	3.0E-01	1.00000	0.00123	1.00246	hcsrcyct12_36_1_8	1.00334	0.00119	1.00572
ncsrcyct11_36_1_15	0.0	36000	36000	8287	6.01	1.0E+00	1.03142	0.00144	1.03430	hcsrcyct12_36_1_15	1.03141	0.00116	1.03374
ncsrcyct11_36_1_15	0.0	36000	36000	8287	6.01	1.0E+00	1.03142	0.00144	1.03430	hcsrcyct12_36_1_15	1.03141	0.00116	1.03374
ncsrcyct11_35_1_15	0.0	35000	35000	8340	6.22	1.0E+00	1.02816	0.00115	1.03045	hcsrcyct12_35_1_15	1.03309	0.00126	1.03561
ncsrcyct11_34_1_15	0.0	34000	34000	8393	6.44	1.0E+00	1.02658	0.00113	1.02884	hcsrcyct12_34_1_15	1.02529	0.00124	1.02776
ncsrcyct11_33_1_15	0.0	33000	33000	8446	6.68	1.0E+00	1.01975	0.00114	1.02203	hcsrcyct12_33_1_15	1.02060	0.00124	1.02308
ncsrcyct11_32_1_15	0.0	32000	32000	8499	6.93	1.0E+00	1.01647	0.00104	1.01854	hcsrcyct12_32_1_15	1.01688	0.00114	1.01916
ncsrcyct11_31_1_15	0.0	31000	31000	8552	7.20	1.0E+00	1.00952	0.00114	1.01179	hcsrcyct12_31_1_15	1.01218	0.00144	1.01505
ncsrcyct11_30_1_15	0.0	30000	30000	8605	7.49	1.0E+00	1.00434	0.00123	1.00679	hcsrcyct12_30_1_15	1.00757	0.00117	1.00992
ncsrcyct11_29_1_15	0.0	29000	29000	8658	7.79	1.0E+00	1.00074	0.00106	1.00287	hcsrcyct12_29_1_15	1.00071	0.00139	1.00348
ncsrcyct11_28_1_15	0.0	28000	28000	8711	8.12	1.0E+00	0.99381	0.00135	0.99652	hcsrcyct12_28_1_15	0.99442	0.00129	0.99700
ncsrcyct11_27_1_15	0.0	27000	27000	8764	8.47	1.0E+00	0.98595	0.00094	0.98782	hcsrcyct12_27_1_15	0.99057	0.00119	0.99296
ncsrcyct11_26_1_15	0.0	26000	26000	8817	8.85	1.0E+00	0.97783	0.00117	0.98017	hcsrcyct12_26_1_15	0.98010	0.00135	0.98281
ncsrcyct11_25_1_15	0.0	25000	25000	8870	9.26	1.0E+00	0.97189	0.00126	0.97440	hcsrcyct12_25_1_15	0.97263	0.00118	0.97499
ncsrcyct11_24_1_15	0.0	24000	24000	8923	9.70	1.0E+00	0.96439	0.00121	0.96681	hcsrcyct12_24_1_15	0.96656	0.00113	0.96881
ncsrcyct11_23_1_15	0.0	23000	23000	8977	10.19	1.0E+00	0.95375	0.00130	0.95635	hcsrcyct12_23_1_15	0.95783	0.00118	0.96018

Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrcyct11_22_1_15	0.0	22000	22000	9030	10.71	1.0E+00	0.94744	0.00132	0.95008	hcsrcyct12_22_1_15	0.94901	0.00143	0.95187
ncsrcyct11_21_1_15	0.0	21000	21000	9083	11.29	1.0E+00	0.93842	0.00127	0.94095	hcsrcyct12_21_1_15	0.93880	0.00126	0.94132
ncsrcyct11_20_1_15	0.0	20000	20000	9136	11.92	1.0E+00	0.92684	0.00118	0.92920	hcsrcyct12_20_1_15	0.92929	0.00124	0.93176
ncsrcyct11_19_1_15	0.0	19000	19000	9189	12.62	1.0E+00	0.91527	0.00109	0.91745	hcsrcyct12_19_1_15	0.91879	0.00101	0.92081
ncsrcyct11_18_1_15	0.0	18000	18000	9242	13.40	1.0E+00	0.90374	0.00111	0.90597	hcsrcyct12_18_1_15	0.90716	0.00105	0.90927
ncsrcyct11_17_1_15	0.0	17000	17000	9295	14.27	1.0E+00	0.89147	0.00133	0.89412	hcsrcyct12_17_1_15	0.89585	0.00104	0.89794
ncsrcyct11_16_1_15	0.0	16000	16000	9348	15.25	1.0E+00	0.87788	0.00101	0.87990	hcsrcyct12_16_1_15	0.87933	0.00118	0.88168
ncsrcyct11_15_1_15	0.0	15000	15000	9401	16.36	1.0E+00	0.86209	0.00110	0.86429	hcsrcyct12_15_1_15	0.86488	0.00110	0.86708
with can spacers (np thickness = 1.4 in.)													
ncsrcyct11_36_2_1	1.4	36000	36000	7673	5.56	1.0E-20	0.87502	0.00112	0.87725	hcsrcyct12_36_2_1	0.87543	0.00107	0.87757
ncsrcyct11_36_2_2	1.4	36000	36000	7673	5.56	1.0E-05	0.87474	0.00108	0.87691	hcsrcyct12_36_2_2	0.87795	0.00117	0.88029
ncsrcyct11_36_2_3	1.4	36000	36000	7673	5.56	1.0E-04	0.87595	0.00126	0.87846	hcsrcyct12_36_2_3	0.87675	0.00112	0.87899
ncsrcyct11_36_2_4	1.4	36000	36000	7673	5.56	1.0E-03	0.87655	0.00100	0.87856	hcsrcyct12_36_2_4	0.87798	0.00106	0.88011
ncsrcyct11_36_2_5	1.4	36000	36000	7673	5.56	1.0E-02	0.87634	0.00104	0.87843	hcsrcyct12_36_2_5	0.87876	0.00109	0.88094
ncsrcyct11_36_2_6	1.4	36000	36000	7673	5.56	1.0E-01	0.87971	0.00102	0.88174	hcsrcyct12_36_2_6	0.88317	0.00111	0.88539
ncsrcyct11_36_2_8	1.4	36000	36000	7673	5.56	3.0E-01	0.88865	0.00115	0.89094	hcsrcyct12_36_2_8	0.89169	0.00103	0.89375
ncsrcyct11_36_2_15	1.4	36000	36000	7673	5.56	1.0E+00	0.91608	0.00120	0.91847	hcsrcyct12_36_2_15	0.91815	0.00118	0.92050
ncsrcyct11_36_2_15	1.4	36000	36000	7673	5.56	1.0E+00	0.91608	0.00120	0.91847	hcsrcyct12_36_2_15	0.91815	0.00118	0.92050
ncsrcyct11_35_2_15	1.4	35000	35000	7726	5.76	1.0E+00	0.91190	0.00116	0.91422	hcsrcyct12_35_2_15	0.91300	0.00117	0.91534
ncsrcyct11_34_2_15	1.4	34000	34000	7779	5.97	1.0E+00	0.90497	0.00112	0.90721	hcsrcyct12_34_2_15	0.90616	0.00116	0.90848
ncsrcyct11_33_2_15	1.4	33000	33000	7832	6.19	1.0E+00	0.90032	0.00120	0.90272	hcsrcyct12_33_2_15	0.90269	0.00118	0.90506
ncsrcyct11_32_2_15	1.4	32000	32000	7885	6.43	1.0E+00	0.89251	0.00102	0.89455	hcsrcyct12_32_2_15	0.89526	0.00120	0.89766
ncsrcyct11_31_2_15	1.4	31000	31000	7938	6.68	1.0E+00	0.88531	0.00136	0.88803	hcsrcyct12_31_2_15	0.88765	0.00108	0.88981
ncsrcyct11_30_2_15	1.4	30000	30000	7992	6.95	1.0E+00	0.88012	0.00120	0.88252	hcsrcyct12_30_2_15	0.88005	0.00120	0.88246

Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, array packaging model for CSI=0.0													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
nciacyct11_36_1_3	0.0	36000	36000	8287	6.01	1.0E-04	1.10334	0.00135	1.10604	hciacyct12_36_1_3	1.10722	0.00119	1.10961
nciacyct11_35_1_3	0.0	35000	35000	8340	6.22	1.0E-04	1.10128	0.00116	1.10360	hciacyct12_35_1_3	1.10067	0.00114	1.10295
nciacyct11_34_1_3	0.0	34000	34000	8393	6.44	1.0E-04	1.09399	0.00125	1.09648	hciacyct12_34_1_3	1.09477	0.00124	1.09726
nciacyct11_33_1_3	0.0	33000	33000	8446	6.68	1.0E-04	1.08794	0.00127	1.09048	hciacyct12_33_1_3	1.08942	0.00134	1.09210
nciacyct11_32_1_3	0.0	32000	32000	8499	6.93	1.0E-04	1.08183	0.00131	1.08444	hciacyct12_32_1_3	1.08089	0.00128	1.08346
nciacyct11_31_1_3	0.0	31000	31000	8552	7.20	1.0E-04	1.07391	0.00114	1.07619	hciacyct12_31_1_3	1.07627	0.00101	1.07829
nciacyct11_30_1_3	0.0	30000	30000	8605	7.49	1.0E-04	1.06840	0.00131	1.07102	hciacyct12_30_1_3	1.06781	0.00107	1.06994
nciacyct11_29_1_3	0.0	29000	29000	8658	7.79	1.0E-04	1.06070	0.00108	1.06286	hciacyct12_29_1_3	1.05946	0.00121	1.06188
nciacyct11_28_1_3	0.0	28000	28000	8711	8.12	1.0E-04	1.05398	0.00116	1.05630	hciacyct12_28_1_3	1.05253	0.00102	1.05457
nciacyct11_27_1_3	0.0	27000	27000	8764	8.47	1.0E-04	1.04385	0.00142	1.04670	hciacyct12_27_1_3	1.04481	0.00121	1.04723
nciacyct11_26_1_3	0.0	26000	26000	8817	8.85	1.0E-04	1.03489	0.00124	1.03736	hciacyct12_26_1_3	1.03688	0.00118	1.03923
nciacyct11_25_1_3	0.0	25000	25000	8870	9.26	1.0E-04	1.02495	0.00128	1.02751	hciacyct12_25_1_3	1.02706	0.00120	1.02946
nciacyct11_24_1_3	0.0	24000	24000	8923	9.70	1.0E-04	1.01610	0.00120	1.01850	hciacyct12_24_1_3	1.01634	0.00118	1.01870
nciacyct11_23_1_3	0.0	23000	23000	8977	10.19	1.0E-04	1.00723	0.00108	1.00938	hciacyct12_23_1_3	1.00427	0.00110	1.00648
nciacyct11_22_1_3	0.0	22000	22000	9030	10.71	1.0E-04	0.99573	0.00122	0.99817	hciacyct12_22_1_3	0.99481	0.00112	0.99705
nciacyct11_21_1_3	0.0	21000	21000	9083	11.29	1.0E-04	0.98149	0.00122	0.98393	hciacyct12_21_1_3	0.98514	0.00127	0.98768
nciacyct11_20_1_3	0.0	20000	20000	9136	11.92	1.0E-04	0.97377	0.00104	0.97585	hciacyct12_20_1_3	0.97210	0.00120	0.97450
nciacyct11_19_1_3	0.0	19000	19000	9189	12.62	1.0E-04	0.95985	0.00127	0.96240	hciacyct12_19_1_3	0.95807	0.00143	0.96092
nciacyct11_18_1_3	0.0	18000	18000	9242	13.40	1.0E-04	0.94375	0.00137	0.94649	hciacyct12_18_1_3	0.94639	0.00124	0.94887
nciacyct11_15_1_3	0.0	15000	15000	9401	16.36	1.0E-04	0.89699	0.00109	0.89917	hciacyct12_15_1_3	0.89646	0.00108	0.89862
nciacyct11_12_1_3	0.0	12000	12000	9560	20.79	1.0E-04	0.83537	0.00118	0.83772	hciacyct12_12_1_3	0.83858	0.00118	0.84093
nciacyct11_9_1_3	0.0	9000	9000	9719	28.19	1.0E-04	0.76061	0.00121	0.76303	hciacyct12_9_1_3	0.75657	0.00112	0.75882

Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciacyct11_6_1_3	0.0	6000	6000	9879	42.97	1.0E-04	0.64959	0.00106	0.65172	hciacyct12_6_1_3	0.64940	0.00109	0.65157
nciacyct11_3_1_3	0.0	3000	3000	10038	87.33	1.0E-04	0.48405	0.00103	0.48611	hciacyct12_3_1_3	0.48552	0.00096	0.48745
with can spacers (np thickness = 1.4 in.)													
nciacyct11_36_2_3	1.4	36000	36000	7673	5.56	1.0E-04	1.01018	0.00139	1.01297	hciacyct12_36_2_3	1.01024	0.00120	1.01263
nciacyct11_35_2_3	1.4	35000	35000	7726	5.76	1.0E-04	1.00029	0.00110	1.00249	hciacyct12_35_2_3	1.00083	0.00105	1.00293
nciacyct11_34_2_3	1.4	34000	34000	7779	5.97	1.0E-04	0.99523	0.00100	0.99723	hciacyct12_34_2_3	0.99499	0.00116	0.99731
nciacyct11_33_2_3	1.4	33000	33000	7832	6.19	1.0E-04	0.98713	0.00110	0.98932	hciacyct12_33_2_3	0.98922	0.00108	0.99139
nciacyct11_32_2_3	1.4	32000	32000	7885	6.43	1.0E-04	0.97809	0.00109	0.98028	hciacyct12_32_2_3	0.98046	0.00098	0.98242
nciacyct11_31_2_3	1.4	31000	31000	7938	6.68	1.0E-04	0.96968	0.00130	0.97227	hciacyct12_31_2_3	0.96951	0.00147	0.97246
nciacyct11_30_2_3	1.4	30000	30000	7992	6.95	1.0E-04	0.96031	0.00132	0.96295	hciacyct12_30_2_3	0.96156	0.00107	0.96370
nciacyct11_29_2_3	1.4	29000	29000	8045	7.24	1.0E-04	0.95128	0.00117	0.95362	hciacyct12_29_2_3	0.95414	0.00120	0.95654
nciacyct11_28_2_3	1.4	28000	28000	8098	7.55	1.0E-04	0.94378	0.00138	0.94654	hciacyct12_28_2_3	0.94376	0.00138	0.94652
nciacyct11_27_2_3	1.4	27000	27000	8151	7.88	1.0E-04	0.93234	0.00111	0.93456	hciacyct12_27_2_3	0.93273	0.00132	0.93536
nciacyct11_26_2_3	1.4	26000	26000	8204	8.24	1.0E-04	0.92078	0.00104	0.92287	hciacyct12_26_2_3	0.92390	0.00128	0.92646
nciacyct11_25_2_3	1.4	25000	25000	8257	8.62	1.0E-04	0.91264	0.00100	0.91465	hciacyct12_25_2_3	0.91352	0.00105	0.91562
nciacyct11_24_2_3	1.4	24000	24000	8310	9.04	1.0E-04	0.89955	0.00124	0.90203	hciacyct12_24_2_3	0.90170	0.00109	0.90388
nciacyct11_23_2_3	1.4	23000	23000	8363	9.49	1.0E-04	0.89118	0.00128	0.89374	hciacyct12_23_2_3	0.89159	0.00128	0.89414
nciacyct11_22_2_3	1.4	22000	22000	8416	9.98	1.0E-04	0.87715	0.00098	0.87910	hciacyct12_22_2_3	0.87791	0.00103	0.87997
nciacyct11_21_2_3	1.4	21000	21000	8469	10.53	1.0E-04	0.86679	0.00109	0.86898	hciacyct12_21_2_3	0.86482	0.00106	0.86693
nciacyct11_20_2_3	1.4	20000	20000	8522	11.12	1.0E-04	0.85029	0.00131	0.85292	hciacyct12_20_2_3	0.85207	0.00119	0.85445
nciacyct11_19_2_3	1.4	19000	19000	8575	11.78	1.0E-04	0.83585	0.00110	0.83805	hciacyct12_19_2_3	0.83631	0.00101	0.83833
nciacyct11_18_2_3	1.4	18000	18000	8628	12.51	1.0E-04	0.82112	0.00105	0.82323	hciacyct12_18_2_3	0.82020	0.00108	0.82236
nciacyct11_15_2_3	1.4	15000	15000	8787	15.29	1.0E-04	0.77012	0.00102	0.77216	hciacyct12_15_2_3	0.77067	0.00099	0.77265
nciacyct11_12_2_3	1.4	12000	12000	8947	19.46	1.0E-04	0.70996	0.00113	0.71222	hciacyct12_12_2_3	0.70716	0.00100	0.70915
nciacyct11_9_2_3	1.4	9000	9000	9106	26.41	1.0E-04	0.38338	0.00093	0.38524	hciacyct12_9_2_3	0.62982	0.00097	0.63175

Table 6.9.6-7. Results for 4.25 in.-diameter cylinder HEU metal content in packaging calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciacyct11_6_2_3	1.4	6000	6000	9265	40.30	1.0E-04	0.63066	0.00100	0.63267	hciacyct12_6_2_3	0.52901	0.00100	0.53101
nciacyct11_3_2_3	1.4	3000	3000	9424	81.99	1.0E-04	0.52971	0.00101	0.53173	hciacyct12_3_2_3	0.38124	0.00075	0.38274

Table 6.9.6-8. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$	content description
flooded containment vessel, reflected										
no can spacers (np thickness = 0.0 in.)										
cvcr5st11_1_1	0.0	18277	18277	9227	13.18	1.0E+00	0.90734	0.00123	0.90980	5 slugs in a pentagonal ring
cvcr5est11_1_1	0.0	18277	18277	9227	13.18	1.0E+00	0.90718	0.00119	0.90955	5 slugs in a pentagonal ring, extended spacing
cvcr50st11_1	0.0	18277	18277	9227	13.18	1.0E+00	0.90671	0.00120	0.90911	5 slugs in cruciform pattern
cvcr5e0st11_1	0.0	18277	18277	9227	13.18	1.0E+00	0.90690	0.00124	0.90938	5 slugs in cruciform pattern, extended spacing
cvcr5u0st11_1	0.0	18277	18277	9227	13.18	1.0E+00	0.90690	0.00122	0.90935	5 slugs in four pointed star pattern
cvcr5l0st11_1	0.0	18277	18277	9227	13.18	1.0E+00	0.90660	0.00113	0.90885	5 slugs, filled hex. ring with 2 slugs missing
cvcr6st11_1_1	0.0	21933	21933	9033	10.75	1.0E+00	0.95173	0.00118	0.95409	6 slugs in a hexagonal ring
cvcr6e0st11_1	0.0	21933	21933	9033	10.75	1.0E+00	0.95531	0.00106	0.95742	6 slugs in pentagonal ring with center slug
cvcr70st11_1	0.0	25588	25588	8839	9.02	1.0E+00	0.99827	0.00135	1.00097	7 slugs in hexagonal ring with center slug
cvcr5st11_1_2	0.0	36555	36555	8257	5.90	1.0E+00	0.99909	0.00125	1.00158	10 slugs in stacked pentagonal rings
cvcr5est11_1_2	0.0	36555	36555	8257	5.90	1.0E+00	1.00409	0.00136	1.00681	10 slugs in stacked pent. rings, extended spacing
cvcr6e4st11_1	0.0	36555	36555	8257	5.90	1.0E+00	1.00361	0.00134	1.00630	10 slugs, lower 6 slugs in hex ring, upper 4 in square
cvcr73st11_1	0.0	36555	36555	8257	5.90	1.0E+00	1.00523	0.00127	1.00776	10 slugs, lower 7 slugs in hex ring, upper 3 in triangle
cvcr6st11_1_2	0.0	43865	43865	7869	4.68	1.0E+00	1.05336	0.00130	1.05597	12 slugs in stacked hexagonal rings

Table 6.9.6-8. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$	content description
with can spacers (np thickness=1.4 in.)										
cvcr5st11_2_1	1.4	18277	18277	8613	12.30	1.0E+00	0.76864	0.00113	0.77089	5 slugs in a pentagonal ring
cvcr5est11_2_1	1.4	18277	18277	8613	12.30	1.0E+00	0.76420	0.00102	0.76624	5 slugs in a pentagonal ring, extended spacing
cvcr50st11_2	1.4	18277	18277	8613	12.30	1.0E+00	0.76929	0.00117	0.77163	5 slugs in cruciform pattern
cvcr5e0st11_2	1.4	18277	18277	8613	12.30	1.0E+00	0.76532	0.00127	0.76785	5 slugs in cruciform pattern, extended spacing
cvcr5u0st11_2	1.4	18277	18277	8613	12.30	1.0E+00	0.76953	0.00108	0.77168	5 slugs in four pointed star pattern
cvcr5l0st11_2	1.4	18277	18277	8613	12.30	1.0E+00	0.77162	0.00102	0.77366	5 slugs, filled hex. ring with 2 slugs missing
cvcr6st11_2_1	1.4	21933	21933	8419	10.02	1.0E+00	0.81300	0.00148	0.81596	6 slugs in a hexagonal ring
cvcr6e0st11_2	1.4	21933	21933	8419	10.02	1.0E+00	0.81943	0.00116	0.82176	6 slugs in pentagonal ring with center slug
cvcr70st11_2	1.4	25588	25588	8225	8.39	1.0E+00	0.86296	0.00104	0.86503	7 slugs in hexagonal ring with center slug
cvcr5st11_2_2	1.4	36555	36555	7643	5.46	1.0E+00	0.90058	0.00115	0.90287	10 slugs in stacked pentagonal rings
cvcr5est11_2_2	1.4	36555	36555	7643	5.46	1.0E+00	0.89862	0.00121	0.90104	10 slugs in stacked pent. rings, extended spacing
cvcr6e4st11_2	1.4	36555	36555	7643	5.46	1.0E+00	0.89991	0.00109	0.90209	10 slugs, lower 6 slugs in hex ring, upper 4 in square
cvcr73st11_2	1.4	36555	36555	7643	5.46	1.0E+00	0.89922	0.00109	0.90139	10 slugs, lower 7 slugs in hex ring, upper 3 in triangle
cvcr6st11_2_2	1.4	43865	43865	7256	4.32	1.0E+00	0.94962	0.00126	0.95213	12 slugs in stacked hexagonal rings
evaluation of model approximations in no can spacer configurations (np thickness=0.0002 in.)										
cvcr6e0st11_1	0.0	21933	21933	9033	10.75	1.0E+00	0.95531	0.00106	0.95742	6 slugs in pentagonal ring with center slug
cv0r6e0s_1	0.0	21933	21933	9033	10.75	1.0E+00	0.95418	0.00135	0.95689	0.0002 cm thick spacers voided in above model
cvwr6e0s_1	0.0	21933	21933	9033	10.75	1.0E+00	0.95384	0.00117	0.95618	0.0002 cm thick spacers replaced with water in above
cvcr70st11_1	0.0	25588	25588	8839	9.02	1.0E+00	0.99827	0.00135	1.00097	7 slugs, hex ring with slug in center
cv0r70s_1	0.0	25588	25588	8839	9.02	1.0E+00	0.99814	0.00118	1.00051	0.0002 cm thick spacers voided in above model
cvwr70s_1	0.0	25588	25588	8839	9.02	1.0E+00	0.99847	0.00120	1.00088	0.0002 cm thick spacers flooded in above model
evaluation of model approximations in configurations with can spacers (np thickness=1.4 in.)										
cvcr6e0st11_2	1.4	21933	21933	8419	10.02	1.0E+00	0.81943	0.00116	0.82176	6 slugs in pentagonal ring with center slug
cv0r6e0s_2	1.4	21933	21933	8419	10.02	1.0E+00	0.84682	0.00118	0.84918	1.4 in thick spacers voided in above model

Table 6.9.6-8. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in CV calculation model

case name	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$	content description
cvcr6e0st11_1	0.0	21933	21933	9033	10.75	1.0E+00	0.95531	0.00106	0.95742	6 slugs in pentagonal ring with center slug
cvwr6e0s_2	1.4	21933	21933	9033	10.75	1.0E+00	0.89988	0.00138	0.90263	1.4 in thick spacers replace with water
cvcr70st11_2	1.4	25588	25588	8225	8.39	1.0E+00	0.86296	0.00104	0.86503	7 slugs, hex ring with slug in center
cv0r70s_2	1.4	25588	25588	8225	8.39	1.0E+00	0.88250	0.00110	0.88470	1.4 in thick spacers voided in above model
cvcr70st11_1	0.0	25588	25588	8839	9.02	1.0E+00	0.99827	0.00135	1.00097	7 slugs, hex ring with slug in center
cvwr70s_2	1.4	25588	25588	8839	9.02	1.0E+00	0.93953	0.00111	0.94175	1.4 in thick spacers replace with water

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, single package reflected													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
ncsr5est11_1_1_15	100	18277	18277	9227	13.18	1.0E+00	0.86857	0.00128	0.87113	hcsr5est12_1_1_15	0.87319	0.00116	0.87551
ncsr5st11_1_1_15	100	18277	18277	9227	13.18	1.0E+00	0.88102	0.00119	0.88339	hcsr5st12_1_1_15	0.88322	0.00142	0.88606
ncsr6st11_1_1_15	100	21933	21933	9033	10.75	1.0E+00	0.91461	0.00110	0.91680				
ncsr5est11_1_2_15	100	36555	36555	8257	5.90	1.0E+00	0.96511	0.00123	0.96756	hcsr5est12_1_2_15	0.96512	0.00128	0.96768
ncsr5st11_1_2_15	100	36555	36555	8257	5.90	1.0E+00	0.96727	0.00116	0.96960	hcsr5st12_1_2_15	0.97082	0.00124	0.97330
ncsr6e4st11_1_1	100	36555	36555	8257	5.90	1.0E-20	0.92156	0.00105	0.92367				
ncsr6e4st11_1_2	100	36555	36555	8257	5.90	1.0E-05	0.92051	0.00114	0.92279				

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsr6e4st11_1_3	100	36555	36555	8257	5.90	1.0E-04	0.92239	0.00107	0.92453				
ncsr6e4st11_1_4	100	36555	36555	8257	5.90	1.0E-03	0.91834	0.00126	0.92086				
ncsr6e4st11_1_5	100	36555	36555	8257	5.90	1.0E-02	0.92233	0.00111	0.92455				
ncsr6e4st11_1_6	100	36555	36555	8257	5.90	1.0E-01	0.92584	0.00123	0.92830				
ncsr6e4st11_1_8	100	36555	36555	8257	5.90	3.0E-01	0.93741	0.00125	0.93990				
ncsr6e4st11_1_15	100	36555	36555	8257	5.90	1.0E+00	0.97010	0.00114	0.97238				
ncsr73st11_1_1	100	36555	36555	8257	5.90	1.0E-20	0.92144	0.00127	0.92399				
ncsr73st11_1_2	100	36555	36555	8257	5.90	1.0E-05	0.92591	0.00108	0.92808				
ncsr73st11_1_3	100	36555	36555	8257	5.90	1.0E-04	0.92106	0.00121	0.92348				
ncsr73st11_1_4	100	36555	36555	8257	5.90	1.0E-03	0.92326	0.00122	0.92570				
ncsr73st11_1_5	100	36555	36555	8257	5.90	1.0E-02	0.92213	0.00113	0.92439				
ncsr73st11_1_6	100	36555	36555	8257	5.90	1.0E-01	0.92784	0.00111	0.93007				
ncsr73st11_1_8	100	36555	36555	8257	5.90	3.0E-01	0.93898	0.00115	0.94128				
ncsr73st11_1_15	100	36555	36555	8257	5.90	1.0E+00	0.96854	0.00128	0.97110				
ncsr6st11_1_2_15	100	43865	43865	7869	4.68	1.0E+00	1.01197	0.00132	1.01461				
with can spacers (np thickness = 1.4 in.)													
ncsr5est11_2_1_1	100	18277	18277	8613	12.30	1.0E-20	0.68597	0.00122	0.68841	hcsr5est12_2_1_1	0.68926	0.00101	0.69128
ncsr5est11_2_1_2	100	18277	18277	8613	12.30	1.0E-05	0.68486	0.00101	0.68688	hcsr5est12_2_1_2	0.68645	0.00110	0.68866
ncsr5est11_2_1_3	100	18277	18277	8613	12.30	1.0E-04	0.68766	0.00128	0.69022	hcsr5est12_2_1_3	0.68796	0.00105	0.69007
ncsr5est11_2_1_4	100	18277	18277	8613	12.30	1.0E-03	0.68729	0.00120	0.68969	hcsr5est12_2_1_4	0.68815	0.00098	0.69010
ncsr5est11_2_1_5	100	18277	18277	8613	12.30	1.0E-02	0.68465	0.00128	0.68720	hcsr5est12_2_1_5	0.69008	0.00097	0.69201
ncsr5est11_2_1_6	100	18277	18277	8613	12.30	1.0E-01	0.68906	0.00105	0.69117	hcsr5est12_2_1_6	0.69613	0.00117	0.69847

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsr5est11_2_1_8	100	18277	18277	8613	12.30	3.0E-01	0.70289	0.00101	0.70491	hcsr5est12_2_1_8	0.70357	0.00107	0.70571
ncsr5est11_2_1_15	100	18277	18277	8613	12.30	1.0E+00	0.73412	0.00109	0.73629	hcsr5est12_2_1_15	0.73557	0.00101	0.73759
ncsr5st11_2_1_1	100	18277	18277	8613	12.30	1.0E-20	0.70896	0.00096	0.71087				
ncsr5st11_2_1_2	100	18277	18277	8613	12.30	1.0E-05	0.70901	0.00095	0.71092				
ncsr5st11_2_1_3	100	18277	18277	8613	12.30	1.0E-04	0.71109	0.00096	0.71300				
ncsr5st11_2_1_4	100	18277	18277	8613	12.30	1.0E-03	0.70980	0.00102	0.71184				
ncsr5st11_2_1_5	100	18277	18277	8613	12.30	1.0E-02	0.71089	0.00103	0.71294				
ncsr5st11_2_1_6	100	18277	18277	8613	12.30	1.0E-01	0.71505	0.00112	0.71729				
ncsr5st11_2_1_8	100	18277	18277	8613	12.30	3.0E-01	0.72364	0.00121	0.72605				
ncsr5st11_2_1_15	100	18277	18277	8613	12.30	1.0E+00	0.74773	0.00114	0.75001	hcsr5st12_2_1_15	0.74885	0.00101	0.75087
ncsr6st11_2_1_1	100	21933	21933	8419	10.02	1.0E-20	0.73305	0.00104	0.73514				
ncsr6st11_2_1_2	100	21933	21933	8419	10.02	1.0E-05	0.73284	0.00105	0.73494				
ncsr6st11_2_1_3	100	21933	21933	8419	10.02	1.0E-04	0.73419	0.00111	0.73641				
ncsr6st11_2_1_4	100	21933	21933	8419	10.02	1.0E-03	0.73339	0.00106	0.73551				
ncsr6st11_2_1_5	100	21933	21933	8419	10.02	1.0E-02	0.73282	0.00101	0.73484				
ncsr6st11_2_1_6	100	21933	21933	8419	10.02	1.0E-01	0.73962	0.00104	0.74170				
ncsr6st11_2_1_8	100	21933	21933	8419	10.02	3.0E-01	0.74981	0.00112	0.75206				
ncsr6st11_2_1_15	100	21933	21933	8419	10.02	1.0E+00	0.78295	0.00118	0.78531				
ncsr5est11_2_2_1	100	36555	36555	7643	5.46	1.0E-20	0.81441	0.00102	0.81646	hcsr5est12_2_2_1	0.81949	0.00126	0.82202
ncsr5est11_2_2_2	100	36555	36555	7643	5.46	1.0E-05	0.81751	0.00107	0.81966	hcsr5est12_2_2_2	0.81765	0.00108	0.81981
ncsr5est11_2_2_3	100	36555	36555	7643	5.46	1.0E-04	0.81443	0.00110	0.81664	hcsr5est12_2_2_3	0.81691	0.00115	0.81922
ncsr5est11_2_2_4	100	36555	36555	7643	5.46	1.0E-03	0.81628	0.00124	0.81876	hcsr5est12_2_2_4	0.81854	0.00123	0.82100

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsr5est11_2_2_5	100	36555	36555	7643	5.46	1.0E-02	0.81513	0.00118	0.81749	hcsr5est12_2_2_5	0.81898	0.00104	0.82106
ncsr5est11_2_2_6	100	36555	36555	7643	5.46	1.0E-01	0.82099	0.00114	0.82326	hcsr5est12_2_2_6	0.82414	0.00111	0.82636
ncsr5est11_2_2_8	100	36555	36555	7643	5.46	3.0E-01	0.83205	0.00109	0.83424	hcsr5est12_2_2_8	0.83469	0.00107	0.83683
ncsr5est11_2_2_15	100	36555	36555	7643	5.46	1.0E+00	0.86471	0.00124	0.86719	hcsr5est12_2_2_15	0.86591	0.00115	0.86822
ncsr5st11_2_2_1	100	36555	36555	7643	5.46	1.0E-20	0.83654	0.00109	0.83872				
ncsr5st11_2_2_2	100	36555	36555	7643	5.46	1.0E-05	0.83389	0.00104	0.83597				
ncsr5st11_2_2_3	100	36555	36555	7643	5.46	1.0E-04	0.83615	0.00113	0.83841				
ncsr5st11_2_2_4	100	36555	36555	7643	5.46	1.0E-03	0.83524	0.00141	0.83806				
ncsr5st11_2_2_5	100	36555	36555	7643	5.46	1.0E-02	0.83580	0.00109	0.83797				
ncsr5st11_2_2_6	100	36555	36555	7643	5.46	1.0E-01	0.84206	0.00110	0.84426				
ncsr5st11_2_2_8	100	36555	36555	7643	5.46	3.0E-01	0.85011	0.00135	0.85281				
ncsr5st11_2_2_15	100	36555	36555	7643	5.46	1.0E+00	0.87549	0.00131	0.87810	hcsr5st12_2_2_15	0.87483	0.00116	0.87715
ncsr6e4st11_2_1	100	36555	36555	7643	5.46	1.0E-20	0.83636	0.00110	0.83857				
ncsr6e4st11_2_2	100	36555	36555	7643	5.46	1.0E-05	0.83532	0.00112	0.83757				
ncsr6e4st11_2_3	100	36555	36555	7643	5.46	1.0E-04	0.83689	0.00118	0.83924				
ncsr6e4st11_2_4	100	36555	36555	7643	5.46	1.0E-03	0.83744	0.00114	0.83972				
ncsr6e4st11_2_5	100	36555	36555	7643	5.46	1.0E-02	0.83615	0.00122	0.83858				
ncsr6e4st11_2_6	100	36555	36555	7643	5.46	1.0E-01	0.84173	0.00127	0.84426				
ncsr6e4st11_2_8	100	36555	36555	7643	5.46	3.0E-01	0.84987	0.00113	0.85213				
ncsr6e4st11_2_15	100	36555	36555	7643	5.46	1.0E+00	0.87722	0.00131	0.87984				
ncsr73st11_2_1	100	36555	36555	7643	5.46	1.0E-20	0.83665	0.00111	0.83887				
ncsr73st11_2_2	100	36555	36555	7643	5.46	1.0E-05	0.83570	0.00116	0.83801				

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsr73st11_2_3	100	36555	36555	7643	5.46	1.0E-04	0.83716	0.00115	0.83946				
ncsr73st11_2_4	100	36555	36555	7643	5.46	1.0E-03	0.83728	0.00117	0.83961				
ncsr73st11_2_5	100	36555	36555	7643	5.46	1.0E-02	0.83790	0.00116	0.84023				
ncsr73st11_2_6	100	36555	36555	7643	5.46	1.0E-01	0.84068	0.00120	0.84309				
ncsr73st11_2_8	100	36555	36555	7643	5.46	3.0E-01	0.84928	0.00106	0.85139				
ncsr73st11_2_15	100	36555	36555	7643	5.46	1.0E+00	0.87257	0.00099	0.87455				
ncsr6st11_2_2_1	100	43865	43865	7256	4.32	1.0E-20	0.86427	0.00104	0.86636				
ncsr6st11_2_2_2	100	43865	43865	7256	4.32	1.0E-05	0.86386	0.00108	0.86601				
ncsr6st11_2_2_3	100	43865	43865	7256	4.32	1.0E-04	0.86637	0.00117	0.86870				
ncsr6st11_2_2_4	100	43865	43865	7256	4.32	1.0E-03	0.86498	0.00125	0.86747				
ncsr6st11_2_2_5	100	43865	43865	7256	4.32	1.0E-02	0.86541	0.00116	0.86773				
ncsr6st11_2_2_6	100	43865	43865	7256	4.32	1.0E-01	0.87070	0.00111	0.87292				
ncsr6st11_2_2_8	100	43865	43865	7256	4.32	3.0E-01	0.88148	0.00122	0.88392				
ncsr6st11_2_2_15	100	43865	43865	7256	4.32	1.0E+00	0.91478	0.00118	0.91713				
content in flooded containment vessel, array packaging model for CSI=0.0													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
ncia5est11_1_1_8_3	100	18277	18277	9227	13.18	1.0E-04	0.92163	0.00126	0.92414	hcia5est12_1_1_8_3	0.91941	0.00126	0.92194
ncia5est11_1_1_7_3	95	18289	17374	9227	13.86	1.0E-04	0.90412	0.00109	0.90630	hcia5est12_1_1_7_3	0.90066	0.00110	0.90285
ncia5est11_1_1_5_3	90	18324	14659	9227	16.43	1.0E-04	0.85207	0.00110	0.85427	hcia5est12_1_1_6_3	0.88401	0.00108	0.88616
ncia5est11_1_1_4_3	80	18347	12843	9227	18.75	1.0E-04	0.81402	0.00108	0.81617	hcia5est12_1_1_5_3	0.84983	0.00117	0.85217
ncia5est11_1_1_6_3	70	18300	16470	9227	14.62	1.0E-04	0.88510	0.00118	0.88746	hcia5est12_1_1_4_3	0.81368	0.00111	0.81590
ncia5est11_1_1_3_3	60	18370	11022	9227	21.85	1.0E-04	0.77131	0.00109	0.77349	hcia5est12_1_1_3_3	0.77296	0.00113	0.77523

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncia5est11_1_1_2_3	40	18417	7367	9227	32.69	1.0E-04	0.67736	0.00103	0.67943	hcia5est12_1_1_2_3	0.67968	0.00108	0.68184
ncia5est11_1_1_1_3	19	18466	3509	9227	68.64	1.0E-04	0.54780	0.00092	0.54964	hcia5est12_1_1_1_3	0.54586	0.00117	0.54819
ncia5st11_1_1_8_3	100	18277	18277	9227	13.18	1.0E-04	0.92611	0.00127	0.92865	hcia5st12_1_1_8_3	0.92609	0.00110	0.92829
ncia5st11_1_1_7_3	95	18289	17374	9227	13.86	1.0E-04	0.90538	0.00116	0.90769	hcia5st12_1_1_7_3	0.90683	0.00113	0.90909
ncia5st11_1_1_5_3	90	18324	14659	9227	16.43	1.0E-04	0.88586	0.00112	0.88811	hcia5st12_1_1_6_3	0.88827	0.00110	0.89046
ncia5st11_1_1_4_3	80	18347	12843	9227	18.75	1.0E-04	0.84871	0.00124	0.85119	hcia5st12_1_1_5_3	0.85050	0.00113	0.85276
ncia5st11_1_1_6_3	70	18300	16470	9227	14.62	1.0E-04	0.80834	0.00102	0.81037	hcia5st12_1_1_4_3	0.80870	0.00112	0.81094
ncia5st11_1_1_3_3	60	18370	11022	9227	21.85	1.0E-04	0.76467	0.00098	0.76663	hcia5st12_1_1_3_3	0.76245	0.00105	0.76454
ncia5st11_1_1_2_3	40	18417	7367	9227	32.69	1.0E-04	0.66040	0.00106	0.66252	hcia5st12_1_1_2_3	0.65955	0.00097	0.66149
ncia5st11_1_1_1_3	19	18466	3509	9227	68.64	1.0E-04	0.51929	0.00090	0.52109	hcia5st12_1_1_1_3	0.51805	0.00084	0.51973
with can spacers (np thickness = 1.4 in.)													
ncia5est11_2_1_8_3	100	18277	18277	8613	12.30	1.0E-04	0.80353	0.00113	0.80580	hcia5est12_2_1_8_3	0.80594	0.00121	0.80835
ncia5est11_2_1_7_3	95	18289	17374	8613	12.94	1.0E-04	0.78741	0.00118	0.78977	hcia5est12_2_1_7_3	0.78684	0.00107	0.78898
ncia5est11_2_1_6_3	90	18300	16470	8613	13.65	1.0E-04	0.77061	0.00112	0.77285	hcia5est12_2_1_6_3	0.77268	0.00114	0.77496
ncia5est11_2_1_5_3	80	18324	14659	8613	15.34	1.0E-04	0.73732	0.00118	0.73969	hcia5est12_2_1_5_3	0.73645	0.00094	0.73834
ncia5est11_2_1_4_3	70	18347	12843	8613	17.51	1.0E-04	0.70261	0.00108	0.70477	hcia5est12_2_1_4_3	0.70418	0.00107	0.70631
ncia5est11_2_1_3_3	60	18370	11022	8613	20.40	1.0E-04	0.66332	0.00094	0.66520	hcia5est12_2_1_3_3	0.66396	0.00114	0.66624
ncia5est11_2_1_2_3	40	18417	7367	8613	30.52	1.0E-04	0.57466	0.00097	0.57660	hcia5est12_2_1_2_3	0.57526	0.00080	0.57687
ncia5est11_2_1_1_3	19	18466	3509	8613	64.08	1.0E-04	0.45117	0.00082	0.45280	hcia5est12_2_1_1_3	0.45114	0.00084	0.45281
ncia70st11_2_8_3	100	25588	25588	8225	8.39	1.0E-04	0.91300	0.00104	0.91507	hcia70st12_2_8_3	0.91329	0.00111	0.91551
ncia70st11_2_7_3	95	25604	24324	8225	8.83	1.0E-04	0.89143	0.00108	0.89360	hcia70st12_2_7_3	0.89210	0.00124	0.89457
ncia70st11_2_6_3	90	25621	23059	8225	9.31	1.0E-04	0.87368	0.00108	0.87585	hcia70st12_2_6_3	0.87198	0.00113	0.87425
ncia70st11_2_5_3	80	25653	20522	8225	10.46	1.0E-04	0.83357	0.00110	0.83577	hcia70st12_2_5_3	0.83150	0.00106	0.83362

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncia70st11_2_4_3	70	25686	17980	8225	11.94	1.0E-04	0.78606	0.00105	0.78816	hcia70st12_2_4_3	0.78783	0.00099	0.78981
ncia70st11_2_3_3	60	25718	15431	8225	13.91	1.0E-04	0.73820	0.00099	0.74017	hcia70st12_2_3_3	0.73745	0.00100	0.73944
ncia70st11_2_2_3	40	25784	10313	8225	20.82	1.0E-04	0.62591	0.00090	0.62771	hcia70st12_2_2_3	0.62664	0.00107	0.62878
ncia70st11_2_1_3	19	25853	4912	8225	43.71	1.0E-04	0.47179	0.00077	0.47333	hcia70st12_2_1_3	0.47178	0.00086	0.47349
ncia5est11_2_2_8_3	100	36555	36555	7643	5.46	1.0E-04	0.98202	0.00112	0.98425	hcia5est12_2_2_8_3	0.98033	0.00111	0.98254
ncia5est11_2_2_7_3	95	36578	34749	7643	5.74	1.0E-04	0.96108	0.00119	0.96346	hcia5est12_2_2_7_3	0.96166	0.00113	0.96392
ncia5est11_2_2_6_3	90	36601	32941	7643	6.06	1.0E-04	0.94424	0.00134	0.94692	hcia5est12_2_2_6_3	0.94560	0.00118	0.94796
ncia5est11_2_2_5_3	80	36647	29318	7643	6.80	1.0E-04	0.90628	0.00109	0.90846	hcia5est12_2_2_5_3	0.90763	0.00117	0.90997
ncia5est11_2_2_4_3	70	36694	25686	7643	7.77	1.0E-04	0.86606	0.00104	0.86814	hcia5est12_2_2_4_3	0.86855	0.00104	0.87064
ncia5est11_2_2_3_3	60	36740	22044	7643	9.05	1.0E-04	0.82451	0.00098	0.82647	hcia5est12_2_2_3_3	0.82536	0.00115	0.82767
ncia5est11_2_2_2_3	40	36834	14734	7643	13.54	1.0E-04	0.72349	0.00093	0.72535	hcia5est12_2_2_2_3	0.72285	0.00114	0.72513
ncia5est11_2_2_1_3	19	36932	7017	7643	28.43	1.0E-04	0.58171	0.00100	0.58370	hcia5est12_2_2_1_3	0.58235	0.00096	0.58427
ncia5st11_2_2_8_3	100	36555	36555	7643	5.46	1.0E-04	0.97720	0.00133	0.97986	hcia5st12_2_2_8_3	0.97562	0.00123	0.97807
ncia5st11_2_2_7_3	95	36578	34749	7643	5.74	1.0E-04	0.95854	0.00105	0.96064	hcia5st12_2_2_7_3	0.95594	0.00097	0.95789
ncia5st11_2_2_6_3	90	36601	32941	7643	6.06	1.0E-04	0.93619	0.00132	0.93883	hcia5st12_2_2_6_3	0.93579	0.00110	0.93800
ncia5st11_2_2_5_3	80	36647	29318	7643	6.80	1.0E-04	0.90011	0.00117	0.90244	hcia5st12_2_2_5_3	0.89786	0.00154	0.90095
ncia5st11_2_2_4_3	70	36694	25686	7643	7.77	1.0E-04	0.85499	0.00102	0.85703	hcia5st12_2_2_4_3	0.85363	0.00119	0.85601
ncia5st11_2_2_3_3	60	36740	22044	7643	9.05	1.0E-04	0.80868	0.00116	0.81101	hcia5st12_2_2_3_3	0.80882	0.00105	0.81091
ncia5st11_2_2_2_3	40	36834	14734	7643	13.54	1.0E-04	0.70077	0.00098	0.70274	hcia5st12_2_2_2_3	0.70205	0.00105	0.70415
ncia5st11_2_2_1_3	19	36932	7017	7643	28.43	1.0E-04	0.55139	0.00095	0.55330	hcia5st12_2_2_1_3	0.55187	0.00101	0.55389

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, array packaging model for CSI=0.4													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
ncf15est11_1_1_8_3	100	18277	18277	9227	13.18	1.0E-04	0.87707	0.00119	0.87944	hcf25est12_1_1_8_3	0.86992	0.00106	0.87204
ncf15est11_1_1_7_3	95	18289	17374	9227	13.86	1.0E-04	0.86115	0.00120	0.86354	hcf25est12_1_1_7_3	0.85401	0.00126	0.85652
ncf15est11_1_1_6_3	90	18300	16470	9227	14.62	1.0E-04	0.84672	0.00112	0.84896	hcf25est12_1_1_6_3	0.83451	0.00102	0.83656
ncf15est11_1_1_5_3	80	18324	14659	9227	16.43	1.0E-04	0.81108	0.00109	0.81327	hcf25est12_1_1_5_3	0.80144	0.00107	0.80358
ncf15est11_1_1_4_3	70	18347	12843	9227	18.75	1.0E-04	0.77287	0.00112	0.77510	hcf25est12_1_1_4_3	0.76516	0.00111	0.76739
ncf15est11_1_1_3_3	60	18370	11022	9227	21.85	1.0E-04	0.73211	0.00114	0.73440	hcf25est12_1_1_3_3	0.72484	0.00118	0.72719
ncf15est11_1_1_2_3	40	18417	7367	9227	32.69	1.0E-04	0.64270	0.00105	0.64480	hcf25est12_1_1_2_3	0.63366	0.00107	0.63580
ncf15est11_1_1_1_3	19	18466	3509	9227	68.64	1.0E-04	0.51398	0.00088	0.51573	hcf25est12_1_1_1_3	0.51052	0.00094	0.51241
with can spacers (np thickness = 1.4 in.)													
ncf15est11_2_1_8_3	100	18277	18277	8613	12.30	1.0E-04	0.76015	0.00112	0.76239	hcf25est12_2_1_8_3	0.75353	0.00102	0.75558
ncf15est11_2_1_7_3	95	18289	17374	8613	12.94	1.0E-04	0.74428	0.00129	0.74686	hcf25est12_2_1_7_3	0.73938	0.00109	0.74156
ncf15est11_2_1_6_3	90	18300	16470	8613	13.65	1.0E-04	0.72783	0.00107	0.72998	hcf25est12_2_1_6_3	0.72401	0.00105	0.72611
ncf15est11_2_1_5_3	80	18324	14659	8613	15.34	1.0E-04	0.69813	0.00098	0.70009	hcf25est12_2_1_5_3	0.69017	0.00089	0.69195
ncf15est11_2_1_4_3	70	18347	12843	8613	17.51	1.0E-04	0.66593	0.00098	0.66789	hcf25est12_2_1_4_3	0.65691	0.00113	0.65916
ncf15est11_2_1_3_3	60	18370	11022	8613	20.40	1.0E-04	0.62541	0.00096	0.62733	hcf25est12_2_1_3_3	0.61903	0.00111	0.62125
ncf15est11_2_1_2_3	40	18417	7367	8613	30.52	1.0E-04	0.54139	0.00091	0.54320	hcf25est12_2_1_2_3	0.53450	0.00087	0.53625
ncf15est11_2_1_1_3	19	18466	3509	8613	64.08	1.0E-04	0.42329	0.00080	0.42489	hcf25est12_2_1_1_3	0.41671	0.00077	0.41825
ncf15est11_2_2_8_3	100	36555	36555	7643	5.46	1.0E-04	0.93621	0.00109	0.93839	hcf25est12_2_2_8_3	0.92186	0.00104	0.92394
ncf15est11_2_2_7_3	95	36578	34749	7643	5.74	1.0E-04	0.91732	0.00132	0.91995	hcf25est12_2_2_7_3	0.90286	0.00137	0.90560
ncf15est11_2_2_6_3	90	36601	32941	7643	6.06	1.0E-04	0.89754	0.00118	0.89990	hcf25est12_2_2_6_3	0.88774	0.00119	0.89013
ncf15est11_2_2_5_3	80	36647	29318	7643	6.80	1.0E-04	0.86210	0.00109	0.86428	hcf25est12_2_2_5_3	0.85335	0.00111	0.85557

Table 6.9.6-9. Results for 1.5in.-diameter × 2.0 in.-tall slug HEU metal content in packaging calculation model

case name	enr	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf15est11_2_2_4_3	70	36694	25686	7643	7.77	1.0E-04	0.82389	0.00121	0.82631	hcf25est12_2_2_4_3	0.81165	0.00110	0.81386
ncf15est11_2_2_3_3	60	36740	22044	7643	9.05	1.0E-04	0.78278	0.00120	0.78519	hcf25est12_2_2_3_3	0.77147	0.00114	0.77375
ncf15est11_2_2_2_3	40	36834	14734	7643	13.54	1.0E-04	0.68461	0.00116	0.68692	hcf25est12_2_2_2_3	0.67454	0.00112	0.67679
ncf15est11_2_2_1_3	19	36932	7017	7643	28.43	1.0E-04	0.54624	0.00099	0.54823	hcf25est12_2_2_1_3	0.53779	0.00105	0.53989

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
metal as 1-in. cubes, flooded containment vessel, reflected										
no can spacers (np thickness = 0.0 in.)										
cvr3sqa_36_1_8_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.93455	0.00107	0.93668
cvr3sqa_36_1_7_15	0.0	95	35164	33406	8332	6.51	1.0E+00	0.91663	0.00128	0.91920
cvr3sqa_36_1_6_15	0.0	90	35186	31667	8332	6.87	1.0E+00	0.90133	0.00123	0.90379
cvr3sqa_36_1_5_15	0.0	80	35230	28184	8332	7.72	1.0E+00	0.87330	0.00119	0.87567
cvr3sqa_36_1_4_15	0.0	70	35275	24693	8332	8.81	1.0E+00	0.84424	0.00113	0.84650
cvr3sqa_36_1_3_15	0.0	60	35320	21192	8332	10.26	1.0E+00	0.81162	0.00124	0.81410
cvr3sqa_36_1_2_15	0.0	40	35410	14164	8332	15.35	1.0E+00	0.73700	0.00098	0.73896
cvr3sqa_36_1_1_15	0.0	19	35505	6746	8332	32.24	1.0E+00	0.63755	0.00119	0.63992
cvr3sqa_36_1_8_1	0.0	100	35142	35142	0	0.00	1.0E-20	0.78442	0.00112	0.78667
cvr3sqa_36_1_8_6	0.0	100	35142	35142	833	0.62	1.0E-01	0.79134	0.00116	0.79366
cvr3sqa_36_1_8_7	0.0	100	35142	35142	1666	1.24	2.0E-01	0.80350	0.00113	0.80577

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvr3sqa_36_1_8_8	0.0	100	35142	35142	2500	1.86	3.0E-01	0.81548	0.00107	0.81761
cvr3sqa_36_1_8_9	0.0	100	35142	35142	3333	2.48	4.0E-01	0.83048	0.00122	0.83293
cvr3sqa_36_1_8_10	0.0	100	35142	35142	4166	3.09	5.0E-01	0.84727	0.00122	0.84971
cvr3sqa_36_1_8_11	0.0	100	35142	35142	4999	3.71	6.0E-01	0.86174	0.00123	0.86420
cvr3sqa_36_1_8_12	0.0	100	35142	35142	5832	4.33	7.0E-01	0.87977	0.00118	0.88213
cvr3sqa_36_1_8_13	0.0	100	35142	35142	6666	4.95	8.0E-01	0.89818	0.00110	0.90037
cvr3sqa_36_1_8_14	0.0	100	35142	35142	7499	5.57	9.0E-01	0.91611	0.00118	0.91846
cvr3sqa_36_1_8_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.93455	0.00107	0.93668
with can spacers (np thickness = 1.4 in.)										
cvr3sqa_36_2_8_15	1.4	100	35142	35142	7719	5.73	1.0E+00	0.85151	0.00123	0.85397
cvr3sqa_36_2_7_15	1.4	95	35164	33406	7719	6.03	1.0E+00	0.83521	0.00123	0.83766
cvr3sqa_36_2_6_15	1.4	90	35186	31667	7719	6.36	1.0E+00	0.82166	0.00125	0.82415
cvr3sqa_36_2_5_15	1.4	80	35230	28184	7719	7.15	1.0E+00	0.78928	0.00112	0.79152
cvr3sqa_36_2_4_15	1.4	70	35275	24693	7719	8.16	1.0E+00	0.75994	0.00113	0.76220
cvr3sqa_36_2_3_15	1.4	60	35320	21192	7719	9.51	1.0E+00	0.72673	0.00112	0.72898
cvr3sqa_36_2_2_15	1.4	40	35410	14164	7719	14.22	1.0E+00	0.65008	0.00102	0.65213
cvr3sqa_36_2_1_15	1.4	19	35505	6746	7719	29.86	1.0E+00	0.54677	0.00102	0.54881
metal as lattice homogenized 1-in. cubes, flooded containment vessel, reflected										
no can spacers (np thickness = 0.0 in.)										
cvr3lha_36_1_8_1	0.0	100	35142	35142	0	0.00	1.0E-20	0.74814	0.00123	0.75060
cvr3lha_36_1_8_6	0.0	100	35142	35142	833	0.62	1.0E-01	0.76415	0.00125	0.76665
cvr3lha_36_1_8_7	0.0	100	35142	35142	1666	1.24	2.0E-01	0.77899	0.00102	0.78103
cvr3lha_36_1_8_8	0.0	100	35142	35142	2500	1.86	3.0E-01	0.79660	0.00143	0.79946
cvr3lha_36_1_8_9	0.0	100	35142	35142	3333	2.48	4.0E-01	0.81635	0.00113	0.81861

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvr3lha_36_1_8_10	0.0	100	35142	35142	4166	3.09	5.0E-01	0.83767	0.00109	0.83986
cvr3lha_36_1_8_11	0.0	100	35142	35142	4999	3.71	6.0E-01	0.85716	0.00116	0.85949
cvr3lha_36_1_8_12	0.0	100	35142	35142	5832	4.33	7.0E-01	0.88187	0.00114	0.88415
cvr3lha_36_1_8_13	0.0	100	35142	35142	6666	4.95	8.0E-01	0.90182	0.00109	0.90399
cvr3lha_36_1_8_14	0.0	100	35142	35142	7499	5.57	9.0E-01	0.92553	0.00148	0.92849
cvr3lha_36_1_8_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.94654	0.00126	0.94906
cvr3lha_36_1_8_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.94654	0.00126	0.94906
cvr3lha_36_1_7_15	0.0	95	35164	33406	8332	6.51	1.0E+00	0.93172	0.00115	0.93403
cvr3lha_36_1_6_15	0.0	90	35186	31667	8332	6.87	1.0E+00	0.91744	0.00126	0.91995
cvr3lha_36_1_5_15	0.0	80	35230	28184	8332	7.72	1.0E+00	0.89049	0.00113	0.89274
cvr3lha_36_1_4_15	0.0	70	35275	24693	8332	8.81	1.0E+00	0.85930	0.00133	0.86196
cvr3lha_36_1_3_15	0.0	60	35320	21192	8332	10.26	1.0E+00	0.82623	0.00131	0.82886
cvr3lha_36_1_2_15	0.0	40	35410	14164	8332	15.35	1.0E+00	0.75317	0.00110	0.75536
cvr3lha_36_1_1_15	0.0	19	35505	6746	8332	32.24	1.0E+00	0.65522	0.00102	0.65726
cvr3lha_36_1_8_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.94654	0.00126	0.94906
cvr3lha_35_1_8_15	0.0	100	34217	34217	8381	6.39	1.0E+00	0.94183	0.00106	0.94396
cvr3lha_34_1_8_15	0.0	100	33292	33292	8430	6.61	1.0E+00	0.93673	0.00125	0.93922
cvr3lha_33_1_8_15	0.0	100	32367	32367	8479	6.84	1.0E+00	0.95706	0.00123	0.95952
cvr3lha_32_1_8_15	0.0	100	31442	31442	8528	7.08	1.0E+00	0.94986	0.00142	0.95271
cvr3lha_31_1_8_15	0.0	100	30518	30518	8578	7.34	1.0E+00	0.94716	0.00118	0.94953
cvr3lha_30_1_8_15	0.0	100	29593	29593	8627	7.61	1.0E+00	0.93908	0.00127	0.94162
cvr3lha_29_1_8_15	0.0	100	28668	28668	8676	7.90	1.0E+00	0.93306	0.00126	0.93557

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvr3lha_28_1_8_15	0.0	100	27743	27743	8725	8.21	1.0E+00	0.93059	0.00137	0.93333
cvr3lha_27_1_8_15	0.0	100	26818	26818	8774	8.54	1.0E+00	0.92502	0.00139	0.92780
cvr3lha_26_1_8_15	0.0	100	25894	25894	8823	8.89	1.0E+00	0.91519	0.00145	0.91810
cvr3lha_25_1_8_15	0.0	100	24969	24969	8872	9.27	1.0E+00	0.91200	0.00125	0.91451
cvr3lha_24_1_8_15	0.0	100	23119	23119	8970	10.13	1.0E+00	0.92028	0.00106	0.92241
cvr3lha_23_1_8_15	0.0	100	22195	22195	9019	10.61	1.0E+00	0.91201	0.00115	0.91430
cvr3lha_22_1_8_15	0.0	100	21270	21270	9068	11.13	1.0E+00	0.90500	0.00138	0.90777
cvr3lha_21_1_8_15	0.0	100	20345	20345	9117	11.70	1.0E+00	0.89763	0.00133	0.90030
cvr3lha_31_1_7_15	0.0	95	30537	29010	8578	7.72	1.0E+00	0.92875	0.00129	0.93134
cvr3lha_30_1_7_15	0.0	95	29612	28131	8627	8.00	1.0E+00	0.92618	0.00111	0.92840
cvr3lha_29_1_7_15	0.0	95	28686	27252	8676	8.31	1.0E+00	0.91841	0.00107	0.92055
cvr3lha_28_1_7_15	0.0	95	27761	26373	8725	8.63	1.0E+00	0.91075	0.00124	0.91322
cvr3lha_27_1_7_15	0.0	95	26835	25494	8774	8.98	1.0E+00	0.90920	0.00117	0.91153
cvr3lha_33_1_6_15	0.0	90	32408	29167	8479	7.59	1.0E+00	0.92553	0.00126	0.92804
cvr3lha_32_1_6_15	0.0	90	31482	28334	8528	7.86	1.0E+00	0.92000	0.00119	0.92238
cvr3lha_31_1_6_15	0.0	90	30556	27501	8578	8.14	1.0E+00	0.91758	0.00132	0.92021
cvr3lha_36_1_5_15	0.0	80	35230	28184	8332	7.72	1.0E+00	0.89049	0.00113	0.89274
cvr3lha_35_1_5_15	0.0	80	34303	27443	8381	7.97	1.0E+00	0.88496	0.00111	0.88719
cvr3lha_34_1_5_15	0.0	80	33376	26701	8430	8.24	1.0E+00	0.88044	0.00106	0.88256
cvr3lha_33_1_5_15	0.0	80	32449	25959	8479	8.53	1.0E+00	0.89355	0.00112	0.89579

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvr3lha_32_1_5_15	0.0	80	31522	25218	8528	8.83	1.0E+00	0.88961	0.00146	0.89253
cvr3lha_31_1_5_15	0.0	80	30595	24476	8578	9.15	1.0E+00	0.88752	0.00141	0.89034
cvr3lha_36_1_4_15	0.0	70	35275	24693	8332	8.81	1.0E+00	0.85930	0.00133	0.86196
cvr3lha_35_1_4_15	0.0	70	34347	24043	8381	9.10	1.0E+00	0.85473	0.00113	0.85698
cvr3lha_34_1_4_15	0.0	70	33419	23393	8430	9.41	1.0E+00	0.85237	0.00129	0.85496
cvr3lha_33_1_4_15	0.0	70	32490	22743	8479	9.73	1.0E+00	0.86299	0.00121	0.86542
cvr3lha_32_1_4_15	0.0	70	31562	22093	8528	10.08	1.0E+00	0.85876	0.00132	0.86140
cvr3lha_31_1_4_15	0.0	70	30634	21444	8578	10.44	1.0E+00	0.85471	0.00125	0.85720
cvr3lha_36_1_3_15	0.0	60	35320	21192	8332	10.26	1.0E+00	0.82623	0.00131	0.82886
cvr3lha_36_1_2_15	0.0	40	35410	14164	8332	15.35	1.0E+00	0.75317	0.00110	0.75536
cvr3lha_36_1_1_15	0.0	19	35505	6746	8332	32.24	1.0E+00	0.65522	0.00102	0.65726
cvr3lha_36_2_8_15	1.4	100	35142	35142	7719	5.73	1.0E+00	0.87286	0.00134	0.87554
cvr3lha_36_2_7_15	1.4	95	35164	33406	7719	6.03	1.0E+00	0.85858	0.00109	0.86077
cvr3lha_36_2_6_15	1.4	90	35186	31667	7719	6.36	1.0E+00	0.84459	0.00107	0.84672
cvr3lha_36_2_5_15	1.4	80	35230	28184	7719	7.15	1.0E+00	0.81698	0.00127	0.81952
cvr3lha_36_2_4_15	1.4	70	35275	24693	7719	8.16	1.0E+00	0.78484	0.00122	0.78727
cvr3lha_36_2_3_15	1.4	60	35320	21192	7719	9.51	1.0E+00	0.75584	0.00105	0.75795
cvr3lha_36_2_2_15	1.4	40	35410	14164	7719	14.22	1.0E+00	0.68360	0.00131	0.68623
cvr3lha_36_2_1_15	1.4	19	35505	6746	7719	29.86	1.0E+00	0.58144	0.00104	0.58352

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
metal as 1-in. cubes fully homogenized with water for flooded containment vessel, reflected										
no can spacers (np thickness = 0.0 in.)										
cvr3cha_36_1_8_1	0.0	100	35142	35142	0	0.00	1.0E-20	0.61068	0.00099	0.61266
cvr3cha_36_1_8_6	0.0	100	35142	35142	833	0.62	1.0E-01	0.64671	0.00117	0.64905
cvr3cha_36_1_8_7	0.0	100	35142	35142	1666	1.24	2.0E-01	0.68117	0.00106	0.68329
cvr3cha_36_1_8_8	0.0	100	35142	35142	2500	1.86	3.0E-01	0.71931	0.00121	0.72174
cvr3cha_36_1_8_9	0.0	100	35142	35142	3333	2.48	4.0E-01	0.75910	0.00125	0.76160
cvr3cha_36_1_8_10	0.0	100	35142	35142	4166	3.09	5.0E-01	0.79344	0.00123	0.79589
cvr3cha_36_1_8_11	0.0	100	35142	35142	4999	3.71	6.0E-01	0.83513	0.00132	0.83777
cvr3cha_36_1_8_12	0.0	100	35142	35142	5833	4.33	7.0E-01	0.87270	0.00117	0.87504
cvr3cha_36_1_8_13	0.0	100	35142	35142	6666	4.95	8.0E-01	0.90988	0.00115	0.91219
cvr3cha_36_1_8_14	0.0	100	35142	35142	7499	5.57	9.0E-01	0.94696	0.00136	0.94968
cvr3cha_36_1_8_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.98062	0.00128	0.98318
cvr3cha_36_1_8_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.98062	0.00128	0.98318
cvr3cha_36_1_7_15	0.0	95	35164	33406	8332	6.51	1.0E+00	0.96729	0.00134	0.96997
cvr3cha_36_1_6_15	0.0	90	35186	31667	8332	6.87	1.0E+00	0.95443	0.00144	0.95731
cvr3cha_36_1_5_15	0.0	80	35231	28184	8332	7.72	1.0E+00	0.93639	0.00114	0.93867
cvr3cha_36_1_4_15	0.0	70	35275	24693	8332	8.81	1.0E+00	0.91729	0.00125	0.91978
cvr3cha_36_1_3_15	0.0	60	35320	21192	8332	10.26	1.0E+00	0.89768	0.00137	0.90042
cvr3cha_36_1_2_15	0.0	40	35410	14164	8332	15.35	1.0E+00	0.85347	0.00132	0.85612
cvr3cha_36_1_1_15	0.0	19	35505	6746	8332	32.24	1.0E+00	0.78799	0.00132	0.79064

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvr3cha_9_1_8_15	0.0	100	8323	8323	9755	30.59	1.0E+00	0.92411	0.00165	0.92741
cvr3cha_8_1_8_15	0.0	100	7398	7398	9804	34.59	1.0E+00	0.91970	0.00146	0.92263
cvr3cha_7_1_8_15	0.0	100	6473	6473	9854	39.73	1.0E+00	0.91473	0.00144	0.91762
cvr3cha_6_1_8_15	0.0	100	5549	5549	9903	46.58	1.0E+00	0.90826	0.00144	0.91114
cvr3cha_5_1_8_15	0.0	100	4624	4624	9952	56.17	1.0E+00	0.89884	0.00156	0.90196
cvr3cha_4_1_8_15	0.0	100	3699	3699	10001	70.56	1.0E+00	0.88830	0.00130	0.89090
cvr3cha_3_1_8_15	0.0	100	2774	2774	10050	94.55	1.0E+00	0.86596	0.00144	0.86884
cvr3cha_2_1_8_15	0.0	100	1850	1850	10099	142.5	1.0E+00	0.82987	0.00147	0.83281
cvr3cha_1_1_8_15	0.0	100	925	925	10148	286.4	1.0E+00	0.73830	0.00123	0.74075
cvr3cha_13_1_7_15	0.0	95	12955	12307	9510	20.17	1.0E+00	0.92721	0.00146	0.93013
cvr3cha_12_1_7_15	0.0	95	11104	10549	9608	23.77	1.0E+00	0.92145	0.00152	0.92449
cvr3cha_11_1_7_15	0.0	95	10179	9670	9657	26.07	1.0E+00	0.92161	0.00139	0.92439
cvr3cha_10_1_7_15	0.0	95	9254	8791	9706	28.82	1.0E+00	0.91850	0.00146	0.92142
cvr3cha_9_1_7_15	0.0	95	8328	7912	9755	32.18	1.0E+00	0.91420	0.00139	0.91699
cvr3cha_8_1_7_15	0.0	95	7403	7033	9804	36.39	1.0E+00	0.91089	0.00129	0.91347
cvr3cha_7_1_7_15	0.0	95	6478	6154	9854	41.79	1.0E+00	0.90510	0.00141	0.90792
cvr3cha_6_1_7_15	0.0	95	5552	5275	9903	49.00	1.0E+00	0.89876	0.00141	0.90158
cvr3cha_5_1_7_15	0.0	95	4627	4396	9952	59.09	1.0E+00	0.89248	0.00137	0.89522
cvr3cha_4_1_7_15	0.0	95	3701	3516	10001	74.23	1.0E+00	0.87921	0.00123	0.88166
cvr3cha_3_1_7_15	0.0	95	2776	2637	10050	99.46	1.0E+00	0.85895	0.00143	0.86181
cvr3cha_2_1_7_15	0.0	95	1851	1758	10099	149.92	1.0E+00	0.82077	0.00151	0.82380
cvr3cha_1_1_7_15	0.0	95	925	879	10148	301.30	1.0E+00	0.72727	0.00130	0.72988

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvr3cha_17_1_6_15	0.0	90	16667	15000	9314	16.21	1.0E+00	0.92297	0.00142	0.92580
cvr3cha_16_1_6_15	0.0	90	15741	14167	9363	17.25	1.0E+00	0.92154	0.00140	0.92434
cvr3cha_15_1_6_15	0.0	90	14815	13334	9412	18.42	1.0E+00	0.92402	0.00131	0.92664
cvr3cha_14_1_6_15	0.0	90	13889	12500	9461	19.75	1.0E+00	0.91968	0.00162	0.92291
cvr3cha_13_1_6_15	0.0	90	12963	11667	9510	21.28	1.0E+00	0.91675	0.00152	0.91979
cvr3cha_28_1_5_15	0.0	80	27814	22251	8725	10.23	1.0E+00	0.92438	0.00137	0.92712
cvr3cha_27_1_5_15	0.0	80	26886	21509	8774	10.65	1.0E+00	0.92213	0.00147	0.92507
cvr3cha_26_1_5_15	0.0	80	25959	20767	8823	11.09	1.0E+00	0.92209	0.00165	0.92540
cvr3cha_25_1_5_15	0.0	80	24105	19284	8921	12.07	1.0E+00	0.91935	0.00157	0.92249
cvr3cha_24_1_5_15	0.0	80	23178	18542	8970	12.63	1.0E+00	0.91637	0.00132	0.91900
cvr3cha_23_1_5_15	0.0	80	22251	17801	9019	13.22	1.0E+00	0.91519	0.00139	0.91798
cvr3cha_36_1_4_15	0.0	70	35275	24693	8332	8.81	1.0E+00	0.91729	0.00125	0.91978
cvr3cha_35_1_4_15	0.0	70	34347	24043	8381	9.10	1.0E+00	0.91586	0.00125	0.91835
cvr3cha_34_1_4_15	0.0	70	33419	23393	8430	9.41	1.0E+00	0.91481	0.00139	0.91758
cvr3cha_33_1_4_15	0.0	70	32490	22743	8479	9.73	1.0E+00	0.91228	0.00128	0.91484
cvr3cha_32_1_4_15	0.0	70	31562	22093	8529	10.08	1.0E+00	0.91196	0.00129	0.91454
cvr3cha_31_1_4_15	0.0	70	30634	21444	8578	10.44	1.0E+00	0.90865	0.00139	0.91143
cvr3cha_36_1_3_15	0.0	60	35320	21192	8332	10.26	1.0E+00	0.89768	0.00137	0.90042
cvr3cha_35_1_3_15	0.0	60	34391	20634	8381	10.60	1.0E+00	0.89413	0.00135	0.89683
cvr3cha_34_1_3_15	0.0	60	33461	20077	8430	10.96	1.0E+00	0.89574	0.00118	0.89810
cvr3cha_33_1_3_15	0.0	60	32532	19519	8479	11.34	1.0E+00	0.89333	0.00129	0.89591

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvr3cha_32_1_3_15	0.0	60	31602	18961	8529	11.74	1.0E+00	0.89469	0.00121	0.89710
cvr3cha_31_1_3_15	0.0	60	30673	18404	8578	12.17	1.0E+00	0.89268	0.00145	0.89558
cvr3cha_36_1_2_15	0.0	40	35410	14164	8332	15.35	1.0E+00	0.85347	0.00132	0.85612
cvr3cha_35_1_2_15	0.0	40	34478	13791	8381	15.86	1.0E+00	0.85471	0.00109	0.85690
cvr3cha_34_1_2_15	0.0	40	33546	13419	8430	16.40	1.0E+00	0.85466	0.00125	0.85716
cvr3cha_33_1_2_15	0.0	40	32614	13046	8479	16.96	1.0E+00	0.85311	0.00132	0.85575
cvr3cha_32_1_2_15	0.0	40	31683	12673	8529	17.57	1.0E+00	0.85294	0.00136	0.85566
cvr3cha_31_1_2_15	0.0	40	30751	12300	8578	18.20	1.0E+00	0.85042	0.00127	0.85295
cvr3cha_36_1_1_15	0.0	19	35505	6746	8332	32.24	1.0E+00	0.78799	0.00132	0.79064
cvr3cha_35_1_1_15	0.0	19	34570	6568	8381	33.30	1.0E+00	0.78798	0.00132	0.79062
cvr3cha_34_1_1_15	0.0	19	33636	6391	8430	34.43	1.0E+00	0.78692	0.00142	0.78976
cvr3cha_33_1_1_15	0.0	19	32702	6213	8479	35.62	1.0E+00	0.78967	0.00115	0.79198
cvr3cha_32_1_1_15	0.0	19	31767	6036	8529	36.88	1.0E+00	0.78868	0.00135	0.79138
cvr3cha_31_1_1_15	0.0	19	30833	5858	8578	38.22	1.0E+00	0.78919	0.00118	0.79155
with can spacers (np thickness = 1.4 in.)										
cvr3cha_36_2_8_15	1.4	100	35142	35142	7719	5.73	1.0E+00	0.96066	0.00128	0.96321
cvr3cha_36_2_7_15	1.4	95	35164	33406	7719	6.03	1.0E+00	0.94267	0.00127	0.94521
cvr3cha_36_2_6_15	1.4	90	35186	31667	7719	6.36	1.0E+00	0.93250	0.00117	0.93484
cvr3cha_36_2_5_15	1.4	80	35231	28184	7719	7.15	1.0E+00	0.91364	0.00126	0.91615
cvr3cha_36_2_4_15	1.4	70	35275	24693	7719	8.16	1.0E+00	0.89707	0.00125	0.89957
cvr3cha_36_2_3_15	1.4	60	35320	21192	7719	9.51	1.0E+00	0.87509	0.00121	0.87751

Table 6.9.6-10. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in CV calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
cvr3cha_36_2_2_15	1.4	40	35410	14164	7719	14.22	1.0E+00	0.82672	0.00135	0.82943
cvr3cha_36_2_1_15	1.4	19	35505	6746	7719	29.86	1.0E+00	0.76024	0.00148	0.76320
cvr3cha_11_2_8_15	1.4	100	10173	10173	9044	23.20	1.0E+00	0.92383	0.00148	0.92679
cvr3cha_10_2_8_15	1.4	100	9248	9248	9093	25.66	1.0E+00	0.91980	0.00132	0.92244
cvr3cha_09_2_8_15	1.4	100	8323	8323	9142	28.67	1.0E+00	0.91510	0.00129	0.91768
cvr3cha_16_2_7_15	1.4	95	15731	14945	8749	15.28	1.0E+00	0.92275	0.00162	0.92599
cvr3cha_15_2_7_15	1.4	95	14806	14066	8798	16.33	1.0E+00	0.92071	0.00155	0.92380
cvr3cha_14_2_7_15	1.4	95	13880	13186	8847	17.51	1.0E+00	0.92004	0.00132	0.92268
cvr3cha_25_2_6_15	1.4	90	24075	21667	8308	10.01	1.0E+00	0.92554	0.00129	0.92813
cvr3cha_24_2_6_15	1.4	90	23149	20834	8357	10.47	1.0E+00	0.92042	0.00132	0.92306
cvr3cha_23_2_6_15	1.4	90	22223	20000	8406	10.97	1.0E+00	0.92148	0.00135	0.92419
cvr3cha_22_2_6_15	1.4	90	21297	19167	8455	11.51	1.0E+00	0.91898	0.00142	0.92181

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, single package reflected														
NCT											**HAC**			
no can spacers (np thickness = 0.0 in.)														
ncsrbmt11_36_1_1	0.0	100	35142	35142	8332	6.19	1.0E-20	0.81144	0.00127	0.81397	hcsrbmt12_36_1_1	0.81597	0.00140	0.81877
ncsrbmt11_36_1_2	0.0	100	35142	35142	8332	6.19	1.0E-05	0.81278	0.00143	0.81563	hcsrbmt12_36_1_2	0.81496	0.00123	0.81741
ncsrbmt11_36_1_3	0.0	100	35142	35142	8332	6.19	1.0E-04	0.81066	0.00124	0.81314	hcsrbmt12_36_1_3	0.81490	0.00149	0.81787
ncsrbmt11_36_1_4	0.0	100	35142	35142	8332	6.19	1.0E-03	0.81064	0.00142	0.81347	hcsrbmt12_36_1_4	0.81512	0.00157	0.81826
ncsrbmt11_36_1_5	0.0	100	35142	35142	8332	6.19	1.0E-02	0.81069	0.00138	0.81346	hcsrbmt12_36_1_5	0.81594	0.00126	0.81846
ncsrbmt11_36_1_6	0.0	100	35142	35142	8332	6.19	1.0E-01	0.81880	0.00126	0.82132	hcsrbmt12_36_1_6	0.82255	0.00126	0.82507
ncsrbmt11_36_1_8	0.0	100	35142	35142	8332	6.19	3.0E-01	0.83502	0.00115	0.83732	hcsrbmt12_36_1_8	0.83846	0.00125	0.84095
ncsrbmt11_36_1_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.88830	0.00122	0.89075	hcsrbmt12_36_1_15	0.88841	0.00140	0.89122
ncsrbmt11_36_1_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.88830	0.00122	0.89075				
ncsrbmt11_35_1_15	0.0	100	34217	34217	8381	6.39	1.0E+00	0.88662	0.00129	0.88921				
ncsrbmt11_34_1_15	0.0	100	33292	33292	8430	6.61	1.0E+00	0.88622	0.00119	0.88860				
ncsrbmt11_33_1_15	0.0	100	32367	32367	8479	6.84	1.0E+00	0.88175	0.00127	0.88429				
ncsrbmt11_32_1_15	0.0	100	31442	31442	8529	7.08	1.0E+00	0.88109	0.00124	0.88357				
ncsrbmt11_31_1_15	0.0	100	30518	30518	8578	7.34	1.0E+00	0.87995	0.00126	0.88247				
ncsrbmt11_30_1_15	0.0	100	29593	29593	8627	7.61	1.0E+00	0.87410	0.00144	0.87697				
ncsrbmt11_29_1_15	0.0	100	28668	28668	8676	7.90	1.0E+00	0.87385	0.00118	0.87621				
ncsrbmt11_28_1_15	0.0	100	27743	27743	8725	8.21	1.0E+00	0.87237	0.00119	0.87474				
ncsrbmt11_27_1_15	0.0	100	26819	26819	8774	8.54	1.0E+00	0.86800	0.00126	0.87053				
ncsrbmt11_26_1_15	0.0	100	25894	25894	8823	8.89	1.0E+00	0.86869	0.00123	0.87115				
ncsrbmt11_25_1_15	0.0	100	24969	24969	8872	9.27	1.0E+00	0.86558	0.00152	0.86862				

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrbmt11_24_1_15	0.0	100	23119	23119	8970	10.13	1.0E+00	0.85827	0.00123	0.86074				
ncsrbmt11_23_1_15	0.0	100	22195	22195	9019	10.61	1.0E+00	0.85657	0.00134	0.85924				
ncsrbmt11_22_1_15	0.0	100	21270	21270	9068	11.13	1.0E+00	0.85373	0.00156	0.85686				
ncsrbmt11_21_1_15	0.0	100	20345	20345	9117	11.70	1.0E+00	0.85521	0.00126	0.85774				
ncsrbmt11_20_1_15	0.0	100	19420	19420	9166	12.32	1.0E+00	0.84989	0.00157	0.85303				
ncsrbmt11_19_1_15	0.0	100	18496	18496	9216	13.00	1.0E+00	0.85069	0.00155	0.85378				
ncsrbmt11_18_1_15	0.0	100	17571	17571	9265	13.76	1.0E+00	0.84676	0.00182	0.85039				
ncsrbmt11_17_1_15	0.0	100	16646	16646	9314	14.60	1.0E+00	0.84566	0.00147	0.84859				
ncsrbmt11_16_1_15	0.0	100	15721	15721	9363	15.54	1.0E+00	0.84458	0.00125	0.84708				
ncsrbmt11_15_1_15	0.0	100	14796	14796	9412	16.60	1.0E+00	0.83932	0.00148	0.84229				
ncsrbmt11_14_1_15	0.0	100	13872	13872	9461	17.80	1.0E+00	0.83752	0.00133	0.84019				
ncsrbmt11_13_1_15	0.0	100	12947	12947	9510	19.17	1.0E+00	0.83532	0.00151	0.83834				
ncsrbmt11_12_1_15	0.0	100	11097	11097	9608	22.60	1.0E+00	0.82792	0.00133	0.83057				
ncsrbmt11_11_1_15	0.0	100	10173	10173	9657	24.78	1.0E+00	0.82643	0.00127	0.82898				
ncsrbmt11_10_1_15	0.0	100	9248	9248	9706	27.39	1.0E+00	0.82649	0.00160	0.82968				
ncsrbmt11_9_1_15	0.0	100	8323	8323	9755	30.59	1.0E+00	0.81840	0.00140	0.82119				
ncsrbmt11_8_1_15	0.0	100	7398	7398	9804	34.59	1.0E+00	0.81808	0.00170	0.82148				
ncsrbmt11_7_1_15	0.0	100	6473	6473	9854	39.73	1.0E+00	0.81130	0.00152	0.81434				
ncsrbmt11_6_1_15	0.0	100	5549	5549	9903	46.58	1.0E+00	0.80480	0.00140	0.80761				
ncsrbmt11_5_1_15	0.0	100	4624	4624	9952	56.17	1.0E+00	0.79723	0.00124	0.79971				
ncsrbmt11_4_1_15	0.0	100	3699	3699	10001	70.56	1.0E+00	0.78533	0.00133	0.78799				
ncsrbmt11_3_1_15	0.0	100	2774	2774	10050	94.55	1.0E+00	0.76796	0.00152	0.77099				
ncsrbmt11_2_1_15	0.0	100	1850	1850	10099	142.51	1.0E+00	0.73495	0.00142	0.73778				
ncsrbmt11_1_1_15	0.0	100	925	925	10148	286.41	1.0E+00	0.65230	0.00132	0.65494				

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
with can spacers (np thickness = 1.4 in.)														
ncsrbmt11_36_2_1	1.4	100	35142	35142	7719	5.73	1.0E-20	0.79252	0.00122	0.79496	hcsrbmt12_36_2_1	0.79368	0.00134	0.79636
ncsrbmt11_36_2_2	1.4	100	35142	35142	7719	5.73	1.0E-05	0.79014	0.00147	0.79309	hcsrbmt12_36_2_2	0.79487	0.00120	0.79727
ncsrbmt11_36_2_3	1.4	100	35142	35142	7719	5.73	1.0E-04	0.79182	0.00134	0.79450	hcsrbmt12_36_2_3	0.79667	0.00135	0.79938
ncsrbmt11_36_2_4	1.4	100	35142	35142	7719	5.73	1.0E-03	0.79144	0.00116	0.79376	hcsrbmt12_36_2_4	0.79705	0.00133	0.79971
ncsrbmt11_36_2_5	1.4	100	35142	35142	7719	5.73	1.0E-02	0.78918	0.00111	0.79141	hcsrbmt12_36_2_5	0.79627	0.00135	0.79898
ncsrbmt11_36_2_6	1.4	100	35142	35142	7719	5.73	1.0E-01	0.80114	0.00117	0.80348	hcsrbmt12_36_2_6	0.80431	0.00130	0.80691
ncsrbmt11_36_2_8	1.4	100	35142	35142	7719	5.73	3.0E-01	0.81416	0.00141	0.81698	hcsrbmt12_36_2_8	0.82035	0.00119	0.82273
ncsrbmt11_36_2_15	1.4	100	35142	35142	7719	5.73	1.0E+00	0.86924	0.00119	0.87162	hcsrbmt12_36_2_15	0.87124	0.00142	0.87408
ncsrbmt11_36_2_15	1.4	100	35142	35142	7719	5.73	1.0E+00	0.86924	0.00119	0.87162				
ncsrbmt11_35_2_15	1.4	100	34217	34217	7768	5.93	1.0E+00	0.86697	0.00130	0.86957				
ncsrbmt11_34_2_15	1.4	100	33292	33292	7817	6.13	1.0E+00	0.86435	0.00138	0.86712				
ncsrbmt11_33_2_15	1.4	100	32367	32367	7866	6.34	1.0E+00	0.86988	0.00130	0.87249				
ncsrbmt11_32_2_15	1.4	100	31442	31442	7915	6.57	1.0E+00	0.86598	0.00145	0.86889				
ncsrbmt11_31_2_15	1.4	100	30518	30518	7964	6.81	1.0E+00	0.86432	0.00153	0.86739				
ncsrbmt11_30_2_15	1.4	100	29593	29593	8013	7.07	1.0E+00	0.85951	0.00163	0.86277				
ncsrbmt11_29_2_15	1.4	100	28668	28668	8062	7.34	1.0E+00	0.85938	0.00134	0.86206				
ncsrbmt11_28_2_15	1.4	100	27743	27743	8111	7.63	1.0E+00	0.85890	0.00133	0.86157				
ncsrbmt11_27_2_15	1.4	100	26819	26819	8160	7.94	1.0E+00	0.85736	0.00143	0.86023				
ncsrbmt11_26_2_15	1.4	100	25894	25894	8209	8.28	1.0E+00	0.85189	0.00129	0.85447				
ncsrbmt11_25_2_15	1.4	100	24969	24969	8258	8.63	1.0E+00	0.84986	0.00148	0.85281				
ncsrbmt11_24_2_15	1.4	100	23119	23119	8357	9.43	1.0E+00	0.85225	0.00131	0.85488				
ncsrbmt11_23_2_15	1.4	100	22195	22195	8406	9.89	1.0E+00	0.84824	0.00142	0.85108				

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrbmt11_22_2_15	1.4	100	21270	21270	8455	10.38	1.0E+00	0.84600	0.00135	0.84869				
ncsrbmt11_21_2_15	1.4	100	20345	20345	8504	10.91	1.0E+00	0.84406	0.00150	0.84706				
ncsrbmt11_20_2_15	1.4	100	19420	19420	8553	11.50	1.0E+00	0.83992	0.00126	0.84244				
ncsrbmt11_19_2_15	1.4	100	18496	18496	8602	12.14	1.0E+00	0.83869	0.00134	0.84138				
ncsrbmt11_18_2_15	1.4	100	17571	17571	8651	12.85	1.0E+00	0.83488	0.00152	0.83793				
ncsrbmt11_17_2_15	1.4	100	16646	16646	8700	13.64	1.0E+00	0.83409	0.00130	0.83669				
ncsrbmt11_16_2_15	1.4	100	15721	15721	8749	14.53	1.0E+00	0.83520	0.00135	0.83789				
ncsrbmt11_15_2_15	1.4	100	14796	14796	8798	15.52	1.0E+00	0.83427	0.00129	0.83686				
ncsrbmt11_14_2_15	1.4	100	13872	13872	8847	16.65	1.0E+00	0.83162	0.00157	0.83476				
ncsrbmt11_13_2_15	1.4	100	12947	12947	8896	17.94	1.0E+00	0.82907	0.00147	0.83201				
ncsrbmt11_12_2_15	1.4	100	11097	11097	8995	21.16	1.0E+00	0.82195	0.00149	0.82493				
ncsrbmt11_11_2_15	1.4	100	10173	10173	9044	23.20	1.0E+00	0.81845	0.00120	0.82084				
ncsrbmt11_10_2_15	1.4	100	9248	9248	9093	25.66	1.0E+00	0.81508	0.00142	0.81792				
ncsrbmt11_9_2_15	1.4	100	8323	8323	9142	28.67	1.0E+00	0.81075	0.00138	0.81351				
ncsrbmt11_8_2_15	1.4	100	7398	7398	9191	32.43	1.0E+00	0.81425	0.00169	0.81764				
ncsrbmt11_7_2_15	1.4	100	6473	6473	9240	37.26	1.0E+00	0.80774	0.00155	0.81084				
ncsrbmt11_6_2_15	1.4	100	5549	5549	9289	43.70	1.0E+00	0.80060	0.00138	0.80336				
ncsrbmt11_5_2_15	1.4	100	4624	4624	9338	52.71	1.0E+00	0.79537	0.00167	0.79870				
ncsrbmt11_4_2_15	1.4	100	3699	3699	9387	66.24	1.0E+00	0.78379	0.00136	0.78651				
ncsrbmt11_3_2_15	1.4	100	2774	2774	9436	88.78	1.0E+00	0.76586	0.00130	0.76846				
ncsrbmt11_2_2_15	1.4	100	1850	1850	9485	133.86	1.0E+00	0.73246	0.00135	0.73516				
ncsrbmt11_1_2_15	1.4	100	925	925	9534	269.10	1.0E+00	0.65664	0.00150	0.65963				

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, array packaging model for CSI=0.0														
NCT											**HAC**			
no can spacers (np thickness = 0.0 in.)														
nciabmt11_36_1_8_1	0.0	100	35142	35142	8332	6.19	1.0E-20	1.13613	0.00121	1.13855	hciabmt12_36_1_8_1	1.13721	0.00124	1.13969
nciabmt11_36_1_8_2	0.0	100	35142	35142	8332	6.19	1.0E-05	1.13830	0.00153	1.14135	hciabmt12_36_1_8_2	1.13634	0.00114	1.13862
nciabmt11_36_1_8_3	0.0	100	35142	35142	8332	6.19	1.0E-04	1.13709	0.00121	1.13952	hciabmt12_36_1_8_3	1.13700	0.00127	1.13954
nciabmt11_36_1_8_4	0.0	100	35142	35142	8332	6.19	1.0E-03	1.13450	0.00115	1.13679	hciabmt12_36_1_8_4	1.13567	0.00121	1.13809
nciabmt11_36_1_8_5	0.0	100	35142	35142	8332	6.19	1.0E-02	1.11154	0.00120	1.11394	hciabmt12_36_1_8_5	1.12232	0.00129	1.12490
nciabmt11_36_1_8_6	0.0	100	35142	35142	8332	6.19	1.0E-01	0.98653	0.00121	0.98894	hciabmt12_36_1_8_6	1.03049	0.00115	1.03278
nciabmt11_36_1_8_8	0.0	100	35142	35142	8332	6.19	3.0E-01	0.91622	0.00135	0.91892	hciabmt12_36_1_8_8	0.95566	0.00126	0.95818
nciabmt11_36_1_8_15	0.0	100	35142	35142	8332	6.19	1.0E+00	0.91008	0.00124	0.91255	hciabmt12_36_1_8_15	0.93645	0.00120	0.93884
nciabmt11_7_1_5_3	0.0	80	6490	5192	9854	49.54	1.0E-04	0.96163	0.00130	0.96423	hciabmt12_7_1_5_3	0.96193	0.00149	0.96490
nciabmt11_6_1_5_3	0.0	80	5563	4450	9903	58.08	1.0E-04	0.95210	0.00130	0.95471	hciabmt12_6_1_5_3	0.95164	0.00139	0.95442
nciabmt11_5_1_5_3	0.0	80	4636	3709	9952	70.04	1.0E-04	0.93892	0.00161	0.94215	hciabmt12_5_1_5_3	0.93880	0.00141	0.94162
nciabmt11_4_1_5_3	0.0	80	3709	2967	10001	87.98	1.0E-04	0.91835	0.00149	0.92133	hciabmt12_4_1_5_3	0.92156	0.00160	0.92476
nciabmt11_3_1_5_3	0.0	80	2781	2225	10050	117.89	1.0E-04	0.89262	0.00129	0.89520	hciabmt12_3_1_5_3	0.89109	0.00160	0.89430
nciabmt11_9_1_4_3	0.0	70	8355	5848	9755	43.54	1.0E-04	0.95952	0.00130	0.96213	hciabmt12_9_1_4_3	0.95495	0.00150	0.95795
nciabmt11_8_1_4_3	0.0	70	7426	5198	9804	49.23	1.0E-04	0.94887	0.00152	0.95191	hciabmt12_8_1_4_3	0.95267	0.00156	0.95578
nciabmt11_7_1_4_3	0.0	70	6498	4549	9854	56.54	1.0E-04	0.94082	0.00132	0.94346	hciabmt12_7_1_4_3	0.94409	0.00125	0.94659
nciabmt11_6_1_4_3	0.0	70	5570	3899	9903	66.29	1.0E-04	0.92987	0.00119	0.93225	hciabmt12_6_1_4_3	0.93280	0.00123	0.93526
nciabmt11_5_1_4_3	0.0	70	4642	3249	9952	79.95	1.0E-04	0.91799	0.00136	0.92070	hciabmt12_5_1_4_3	0.92053	0.00147	0.92347

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciabmt11_10_1_3_3	0.0	60	9295	5577	9706	45.43	1.0E-04	0.94106	0.00152	0.94409	hciabmt12_10_1_3_3	0.94167	0.00126	0.94419
nciabmt11_9_1_3_3	0.0	60	8365	5019	9755	50.73	1.0E-04	0.93671	0.00123	0.93918	hciabmt12_9_1_3_3	0.93973	0.00135	0.94242
nciabmt11_8_1_3_3	0.0	60	7436	4462	9804	57.36	1.0E-04	0.92907	0.00129	0.93166	hciabmt12_8_1_3_3	0.93016	0.00128	0.93273
nciabmt11_7_1_3_3	0.0	60	6506	3904	9854	65.88	1.0E-04	0.92171	0.00118	0.92407	hciabmt12_7_1_3_3	0.92300	0.00130	0.92560
nciabmt11_6_1_3_3	0.0	60	5577	3346	9903	77.24	1.0E-04	0.91221	0.00147	0.91515	hciabmt12_6_1_3_3	0.91017	0.00128	0.91274
with can spacers (np thickness = 1.4 in.)														
nciabmt11_36_2_8_1	1.4	100	35142	35142	7719	5.73	1.0E-20	1.11012	0.00118	1.11249	hciabmt12_36_2_8_1	1.11021	0.00115	1.11250
nciabmt11_36_2_8_2	1.4	100	35142	35142	7719	5.73	1.0E-05	1.10934	0.00103	1.11141	hciabmt12_36_2_8_2	1.10929	0.00137	1.11202
nciabmt11_36_2_8_3	1.4	100	35142	35142	7719	5.73	1.0E-04	1.10991	0.00131	1.11252	hciabmt12_36_2_8_3	1.10922	0.00112	1.11145
nciabmt11_36_2_8_4	1.4	100	35142	35142	7719	5.73	1.0E-03	1.10774	0.00123	1.11020	hciabmt12_36_2_8_4	1.10732	0.00115	1.10963
nciabmt11_36_2_8_5	1.4	100	35142	35142	7719	5.73	1.0E-02	1.08309	0.00140	1.08589	hciabmt12_36_2_8_5	1.09559	0.00114	1.09786
nciabmt11_36_2_8_6	1.4	100	35142	35142	7719	5.73	1.0E-01	0.95955	0.00128	0.96212	hciabmt12_36_2_8_6	1.00216	0.00124	1.00463
nciabmt11_36_2_8_8	1.4	100	35142	35142	7719	5.73	3.0E-01	0.88829	0.00112	0.89053	hciabmt12_36_2_8_8	0.92859	0.00158	0.93175
nciabmt11_36_2_8_15	1.4	100	35142	35142	7719	5.73	1.0E+00	0.88638	0.00158	0.88953	hciabmt12_36_2_8_15	0.91405	0.00147	0.91698
nciabmt11_5_2_8_3	1.4	100	4624	4624	9338	52.71	1.0E-04	0.94785	0.00147	0.95079	hciabmt12_5_2_8_3	0.95226	0.00143	0.95511
nciabmt11_4_2_8_3	1.4	100	3699	3699	9387	66.24	1.0E-04	0.92504	0.00170	0.92845	hciabmt12_4_2_8_3	0.93069	0.00142	0.93352
nciabmt11_3_2_8_3	1.4	100	2774	2774	9436	88.78	1.0E-04	0.90131	0.00139	0.90409	hciabmt12_3_2_8_3	0.90243	0.00127	0.90497
nciabmt11_2_2_8_3	1.4	100	1850	1850	9485	133.86	1.0E-04	0.85414	0.00141	0.85696	hciabmt12_2_2_8_3	0.85600	0.00123	0.85846
nciabmt11_1_2_8_3	1.4	100	925	925	9534	269.10	1.0E-04	0.74985	0.00124	0.75232	hciabmt12_1_2_8_3	0.75078	0.00135	0.75347
nciabmt11_6_2_7_3	1.4	95	5552	5275	9289	45.97	1.0E-04	0.95078	0.00124	0.95327	hciabmt12_6_2_7_3	0.95399	0.00153	0.95704
nciabmt11_5_2_7_3	1.4	95	4627	4396	9338	55.45	1.0E-04	0.93742	0.00130	0.94002	hciabmt12_5_2_7_3	0.93696	0.00142	0.93981
nciabmt11_4_2_7_3	1.4	95	3701	3516	9387	69.68	1.0E-04	0.91690	0.00149	0.91987	hciabmt12_4_2_7_3	0.92094	0.00140	0.92374

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciabmt11_3_2_7_3	1.4	95	2776	2637	9436	93.39	1.0E-04	0.89089	0.00127	0.89343	hciabmt12_3_2_7_3	0.89250	0.00144	0.89537
nciabmt11_2_2_7_3	1.4	95	1851	1758	9485	140.81	1.0E-04	0.84225	0.00143	0.84510	hciabmt12_2_2_7_3	0.84604	0.00135	0.84875
nciabmt11_6_2_6_3	1.4	90	5556	5000	9289	48.49	1.0E-04	0.93703	0.00127	0.93956	hciabmt12_6_2_6_3	0.93967	0.00130	0.94227
nciabmt11_5_2_6_3	1.4	90	4630	4167	9338	58.49	1.0E-04	0.92640	0.00142	0.92925	hciabmt12_5_2_6_3	0.92390	0.00155	0.92700
nciabmt11_4_2_6_3	1.4	90	3704	3333	9387	73.50	1.0E-04	0.90541	0.00147	0.90835	hciabmt12_4_2_6_3	0.90643	0.00133	0.90909
nciabmt11_3_2_6_3	1.4	90	2778	2500	9436	98.52	1.0E-04	0.87970	0.00157	0.88283	hciabmt12_3_2_6_3	0.87916	0.00154	0.88224
nciabmt11_2_2_6_3	1.4	90	1852	1667	9485	148.54	1.0E-04	0.83371	0.00129	0.83628	hciabmt12_2_2_6_3	0.83414	0.00130	0.83674
nciabmt11_8_2_5_3	1.4	80	7417	5934	9191	40.43	1.0E-04	0.94131	0.00162	0.94455	hciabmt12_8_2_5_3	0.93963	0.00149	0.94261
nciabmt11_7_2_5_3	1.4	80	6490	5192	9240	46.45	1.0E-04	0.92939	0.00127	0.93193	hciabmt12_7_2_5_3	0.93070	0.00160	0.93391
nciabmt11_6_2_5_3	1.4	80	5563	4450	9289	54.48	1.0E-04	0.91981	0.00127	0.92235	hciabmt12_6_2_5_3	0.91987	0.00157	0.92301
nciabmt11_5_2_5_3	1.4	80	4636	3709	9338	65.72	1.0E-04	0.90533	0.00127	0.90787	hciabmt12_5_2_5_3	0.90772	0.00136	0.91044
nciabmt11_4_2_5_3	1.4	80	3709	2967	9387	82.59	1.0E-04	0.88537	0.00136	0.88808	hciabmt12_4_2_5_3	0.88792	0.00150	0.89092
nciabmt11_11_2_4_3	1.4	70	10211	7148	9044	33.02	1.0E-04	0.93094	0.00141	0.93376	hciabmt12_11_2_4_3	0.93119	0.00138	0.93395
nciabmt11_10_2_4_3	1.4	70	9283	6498	9093	36.52	1.0E-04	0.92534	0.00139	0.92813	hciabmt12_10_2_4_3	0.92795	0.00129	0.93052
nciabmt11_9_2_4_3	1.4	70	8355	5848	9142	40.80	1.0E-04	0.91866	0.00122	0.92110	hciabmt12_9_2_4_3	0.92290	0.00125	0.92540
nciabmt11_8_2_4_3	1.4	70	7426	5198	9191	46.15	1.0E-04	0.91902	0.00137	0.92175	hciabmt12_8_2_4_3	0.91835	0.00126	0.92086
nciabmt11_7_2_4_3	1.4	70	6498	4549	9240	53.02	1.0E-04	0.90863	0.00152	0.91166	hciabmt12_7_2_4_3	0.91042	0.00137	0.91316
nciabmt11_15_2_3_3	1.4	60	14872	8923	8798	25.74	1.0E-04	0.93047	0.00133	0.93313	hciabmt12_15_2_3_3	0.93032	0.00114	0.93259
nciabmt11_14_2_3_3	1.4	60	13942	8365	8847	27.61	1.0E-04	0.92560	0.00138	0.92837	hciabmt12_14_2_3_3	0.92828	0.00143	0.93115
nciabmt11_13_2_3_3	1.4	60	12083	7250	8946	32.21	1.0E-04	0.91963	0.00126	0.92214	hciabmt12_13_2_3_3	0.92389	0.00124	0.92638

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciabmt11_12_2_3_3	1.4	60	11154	6692	8995	35.08	1.0E-04	0.91502	0.00155	0.91812	hciabmt12_12_2_3_3	0.91776	0.00138	0.92053
nciabmt11_11_2_3_3	1.4	60	10224	6135	9044	38.48	1.0E-04	0.90892	0.00140	0.91172	hciabmt12_11_2_3_3	0.91237	0.00133	0.91503
content in flooded containment vessel, array packaging model for CSI=0.4														
NCT											**HAC**			
no can spacers (np thickness = 0.0 in.)														
											hcf2bmt12_11_1_5_3	0.91900	0.00131	0.92163
											hcf2bmt12_10_1_5_3	0.91775	0.00161	0.92097
											hcf2bmt12_9_1_5_3	0.91229	0.00127	0.91483
ncf1bmt11_8_1_5_3	0.0	80	7417	5934	9804	43.13	1.0E-04	0.92824	0.00156	0.93135	hcf2bmt12_8_1_5_3	0.90367	0.00138	0.90643
ncf1bmt11_7_1_5_3	0.0	80	6490	5192	9854	49.54	1.0E-04	0.92088	0.00131	0.92349				
ncf1bmt11_6_1_5_3	0.0	80	5563	4450	9903	58.08	1.0E-04	0.91164	0.00153	0.91470				
ncf1bmt11_5_1_5_3	0.0	80	4636	3709	9952	70.04	1.0E-04	0.90130	0.00135	0.90400				
ncf1bmt11_4_1_5_3	0.0	80	3709	2967	10001	87.98	1.0E-04	0.88094	0.00128	0.88350				
											hcf2bmt12_15_1_4_3	0.91711	0.00152	0.92016
											hcf2bmt12_14_1_4_3	0.91432	0.00164	0.91760
ncf1bmt11_13_1_4_3	0.0	70	12996	9097	9510	27.28	1.0E-04	0.93558	0.00138	0.93834	hcf2bmt12_13_1_4_3	0.91429	0.00141	0.91711
ncf1bmt11_12_1_4_3	0.0	70	11140	7798	9608	32.16	1.0E-04	0.92957	0.00130	0.93217	hcf2bmt12_12_1_4_3	0.90853	0.00161	0.91175
ncf1bmt11_11_1_4_3	0.0	70	10211	7148	9657	35.26	1.0E-04	0.92397	0.00139	0.92675				
ncf1bmt11_10_1_4_3	0.0	70	9283	6498	9706	38.99	1.0E-04	0.92240	0.00135	0.92510				
ncf1bmt11_9_1_4_3	0.0	70	8355	5848	9755	43.54	1.0E-04	0.91886	0.00139	0.92163				
											hcf2bmt12_21_1_3_3	0.91091	0.00139	0.91369
											hcf2bmt12_20_1_3_3	0.90915	0.00144	0.91203

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf1bmt11_19_1_3_3	0.0	60	18589	11154	9216	21.57	1.0E-04	0.92771	0.00137	0.93044	hcf2bmt12_19_1_3_3	0.90638	0.00160	0.90958
ncf1bmt11_18_1_3_3	0.0	60	17660	10596	9265	22.82	1.0E-04	0.92867	0.00148	0.93164	hcf2bmt12_18_1_3_3	0.90466	0.00124	0.90715
ncf1bmt11_17_1_3_3	0.0	60	16731	10038	9314	24.22	1.0E-04	0.92948	0.00113	0.93173				
ncf1bmt11_16_1_3_3	0.0	60	15801	9481	9363	25.78	1.0E-04	0.92252	0.00158	0.92569				
ncf1bmt11_15_1_3_3	0.0	60	14872	8923	9412	27.53	1.0E-04	0.91999	0.00123	0.92246				
ncf1bmt11_14_1_3_3	0.0	60	13942	8365	9461	29.52	1.0E-04	0.91961	0.00144	0.92248				
with can spacers (np thickness = 1.4 in.)														
											hcf2bmt12_10_2_8_3	0.93154	0.00152	0.93458
ncf1bmt11_9_2_8_3	1.4	100	8323	8323	9142	28.67	1.0E-04	0.94429	0.00138	0.94704	hcf2bmt12_9_2_8_3	0.92329	0.00147	0.92622
ncf1bmt11_8_2_8_3	1.4	100	7398	7398	9191	32.43	1.0E-04	0.94337	0.00169	0.94674	hcf2bmt12_8_2_8_3	0.92153	0.00144	0.92442
ncf1bmt11_7_2_8_3	1.4	100	6473	6473	9240	37.26	1.0E-04	0.93117	0.00172	0.93460				
ncf1bmt11_6_2_8_3	1.4	100	5549	5549	9289	43.70	1.0E-04	0.92119	0.00147	0.92412				
											hcf2bmt12_13_2_7_3	0.93389	0.00167	0.93722
											hcf2bmt12_12_2_7_3	0.92649	0.00146	0.92941
ncf1bmt11_11_2_7_3	1.4	95	10179	9670	9044	24.41	1.0E-04	0.94326	0.00139	0.94604	hcf2bmt12_11_2_7_3	0.92061	0.00130	0.92320
ncf1bmt11_10_2_7_3	1.4	95	9254	8791	9093	27.00	1.0E-04	0.93829	0.00154	0.94138	hcf2bmt12_10_2_7_3	0.91423	0.00145	0.91712
ncf1bmt11_9_2_7_3	1.4	95	8328	7912	9142	30.16	1.0E-04	0.93239	0.00181	0.93600	hcf2bmt12_9_2_7_3	0.90883	0.00137	0.91156
ncf1bmt11_8_2_7_3	1.4	95	7403	7033	9191	34.11	1.0E-04	0.92812	0.00144	0.93100				
ncf1bmt11_7_2_7_3	1.4	95	6478	6154	9240	39.19	1.0E-04	0.91938	0.00130	0.92199				
											hcf2bmt12_15_2_6_3	0.93106	0.00129	0.93364
											hcf2bmt12_14_2_6_3	0.92492	0.00129	0.92749

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf1bmt11_13_2_6_3	1.4	90	12963	11667	8896	19.90	1.0E-04	0.94806	0.00123	0.95052	hcf2bmt12_13_2_6_3	0.92272	0.00138	0.92548
ncf1bmt11_12_2_6_3	1.4	90	11111	10000	8995	23.48	1.0E-04	0.93464	0.00123	0.93710	hcf2bmt12_12_2_6_3	0.91625	0.00149	0.91924
ncf1bmt11_11_2_6_3	1.4	90	10185	9167	9044	25.75	1.0E-04	0.93068	0.00148	0.93363	hcf2bmt12_11_2_6_3	0.91097	0.00136	0.91370
ncf1bmt11_10_2_6_3	1.4	90	9260	8334	9093	28.48	1.0E-04	0.92732	0.00150	0.93032				
ncf1bmt11_9_2_6_3	1.4	90	8334	7500	9142	31.81	1.0E-04	0.91744	0.00145	0.92034				
ncf1bmt11_8_2_6_3	1.4	90	7408	6667	9191	35.98	1.0E-04	0.91952	0.00133	0.92218				
ncf1bmt11_17_2_5_3	1.4	80	16688	13351	8700	17.01	1.0E-04	0.93531	0.00128	0.93787	hcf2bmt12_17_2_5_3	0.91255	0.00114	0.91482
ncf1bmt11_16_2_5_3	1.4	80	15761	12609	8749	18.11	1.0E-04	0.93511	0.00160	0.93832	hcf2bmt12_16_2_5_3	0.91363	0.00123	0.91608
ncf1bmt11_15_2_5_3	1.4	80	14834	11867	8798	19.35	1.0E-04	0.93431	0.00141	0.93713	hcf2bmt12_15_2_5_3	0.91038	0.00115	0.91268
ncf1bmt11_14_2_5_3	1.4	80	13907	11125	8847	20.76	1.0E-04	0.92939	0.00133	0.93205	hcf2bmt12_14_2_5_3	0.90762	0.00139	0.91041
ncf1bmt11_13_2_5_3	1.4	80	12980	10384	8896	22.36	1.0E-04	0.92453	0.00131	0.92715	hcf2bmt12_13_2_5_3	0.90539	0.00137	0.90812
ncf1bmt11_12_2_5_3	1.4	80	11125	8900	8995	26.38	1.0E-04	0.91584	0.00142	0.91868	hcf2bmt12_12_2_5_3	0.89295	0.00174	0.89642
ncf1bmt11_24_2_4_3	1.4	70	23207	16245	8357	13.43	1.0E-04	0.93515	0.00143	0.93801	hcf2bmt12_24_2_4_3	0.91356	0.00125	0.91606
ncf1bmt11_23_2_4_3	1.4	70	22279	15595	8406	14.07	1.0E-04	0.93264	0.00113	0.93490	hcf2bmt12_23_2_4_3	0.91116	0.00113	0.91342
ncf1bmt11_22_2_4_3	1.4	70	21351	14946	8455	14.77	1.0E-04	0.93058	0.00128	0.93314	hcf2bmt12_22_2_4_3	0.90737	0.00145	0.91027
ncf1bmt11_21_2_4_3	1.4	70	20422	14296	8504	15.53	1.0E-04	0.92635	0.00112	0.92859	hcf2bmt12_21_2_4_3	0.90516	0.00140	0.90796
ncf1bmt11_20_2_4_3	1.4	70	19494	13646	8553	16.36	1.0E-04	0.92535	0.00141	0.92818	hcf2bmt12_20_2_4_3	0.90283	0.00136	0.90555
ncf1bmt11_19_2_4_3	1.4	70	18566	12996	8602	17.28	1.0E-04	0.92097	0.00177	0.92450	hcf2bmt12_19_2_4_3	0.89757	0.00144	0.90046
ncf1bmt11_18_2_4_3	1.4	70	17638	12346	8651	18.29	1.0E-04	0.91681	0.00140	0.91961	hcf2bmt12_18_2_4_3	0.89367	0.00144	0.89656
ncf1bmt11_36_2_3_3	1.4	60	35320	21192	7719	9.51	1.0E-04	0.93212	0.00121	0.93455	hcf2bmt12_36_2_3_3	0.90846	0.00137	0.91121
ncf1bmt11_35_2_3_3	1.4	60	34391	20634	7768	9.83	1.0E-04	0.93168	0.00129	0.93426	hcf2bmt12_35_2_3_3	0.90742	0.00118	0.90977

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf1bmt11_34_2_3_3	1.4	60	33461	20077	7817	10.16	1.0E-04	0.93079	0.00145	0.93368	hcf2bmt12_34_2_3_3	0.90657	0.00134	0.90925
ncf1bmt11_33_2_3_3	1.4	60	32532	19519	7866	10.52	1.0E-04	0.92781	0.00131	0.93042	hcf2bmt12_33_2_3_3	0.90603	0.00117	0.90837
ncf1bmt11_32_2_3_3	1.4	60	31602	18961	7915	10.90	1.0E-04	0.92550	0.00131	0.92811	hcf2bmt12_32_2_3_3	0.90015	0.00127	0.90270
ncf1bmt11_31_2_3_3	1.4	60	30673	18404	7964	11.29	1.0E-04	0.92597	0.00128	0.92853	hcf2bmt12_31_2_3_3	0.90333	0.00122	0.90577
ncf1bmt11_30_2_3_3	1.4	60	29743	17846	8013	11.72	1.0E-04	0.92361	0.00120	0.92601	hcf2bmt12_30_2_3_3	0.89683	0.00144	0.89971
ncf1bmt11_29_2_3_3	1.4	60	28814	17288	8062	12.17	1.0E-04	0.92063	0.00143	0.92350				
content in flooded containment vessel, array packaging model for CSI=0.8														
NCT											**HAC**			
no can spacers (np thickness = 0.0 in.)														
ncf2bmt11_17_1_5_3	0.0	80	16688	13351	9314	18.21	1.0E-04	0.93655	0.00144	0.93942	hcf3bmt12_17_1_5_3	0.92003	0.00129	0.92262
ncf2bmt11_16_1_5_3	0.0	80	15761	12609	9363	19.38	1.0E-04	0.93242	0.00143	0.93529	hcf3bmt12_16_1_5_3	0.91399	0.00148	0.91694
ncf2bmt11_15_1_5_3	0.0	80	14834	11867	9412	20.70	1.0E-04	0.92982	0.00135	0.93251	hcf3bmt12_15_1_5_3	0.91169	0.00139	0.91448
ncf2bmt11_14_1_5_3	0.0	80	13907	11125	9461	22.20	1.0E-04	0.92699	0.00137	0.92972	hcf3bmt12_14_1_5_3	0.90943	0.00135	0.91213
ncf2bmt11_13_1_5_3	0.0	80	12980	10384	9510	23.90	1.0E-04	0.92634	0.00138	0.92909	hcf3bmt12_13_1_5_3	0.90348	0.00133	0.90615
ncf2bmt11_12_1_5_3	0.0	80	11125	8900	9608	28.18	1.0E-04	0.91826	0.00166	0.92158	hcf3bmt12_12_1_5_3	0.89805	0.00155	0.90115
ncf2bmt11_21_1_4_3	0.0	70	20422	14296	9117	16.65	1.0E-04	0.92723	0.00123	0.92968				
ncf2bmt11_20_1_4_3	0.0	70	19494	13646	9166	17.53	1.0E-04	0.92094	0.00124	0.92342	hcf3bmt12_20_1_4_3	0.90398	0.00124	0.90646
ncf2bmt11_19_1_4_3	0.0	70	18566	12996	9216	18.51	1.0E-04	0.92341	0.00144	0.92629	hcf3bmt12_19_1_4_3	0.90150	0.00151	0.90452
ncf2bmt11_18_1_4_3	0.0	70	17638	12346	9265	19.59	1.0E-04	0.91814	0.00135	0.92085	hcf3bmt12_18_1_4_3	0.89955	0.00134	0.90222
ncf2bmt11_17_1_4_3	0.0	70	16709	11697	9314	20.78	1.0E-04	0.91793	0.00133	0.92058	hcf3bmt12_17_1_4_3	0.89730	0.00133	0.89996
ncf2bmt11_16_1_4_3	0.0	70	15781	11047	9363	22.12	1.0E-04	0.91629	0.00133	0.91895	hcf3bmt12_16_1_4_3	0.89458	0.00122	0.89702
ncf2bmt11_15_1_4_3	0.0	70	14853	10397	9412	23.63	1.0E-04	0.91068	0.00125	0.91317	hcf3bmt12_15_1_4_3	0.89088	0.00130	0.89347

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf2bmt11_36_1_3_3	0.0	60	35320	21192	8332	10.26	1.0E-04	0.93348	0.00105	0.93558	hcf3bmt12_36_1_3_3	0.91223	0.00113	0.91450
ncf2bmt11_35_1_3_3	0.0	60	34391	20634	8381	10.60	1.0E-04	0.93036	0.00127	0.93290	hcf3bmt12_35_1_3_3	0.91033	0.00128	0.91288
ncf2bmt11_34_1_3_3	0.0	60	33461	20077	8430	10.96	1.0E-04	0.92584	0.00127	0.92837	hcf3bmt12_34_1_3_3	0.90950	0.00126	0.91202
ncf2bmt11_33_1_3_3	0.0	60	32532	19519	8479	11.34	1.0E-04	0.92680	0.00142	0.92965	hcf3bmt12_33_1_3_3	0.90720	0.00143	0.91007
ncf2bmt11_32_1_3_3	0.0	60	31602	18961	8529	11.74	1.0E-04	0.92588	0.00144	0.92877	hcf3bmt12_32_1_3_3	0.90425	0.00126	0.90678
ncf2bmt11_31_1_3_3	0.0	60	30673	18404	8578	12.17	1.0E-04	0.92420	0.00123	0.92665	hcf3bmt12_31_1_3_3	0.90271	0.00118	0.90506
ncf2bmt11_30_1_3_3	0.0	60	29743	17846	8627	12.62	1.0E-04	0.92236	0.00165	0.92566	hcf3bmt12_30_1_3_3	0.90323	0.00138	0.90599
ncf2bmt11_29_1_3_3	0.0	60	28814	17288	8676	13.10	1.0E-04	0.91822	0.00113	0.92047	hcf3bmt12_29_1_3_3	0.89982	0.00121	0.90224
with can spacers (np thickness = 1.4 in.)														
ncf2bmt11_12_2_8_3	1.4	100	11097	11097	8995	21.16	1.0E-04	0.93137	0.00124	0.93385	hcf3bmt12_12_2_8_3	0.91417	0.00139	0.91696
ncf2bmt11_11_2_8_3	1.4	100	10173	10173	9044	23.20	1.0E-04	0.92641	0.00144	0.92928	hcf3bmt12_11_2_8_3	0.91315	0.00164	0.91642
ncf2bmt11_10_2_8_3	1.4	100	9248	9248	9093	25.66	1.0E-04	0.92058	0.00138	0.92334	hcf3bmt12_10_2_8_3	0.90570	0.00166	0.90902
ncf2bmt11_9_2_8_3	1.4	100	8323	8323	9142	28.67	1.0E-04	0.91671	0.00138	0.91947	hcf3bmt12_9_2_8_3	0.89648	0.00131	0.89911
ncf2bmt11_8_2_8_3	1.4	100	7398	7398	9191	32.43	1.0E-04	0.91365	0.00171	0.91706	hcf3bmt12_8_2_8_3	0.89682	0.00139	0.89960
ncf2bmt11_7_2_8_3	1.4	100	6473	6473	9240	37.26	1.0E-04	0.90684	0.00166	0.91016	hcf3bmt12_7_2_8_3	0.88907	0.00143	0.89192
ncf2bmt11_6_2_8_3	1.4	100	5549	5549	9289	43.70	1.0E-04	0.89705	0.00145	0.89995	hcf3bmt12_6_2_8_3	0.87797	0.00166	0.88130
ncf2bmt11_14_2_7_3	1.4	95	13880	13186	8847	17.51	1.0E-04	0.93174	0.00131	0.93437	hcf3bmt12_14_2_7_3	0.91453	0.00162	0.91777
ncf2bmt11_13_2_7_3	1.4	95	12955	12307	8896	18.87	1.0E-04	0.92685	0.00140	0.92965	hcf3bmt12_13_2_7_3	0.91006	0.00135	0.91276
ncf2bmt11_12_2_7_3	1.4	95	11104	10549	8995	22.25	1.0E-04	0.91939	0.00136	0.92210	hcf3bmt12_12_2_7_3	0.89784	0.00132	0.90048
ncf2bmt11_11_2_7_3	1.4	95	10179	9670	9044	24.41	1.0E-04	0.91215	0.00134	0.91483	hcf3bmt12_11_2_7_3	0.89423	0.00146	0.89715
ncf2bmt11_10_2_7_3	1.4	95	9254	8791	9093	27.00	1.0E-04	0.90898	0.00126	0.91151	hcf3bmt12_10_2_7_3	0.89121	0.00159	0.89438
ncf2bmt11_9_2_7_3	1.4	95	8328	7912	9142	30.16	1.0E-04	0.90123	0.00147	0.90416	hcf3bmt12_9_2_7_3	0.88311	0.00145	0.88602

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf2bmt11_16_2_6_3	1.4	90	15741	14167	8749	16.12	1.0E-04	0.92855	0.00124	0.93103	hcf3bmt12_16_2_6_3	0.91007	0.00134	0.91276
ncf2bmt11_15_2_6_3	1.4	90	14815	13334	8798	17.22	1.0E-04	0.92599	0.00107	0.92813	hcf3bmt12_15_2_6_3	0.90421	0.00136	0.90693
ncf2bmt11_14_2_6_3	1.4	90	13889	12500	8847	18.47	1.0E-04	0.91938	0.00131	0.92200	hcf3bmt12_14_2_6_3	0.90163	0.00129	0.90422
ncf2bmt11_13_2_6_3	1.4	90	12963	11667	8896	19.90	1.0E-04	0.91387	0.00110	0.91607	hcf3bmt12_13_2_6_3	0.89824	0.00123	0.90069
ncf2bmt11_12_2_6_3	1.4	90	11111	10000	8995	23.48	1.0E-04	0.90989	0.00135	0.91258	hcf3bmt12_12_2_6_3	0.88832	0.00136	0.89105
ncf2bmt11_11_2_6_3	1.4	90	10185	9167	9044	25.75	1.0E-04	0.90334	0.00152	0.90637	hcf3bmt12_11_2_6_3	0.88574	0.00168	0.88911
ncf2bmt11_10_2_6_3	1.4	90	9260	8334	9093	28.48	1.0E-04	0.89868	0.00172	0.90212	hcf3bmt12_10_2_6_3	0.87986	0.00134	0.88254
ncf2bmt11_9_2_6_3	1.4	90	8334	7500	9142	31.81	1.0E-04	0.89190	0.00154	0.89499	hcf3bmt12_9_2_6_3	0.87453	0.00140	0.87733
											hcf3bmt12_24_2_5_3	0.90790	0.00134	0.91058
											hcf3bmt12_23_2_5_3	0.90282	0.00121	0.90523
ncf2bmt11_22_2_5_3	1.4	80	21324	17059	8455	12.94	1.0E-04	0.92358	0.00131	0.92619	hcf3bmt12_22_2_5_3	0.90006	0.00139	0.90284
ncf2bmt11_21_2_5_3	1.4	80	20397	16317	8504	13.60	1.0E-04	0.91640	0.00145	0.91930	hcf3bmt12_21_2_5_3	0.89948	0.00134	0.90216
ncf2bmt11_20_2_5_3	1.4	80	19470	15576	8553	14.33	1.0E-04	0.91428	0.00133	0.91694	hcf3bmt12_20_2_5_3	0.89698	0.00122	0.89941
ncf2bmt11_19_2_5_3	1.4	80	18542	14834	8602	15.14	1.0E-04	0.91020	0.00130	0.91281	hcf3bmt12_19_2_5_3	0.89282	0.00129	0.89541
ncf2bmt11_18_2_5_3	1.4	80	17615	14092	8651	16.02	1.0E-04	0.90784	0.00135	0.91054	hcf3bmt12_18_2_5_3	0.88897	0.00125	0.89148
ncf2bmt11_17_2_5_3	1.4	80	16688	13351	8700	17.01	1.0E-04	0.90364	0.00123	0.90610	hcf3bmt12_17_2_5_3	0.88452	0.00123	0.88697
ncf2bmt11_16_2_5_3	1.4	80	15761	12609	8749	18.11	1.0E-04	0.90402	0.00132	0.90666	hcf3bmt12_16_2_5_3	0.88688	0.00121	0.88929
ncf2bmt11_15_2_5_3	1.4	80	14834	11867	8798	19.35	1.0E-04	0.90496	0.00145	0.90786	hcf3bmt12_15_2_5_3	0.88496	0.00135	0.88765
ncf2bmt11_33_2_4_3	1.4	70	32490	22743	7866	9.03	1.0E-04	0.92631	0.00120	0.92871	hcf3bmt12_33_2_4_3	0.90516	0.00118	0.90752
ncf2bmt11_32_2_4_3	1.4	70	31562	22093	7915	9.35	1.0E-04	0.92304	0.00128	0.92560	hcf3bmt12_32_2_4_3	0.90236	0.00135	0.90507
ncf2bmt11_31_2_4_3	1.4	70	30634	21444	7964	9.69	1.0E-04	0.92250	0.00132	0.92514	hcf3bmt12_31_2_4_3	0.90127	0.00111	0.90349
ncf2bmt11_30_2_4_3	1.4	70	29705	20794	8013	10.06	1.0E-04	0.92048	0.00138	0.92325	hcf3bmt12_30_2_4_3	0.89944	0.00124	0.90192

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf2bmt11_29_2_4_3	1.4	70	28777	20144	8062	10.45	1.0E-04	0.91607	0.00135	0.91878	hcf3bmt12_29_2_4_3	0.89544	0.00139	0.89823
ncf2bmt11_28_2_4_3	1.4	70	27849	19494	8111	10.86	1.0E-04	0.91338	0.00129	0.91596	hcf3bmt12_28_2_4_3	0.89451	0.00127	0.89706
ncf2bmt11_27_2_4_3	1.4	70	26921	18844	8160	11.30	1.0E-04	0.91255	0.00127	0.91510	hcf3bmt12_27_2_4_3	0.88990	0.00135	0.89261
ncf2bmt11_36_2_3_3	1.4	60	35320	21192	7719	9.51	1.0E-04	0.90382	0.00130	0.90642	hcf3bmt12_36_2_3_3	0.88262	0.00120	0.88503
ncf2bmt11_35_2_3_3	1.4	60	34391	20634	7768	9.83	1.0E-04	0.90020	0.00136	0.90291	hcf3bmt12_35_2_3_3	0.87857	0.00132	0.88120
ncf2bmt11_34_2_3_3	1.4	60	33461	20077	7817	10.16	1.0E-04	0.89689	0.00121	0.89932	hcf3bmt12_34_2_3_3	0.87717	0.00111	0.87939
ncf2bmt11_33_2_3_3	1.4	60	32532	19519	7866	10.52	1.0E-04	0.89834	0.00117	0.90069	hcf3bmt12_33_2_3_3	0.87502	0.00127	0.87757
ncf2bmt11_32_2_3_3	1.4	60	31602	18961	7915	10.90	1.0E-04	0.89483	0.00136	0.89755	hcf3bmt12_32_2_3_3	0.87552	0.00129	0.87809
ncf2bmt11_31_2_3_3	1.4	60	30673	18404	7964	11.29	1.0E-04	0.89450	0.00137	0.89723	hcf3bmt12_31_2_3_3	0.87475	0.00139	0.87752
ncf2bmt11_30_2_3_3	1.4	60	29743	17846	8013	11.72	1.0E-04	0.89227	0.00133	0.89493	hcf3bmt12_30_2_3_3	0.87454	0.00121	0.87695
content in flooded containment vessel, array packaging model for CSI=2.0														
NCT											**HAC**			
no can spacers (np thickness = 0.0 in.)														
ncf3bmt11_24_1_5_3	0.0	80	23178	18542	8970	12.63	1.0E-04	0.92510	0.00131	0.92772	hcf4bmt12_24_1_5_3	0.88778	0.00138	0.89054
ncf3bmt11_23_1_5_3	0.0	80	22251	17801	9019	13.22	1.0E-04	0.92307	0.00144	0.92595	hcf4bmt12_23_1_5_3	0.88545	0.00131	0.88806
ncf3bmt11_22_1_5_3	0.0	80	21324	17059	9068	13.87	1.0E-04	0.91977	0.00125	0.92228	hcf4bmt12_22_1_5_3	0.88238	0.00140	0.88519
ncf3bmt11_21_1_5_3	0.0	80	20397	16317	9117	14.58	1.0E-04	0.91607	0.00134	0.91876	hcf4bmt12_21_1_5_3	0.87917	0.00128	0.88173
ncf3bmt11_20_1_5_3	0.0	80	19470	15576	9166	15.36	1.0E-04	0.91812	0.00123	0.92059	hcf4bmt12_20_1_5_3	0.87731	0.00132	0.87995
ncf3bmt11_36_1_4_3	0.0	70	35275	24693	8332	8.81	1.0E-04	0.93179	0.00144	0.93467	hcf4bmt12_36_1_4_3	0.89390	0.00117	0.89625
ncf3bmt11_35_1_4_3	0.0	70	34347	24043	8381	9.10	1.0E-04	0.92998	0.00125	0.93248	hcf4bmt12_35_1_4_3	0.89164	0.00140	0.89444
ncf3bmt11_34_1_4_3	0.0	70	33419	23393	8430	9.41	1.0E-04	0.92792	0.00128	0.93049	hcf4bmt12_34_1_4_3	0.88829	0.00123	0.89075
ncf3bmt11_33_1_4_3	0.0	70	32490	22743	8479	9.73	1.0E-04	0.92421	0.00134	0.92690	hcf4bmt12_33_1_4_3	0.88600	0.00117	0.88834

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf3bmt11_32_1_4_3	0.0	70	31562	22093	8529	10.08	1.0E-04	0.92329	0.00131	0.92591	hcf4bmt12_32_1_4_3	0.88581	0.00140	0.88861
ncf3bmt11_31_1_4_3	0.0	70	30634	21444	8578	10.44	1.0E-04	0.91896	0.00132	0.92160	hcf4bmt12_31_1_4_3	0.88314	0.00132	0.88577
ncf3bmt11_36_1_3_3	0.0	60	35320	21192	8332	10.26	1.0E-04	0.90201	0.00123	0.90447	hcf4bmt12_36_1_3_3	0.86792	0.00130	0.87053
ncf3bmt11_35_1_3_3	0.0	60	34391	20634	8381	10.60	1.0E-04	0.90103	0.00130	0.90363	hcf4bmt12_35_1_3_3	0.86477	0.00150	0.86777
ncf3bmt11_34_1_3_3	0.0	60	33461	20077	8430	10.96	1.0E-04	0.89984	0.00147	0.90278	hcf4bmt12_34_1_3_3	0.86396	0.00137	0.86670
ncf3bmt11_33_1_3_3	0.0	60	32532	19519	8479	11.34	1.0E-04	0.89745	0.00130	0.90004	hcf4bmt12_33_1_3_3	0.86136	0.00134	0.86404
ncf3bmt11_32_1_3_3	0.0	60	31602	18961	8529	11.74	1.0E-04	0.89310	0.00137	0.89585	hcf4bmt12_32_1_3_3	0.86115	0.00124	0.86362
ncf3bmt11_31_1_3_3	0.0	60	30673	18404	8578	12.17	1.0E-04	0.89440	0.00135	0.89711	hcf4bmt12_31_1_3_3	0.85909	0.00151	0.86212
with can spacers (np thickness = 1.4 in.)														
ncf3bmt11_19_2_8_3	1.4	100	18496	18496	8602	12.14	1.0E-04	0.93577	0.00135	0.93847	hcf4bmt12_19_2_8_3	0.89811	0.00149	0.90110
ncf3bmt11_18_2_8_3	1.4	100	17571	17571	8651	12.85	1.0E-04	0.93186	0.00154	0.93494	hcf4bmt12_18_2_8_3	0.89794	0.00151	0.90096
ncf3bmt11_17_2_8_3	1.4	100	16646	16646	8700	13.64	1.0E-04	0.92731	0.00135	0.93002	hcf4bmt12_17_2_8_3	0.89377	0.00134	0.89644
ncf3bmt11_16_2_8_3	1.4	100	15721	15721	8749	14.53	1.0E-04	0.92992	0.00126	0.93244	hcf4bmt12_16_2_8_3	0.89138	0.00121	0.89379
ncf3bmt11_15_2_8_3	1.4	100	14796	14796	8798	15.52	1.0E-04	0.92597	0.00134	0.92865	hcf4bmt12_15_2_8_3	0.89085	0.00130	0.89345
ncf3bmt11_14_2_8_3	1.4	100	13872	13872	8847	16.65	1.0E-04	0.91788	0.00124	0.92037	hcf4bmt12_14_2_8_3	0.88486	0.00143	0.88772
ncf3bmt11_13_2_8_3	1.4	100	12947	12947	8896	17.94	1.0E-04	0.91410	0.00116	0.91642	hcf4bmt12_13_2_8_3	0.88161	0.00147	0.88454
ncf3bmt11_12_2_8_3	1.4	100	11097	11097	8995	21.16	1.0E-04	0.90586	0.00164	0.90915	hcf4bmt12_12_2_8_3	0.87451	0.00129	0.87708
ncf3bmt11_11_2_8_3	1.4	100	10173	10173	9044	23.20	1.0E-04	0.90034	0.00144	0.90322	hcf4bmt12_11_2_8_3	0.86789	0.00129	0.87047
ncf3bmt11_24_2_7_3	1.4	95	23134	21977	8357	9.92	1.0E-04	0.93439	0.00143	0.93724	hcf4bmt12_24_2_7_3	0.89896	0.00122	0.90141
ncf3bmt11_23_2_7_3	1.4	95	22209	21098	8406	10.40	1.0E-04	0.93453	0.00131	0.93716	hcf4bmt12_23_2_7_3	0.89761	0.00131	0.90024
ncf3bmt11_22_2_7_3	1.4	95	21283	20219	8455	10.91	1.0E-04	0.92992	0.00130	0.93252	hcf4bmt12_22_2_7_3	0.89290	0.00142	0.89574
ncf3bmt11_21_2_7_3	1.4	95	20358	19340	8504	11.48	1.0E-04	0.92588	0.00136	0.92860	hcf4bmt12_21_2_7_3	0.89171	0.00135	0.89441

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncf3bmt11_20_2_7_3	1.4	95	19433	18461	8553	12.09	1.0E-04	0.92140	0.00126	0.92392	hcf4bmt12_20_2_7_3	0.88860	0.00138	0.89135
ncf3bmt11_19_2_7_3	1.4	95	18507	17582	8602	12.77	1.0E-04	0.91794	0.00128	0.92049	hcf4bmt12_19_2_7_3	0.88544	0.00131	0.88806
ncf3bmt11_18_2_7_3	1.4	95	17582	16703	8651	13.52	1.0E-04	0.91432	0.00143	0.91717	hcf4bmt12_18_2_7_3	0.87916	0.00119	0.88154
ncf3bmt11_28_2_6_3	1.4	90	27778	25001	8111	8.47	1.0E-04	0.93537	0.00113	0.93763	hcf4bmt12_28_2_6_3	0.89885	0.00127	0.90138
ncf3bmt11_27_2_6_3	1.4	90	26852	24167	8160	8.81	1.0E-04	0.93322	0.00129	0.93581	hcf4bmt12_27_2_6_3	0.89628	0.00137	0.89902
ncf3bmt11_26_2_6_3	1.4	90	25927	23334	8209	9.18	1.0E-04	0.92880	0.00119	0.93117	hcf4bmt12_26_2_6_3	0.89189	0.00127	0.89443
ncf3bmt11_25_2_6_3	1.4	90	24075	21667	8308	10.01	1.0E-04	0.92446	0.00149	0.92745	hcf4bmt12_25_2_6_3	0.88877	0.00144	0.89165
ncf3bmt11_24_2_6_3	1.4	90	23149	20834	8357	10.47	1.0E-04	0.92270	0.00138	0.92547	hcf4bmt12_24_2_6_3	0.88731	0.00129	0.88990
ncf3bmt11_23_2_6_3	1.4	90	22223	20000	8406	10.97	1.0E-04	0.91857	0.00138	0.92133	hcf4bmt12_23_2_6_3	0.88245	0.00133	0.88512
ncf3bmt11_22_2_6_3	1.4	90	21297	19167	8455	11.51	1.0E-04	0.91639	0.00145	0.91929	hcf4bmt12_22_2_6_3	0.87838	0.00119	0.88076
ncf3bmt11_34_2_5_3	1.4	80	33376	26701	7817	7.64	1.0E-04	0.92540	0.00127	0.92795	hcf4bmt12_34_2_5_3	0.88608	0.00131	0.88869
ncf3bmt11_33_2_5_3	1.4	80	32449	25959	7866	7.91	1.0E-04	0.92436	0.00140	0.92716	hcf4bmt12_33_2_5_3	0.88749	0.00156	0.89061
ncf3bmt11_32_2_5_3	1.4	80	31522	25218	7915	8.19	1.0E-04	0.91919	0.00120	0.92159	hcf4bmt12_32_2_5_3	0.88581	0.00130	0.88841
ncf3bmt11_31_2_5_3	1.4	80	30595	24476	7964	8.49	1.0E-04	0.91747	0.00126	0.92000	hcf4bmt12_31_2_5_3	0.88299	0.00141	0.88582
ncf3bmt11_36_2_4_3	1.4	70	35275	24693	7719	8.16	1.0E-04	0.90114	0.00120	0.90353	hcf4bmt12_36_2_4_3	0.86624	0.00106	0.86835
ncf3bmt11_35_2_4_3	1.4	70	34347	24043	7768	8.43	1.0E-04	0.89908	0.00131	0.90169	hcf4bmt12_35_2_4_3	0.86262	0.00143	0.86549
ncf3bmt11_34_2_4_3	1.4	70	33419	23393	7817	8.72	1.0E-04	0.89841	0.00115	0.90070	hcf4bmt12_34_2_4_3	0.86008	0.00129	0.86265
ncf3bmt11_36_2_3_3	1.4	60	35320	21192	7719	9.51	1.0E-04	0.87206	0.00120	0.87446	hcf4bmt12_36_2_3_3	0.83873	0.00122	0.84116
ncf3bmt11_35_2_3_3	1.4	60	34391	20634	7768	9.83	1.0E-04	0.86988	0.00123	0.87235	hcf4bmt12_35_2_3_3	0.83470	0.00130	0.83731
ncf3bmt11_34_2_3_3	1.4	60	33461	20077	7817	10.16	1.0E-04	0.86818	0.00130	0.87078	hcf4bmt12_34_2_3_3	0.83204	0.00117	0.83439

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, array packaging model for CSI=3.1														
NCT											**HAC**			
no can spacers (np thickness = 0.0 in.)														
nctf5bmt11_36_1_5_3	0.0	80	35231	28184	8332	7.72	1.0E-04	0.92519	0.00130	0.92779	hctf5bmt12_36_1_5_3	0.90361	0.00119	0.90600
nctf5bmt11_35_1_5_3	0.0	80	34303	27443	8381	7.97	1.0E-04	0.91980	0.00138	0.92255	hctf5bmt12_35_1_5_3	0.90246	0.00137	0.90520
nctf5bmt11_34_1_5_3	0.0	80	33376	26701	8430	8.24	1.0E-04	0.92113	0.00138	0.92389	hctf5bmt12_34_1_5_3	0.89974	0.00136	0.90246
nctf5bmt11_33_1_5_3	0.0	80	32449	25959	8479	8.53	1.0E-04	0.91846	0.00117	0.92079	hctf5bmt12_33_1_5_3	0.89587	0.00129	0.89845
nctf5bmt11_32_1_5_3	0.0	80	31522	25218	8529	8.83	1.0E-04	0.91556	0.00119	0.91795	hctf5bmt12_32_1_5_3	0.89459	0.00148	0.89755
nctf5bmt11_36_1_4_3	0.0	70	35275	24693	8332	8.81	1.0E-04	0.90020	0.00139	0.90299	hctf5bmt12_36_1_4_3	0.87905	0.00142	0.88188
nctf5bmt11_35_1_4_3	0.0	70	34347	24043	8381	9.10	1.0E-04	0.89748	0.00118	0.89984	hctf5bmt12_35_1_4_3	0.87388	0.00126	0.87639
nctf5bmt11_34_1_4_3	0.0	70	33419	23393	8430	9.41	1.0E-04	0.89206	0.00115	0.89437	hctf5bmt12_34_1_4_3	0.87550	0.00150	0.87851
nctf5bmt11_36_1_3_3	0.0	60	35320	21192	8332	10.26	1.0E-04	0.87170	0.00131	0.87433	hctf5bmt12_36_1_3_3	0.85181	0.00121	0.85423
nctf5bmt11_35_1_3_3	0.0	60	34391	20634	8381	10.60	1.0E-04	0.87122	0.00146	0.87414	hctf5bmt12_35_1_3_3	0.85100	0.00135	0.85369
nctf5bmt11_26_2_8_3	1.4	100	25894	25894	8209	8.28	1.0E-04	0.92880	0.00114	0.93108	hctf5bmt12_26_2_8_3	0.90779	0.00115	0.91009
nctf5bmt11_25_2_8_3	1.4	100	24969	24969	8258	8.63	1.0E-04	0.92250	0.00118	0.92485	hctf5bmt12_25_2_8_3	0.90619	0.00136	0.90890
nctf5bmt11_24_2_8_3	1.4	100	23119	23119	8357	9.43	1.0E-04	0.92133	0.00137	0.92406	hctf5bmt12_24_2_8_3	0.90163	0.00125	0.90413
nctf5bmt11_23_2_8_3	1.4	100	22195	22195	8406	9.89	1.0E-04	0.92154	0.00124	0.92401	hctf5bmt12_23_2_8_3	0.90028	0.00150	0.90329
nctf5bmt11_22_2_8_3	1.4	100	21270	21270	8455	10.38	1.0E-04	0.91455	0.00141	0.91737	hctf5bmt12_22_2_8_3	0.89693	0.00148	0.89990
nctf5bmt11_21_2_8_3	1.4	100	20345	20345	8504	10.91	1.0E-04	0.91027	0.00140	0.91306	hctf5bmt12_21_2_8_3	0.89420	0.00140	0.89700
nctf5bmt11_30_2_7_3	1.4	95	29612	28131	8013	7.43	1.0E-04	0.92409	0.00126	0.92660	hctf5bmt12_30_2_7_3	0.90413	0.00129	0.90670
nctf5bmt11_29_2_7_3	1.4	95	28686	27252	8062	7.72	1.0E-04	0.92175	0.00160	0.92495	hctf5bmt12_29_2_7_3	0.90149	0.00125	0.90400

Table 6.9.6-11. Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model

case name	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nctf5bmt11_28_2_7_3	1.4	95	27761	26373	8111	8.03	1.0E-04	0.91662	0.00149	0.91960	hctf5bmt12_28_2_7_3	0.89554	0.00127	0.89809
nctf5bmt11_27_2_7_3	1.4	95	26835	25494	8160	8.35	1.0E-04	0.91290	0.00112	0.91515	hctf5bmt12_27_2_7_3	0.89349	0.00120	0.89588
nctf5bmt11_26_2_7_3	1.4	95	25910	24615	8209	8.71	1.0E-04	0.90934	0.00124	0.91182	hctf5bmt12_26_2_7_3	0.88954	0.00116	0.89187
nctf5bmt11_25_2_7_3	1.4	95	24985	23736	8258	9.08	1.0E-04	0.90900	0.00116	0.91131	hctf5bmt12_25_2_7_3	0.88811	0.00120	0.89051
nctf5bmt11_24_2_7_3	1.4	95	23134	21977	8357	9.92	1.0E-04	0.90460	0.00146	0.90752	hctf5bmt12_24_2_7_3	0.88850	0.00132	0.89113
nctf5bmt11_35_2_6_3	1.4	90	34260	30834	7768	6.58	1.0E-04	0.92200	0.00132	0.92464	hctf5bmt12_35_2_6_3	0.90072	0.00123	0.90318
nctf5bmt11_34_2_6_3	1.4	90	33334	30001	7817	6.80	1.0E-04	0.91799	0.00130	0.92059	hctf5bmt12_34_2_6_3	0.89921	0.00112	0.90145
nctf5bmt11_33_2_6_3	1.4	90	32408	29167	7866	7.04	1.0E-04	0.91789	0.00136	0.92061	hctf5bmt12_33_2_6_3	0.89931	0.00137	0.90206
nctf5bmt11_32_2_6_3	1.4	90	31482	28334	7915	7.29	1.0E-04	0.91514	0.00113	0.91740	hctf5bmt12_32_2_6_3	0.89395	0.00118	0.89631
nctf5bmt11_36_2_5_3	1.4	80	35231	28184	7719	7.15	1.0E-04	0.89457	0.00141	0.89739	hctf5bmt12_36_2_5_3	0.87726	0.00158	0.88041
nctf5bmt11_35_2_5_3	1.4	80	34303	27443	7768	7.39	1.0E-04	0.89528	0.00129	0.89787	hctf5bmt12_35_2_5_3	0.87420	0.00120	0.87660
nctf5bmt11_34_2_5_3	1.4	80	33376	26701	7817	7.64	1.0E-04	0.89346	0.00115	0.89576	hctf5bmt12_34_2_5_3	0.87530	0.00122	0.87775
nctf5bmt11_36_2_4_3	1.4	70	35275	24693	7719	8.16	1.0E-04	0.87119	0.00121	0.87361	hctf5bmt12_36_2_4_3	0.85030	0.00147	0.85323
nctf5bmt11_35_2_4_3	1.4	70	34347	24043	7768	8.43	1.0E-04	0.86740	0.00110	0.86959	hctf5bmt12_35_2_4_3	0.84958	0.00107	0.85173
nctf5bmt11_36_2_3_3	1.4	60	35320	21192	7719	9.51	1.0E-04	0.84212	0.00121	0.84454	hctf5bmt12_36_2_3_3	0.82413	0.00117	0.82647
nctf5bmt11_35_2_3_3	1.4	60	34391	20634	7768	9.83	1.0E-04	0.83953	0.00135	0.84223	hctf5bmt12_35_2_3_3	0.82142	0.00125	0.82393

Table 6.9.6-11b. Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models.

Note: Reference results for content homogenized over volume of containment vessel are highlighted. Results shown below the reference results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

nciabmt11	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$				
nciapbmflt11	**np (in.)**	**PF**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**nciapbmfdt11**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
content in flooded containment vessel, array packaging model for CSI=0.0														
no can spacers (np thickness = 0.0 in.)														
_4_1_5_3	0.0	80.0	3709	2967	10001	87.98	1.0E-04	0.91835	0.00149	0.92133				
_1_2_4_5	0.0	0.2	4000	3200	9443	82.26	1.0E-04	0.68903	0.00121	0.69146	_1_2_4_5	0.85247	0.00116	0.85479
_1_3_4_5	0.0	0.3	4000	3200	9443	82.26	1.0E-04	0.65516	0.00136	0.65788	_1_3_4_5	0.84236	0.00121	0.84477
_1_4_4_5	0.0	0.4	4000	3200	9443	82.26	1.0E-04	0.63720	0.00123	0.63965	_1_4_4_5	0.83993	0.00137	0.84267
_1_5_4_5	0.0	0.5	4000	3200	9443	82.26	1.0E-04	0.62195	0.00105	0.62405	_1_5_4_5	0.83701	0.00126	0.83953
_1_6_4_5	0.0	0.6	4000	3200	9443	82.26	1.0E-04	0.61282	0.00101	0.61484	_1_6_4_5	0.83523	0.00118	0.83758
_5_1_4_3	0.0	70.0	4642	3249	9952	79.95	1.0E-04	0.91799	0.00136	0.92070				
_1_2_5_4	0.0	0.2	5000	3500	9390	74.82	1.0E-04	0.70497	0.00140	0.70778	_1_2_5_4	0.85830	0.00155	0.86140
_1_3_5_4	0.0	0.3	5000	3500	9390	74.82	1.0E-04	0.66703	0.00120	0.66942	_1_3_5_4	0.85296	0.00124	0.85545
_1_4_5_4	0.0	0.4	5000	3500	9390	74.82	1.0E-04	0.64665	0.00120	0.64904	_1_4_5_4	0.84681	0.00155	0.84991
_1_5_5_4	0.0	0.5	5000	3500	9390	74.82	1.0E-04	0.63242	0.00127	0.63496	_1_5_5_4	0.84544	0.00142	0.84827
_1_6_5_4	0.0	0.6	5000	3500	9390	74.82	1.0E-04	0.62104	0.00129	0.62362	_1_6_5_4	0.84411	0.00122	0.84656
_6_1_3_3	0.0	60.0	5577	3346	9903	77.24	1.0E-04	0.91221	0.00147	0.91515				
_1_2_6_3	0.0	0.2	6000	3600	9338	72.36	1.0E-04	0.71137	0.00124	0.71386	_1_2_6_3	0.85681	0.00117	0.85916
_1_3_6_3	0.0	0.3	6000	3600	9338	72.36	1.0E-04	0.67406	0.00124	0.67654	_1_3_6_3	0.85226	0.00126	0.85478
_1_4_6_3	0.0	0.4	6000	3600	9338	72.36	1.0E-04	0.65407	0.00115	0.65637	_1_4_6_3	0.84813	0.00119	0.85052

Table 6.9.6-11b. Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models.

Note: Reference results for content homogenized over volume of containment vessel are highlighted. Results shown below the reference results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

nciabmt11	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$				
nciapbmflt11	**np (in.)**	**PF**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**nciapbmfdt11**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
_1_5_6_3	0.0	0.5	6000	3600	9338	72.36	1.0E-04	0.63393	0.00117	0.63626	_1_5_6_3	0.84385	0.00128	0.84642
_1_6_6_3	0.0	0.6	6000	3600	9338	72.36	1.0E-04	0.62196	0.00126	0.62449	_1_6_6_3	0.84286	0.00127	0.84541
with can spacers (np thickness = 1.4 in.)														
_3_2_8_3	1.4	100.0	2774	2774	9436	88.78	1.0E-04	0.90131	0.00139	0.90409				
_2_2_3_8	1.4	0.2	3000	3000	8882	82.86	1.0E-04	0.57463	0.00111	0.57684	_2_2_3_8	0.81623	0.00130	0.81883
_2_3_3_8	1.4	0.3	3000	3000	8882	82.86	1.0E-04	0.54703	0.00098	0.54900	_2_3_3_8	0.81643	0.00134	0.81912
_2_4_3_8	1.4	0.4	3000	3000	8882	82.86	1.0E-04	0.53274	0.00097	0.53467	_2_4_3_8	0.81357	0.00122	0.81600
_2_5_3_8	1.4	0.5	3000	3000	8882	82.86	1.0E-04	0.52613	0.00105	0.52822	_2_5_3_8	0.81038	0.00125	0.81288
_2_6_3_8	1.4	0.6	3000	3000	8882	82.86	1.0E-04	0.51882	0.00092	0.52065	_2_6_3_8	0.81249	0.00116	0.81482
_4_2_7_3	1.4	95.0	3701	3516	9387	69.68	1.0E-04	0.91690	0.00149	0.91987				
_2_2_4_7	1.4	0.2	4000	3800	8829	65.05	1.0E-04	0.61562	0.00115	0.61792	_2_2_4_7	0.85451	0.00154	0.85759
_2_3_4_7	1.4	0.3	4000	3800	8829	65.05	1.0E-04	0.58602	0.00121	0.58843	_2_3_4_7	0.84752	0.00128	0.85009
_2_4_4_7	1.4	0.4	4000	3800	8829	65.05	1.0E-04	0.56904	0.00124	0.57153	_2_4_4_7	0.84935	0.00118	0.85170
_2_5_4_7	1.4	0.5	4000	3800	8829	65.05	1.0E-04	0.55712	0.00096	0.55904	_2_5_4_7	0.84837	0.00138	0.85113
_2_6_4_7	1.4	0.6	4000	3800	8829	65.05	1.0E-04	0.55125	0.00100	0.55326	_2_6_4_7	0.84715	0.00114	0.84943
_4_2_6_3	1.4	90.0	3704	3333	9387	73.50	1.0E-04	0.90541	0.00147	0.90835				
_2_2_4_6	1.4	0.2	4000	3600	8829	68.67	1.0E-04	0.60511	0.00103	0.60717	_2_2_4_6	0.84248	0.00138	0.84524
_2_3_4_6	1.4	0.3	4000	3600	8829	68.67	1.0E-04	0.57445	0.00092	0.57628	_2_3_4_6	0.83740	0.00119	0.83978
_2_4_4_6	1.4	0.4	4000	3600	8829	68.67	1.0E-04	0.55835	0.00103	0.56041	_2_4_4_6	0.83957	0.00113	0.84184

Table 6.9.6-11b. Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models.

Note: Reference results for content homogenized over volume of containment vessel are highlighted. Results shown below the reference results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

nciabmt11	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$				
nciapbmflt11	**np (in.)**	**PF**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**nciapbmfdt11**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
_2_5_4_6	1.4	0.5	4000	3600	8829	68.67	1.0E-04	0.54727	0.00106	0.54939	_2_5_4_6	0.83601	0.00137	0.83875
_2_6_4_6	1.4	0.6	4000	3600	8829	68.67	1.0E-04	0.53974	0.00107	0.54189	_2_6_4_6	0.83732	0.00140	0.84011
_6_2_5_3	1.4	80.0	5563	4450	9289	54.48	1.0E-04	0.91981	0.00127	0.92235				
_2_2_6_5	1.4	0.2	6000	4800	8723	50.93	1.0E-04	0.66266	0.00117	0.66500	_2_2_6_5	0.87671	0.00141	0.87952
_2_3_6_5	1.4	0.3	6000	4800	8723	50.93	1.0E-04	0.62900	0.00108	0.63116	_2_3_6_5	0.87268	0.00141	0.87551
_2_4_6_5	1.4	0.4	6000	4800	8723	50.93	1.0E-04	0.60636	0.00106	0.60848	_2_4_6_5	0.87070	0.00137	0.87344
_2_5_6_5	1.4	0.5	6000	4800	8723	50.93	1.0E-04	0.59549	0.00110	0.59769	_2_5_6_5	0.87064	0.00126	0.87316
_2_6_6_5	1.4	0.6	6000	4800	8723	50.93	1.0E-04	0.58580	0.00104	0.58789	_2_6_6_5	0.86937	0.00136	0.87209
_8_2_4_3	1.4	70.0	7426	5198	9191	46.15	1.0E-04	0.91902	0.00137	0.92175				
_2_2_8_4	1.4	0.2	8000	5600	8618	43.16	1.0E-04	0.69894	0.00117	0.70128	_2_2_8_4	0.88757	0.00154	0.89065
_2_3_8_4	1.4	0.3	8000	5600	8618	43.16	1.0E-04	0.65861	0.00101	0.66064	_2_3_8_4	0.88142	0.00149	0.88440
_2_4_8_4	1.4	0.4	8000	5600	8618	43.16	1.0E-04	0.63538	0.00119	0.63775	_2_4_8_4	0.88292	0.00164	0.88621
_2_5_8_4	1.4	0.5	8000	5600	8618	43.16	1.0E-04	0.62021	0.00120	0.62260	_2_5_8_4	0.88202	0.00141	0.88484
_2_6_8_4	1.4	0.6	8000	5600	8618	43.16	1.0E-04	0.61023	0.00116	0.61255	_2_6_8_4	0.88175	0.00132	0.88439
_12_2_3_3	1.4	60.0	11154	6692	8995	35.08	1.0E-04	0.91502	0.00155	0.91812				
_2_2_12_3	1.4	0.2	12000	7200	8407	32.81	1.0E-04	0.75340	0.00124	0.75588	_2_2_12_3	0.90142	0.00133	0.90409
_2_3_12_3	1.4	0.3	12000	7200	8407	32.81	1.0E-04	0.71017	0.00101	0.71220	_2_3_12_3	0.90203	0.00119	0.90441
_2_4_12_3	1.4	0.4	12000	7200	8407	32.81	1.0E-04	0.68355	0.00103	0.68561	_2_4_12_3	0.89718	0.00145	0.90009

Table 6.9.6-11b. Comparison of NCT results for HEU broken metal content in ES-3100 NCT packaging calculation models.

Note: Reference results for content homogenized over volume of containment vessel are highlighted. Results shown below the reference results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

nciabmt11	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$				
nciapbmflt11	**np (in.)**	**PF**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**nciapbmfdt11**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
_2_5_12_3	1.4	0.5	12000	7200	8407	32.81	1.0E-04	0.66830	0.00090	0.67011	_2_5_12_3	0.90008	0.00114	0.90237
_2_6_12_3	1.4	0.6	12000	7200	8407	32.81	1.0E-04	0.65711	0.00100	0.65912	_2_6_12_3	0.89900	0.00120	0.90140

Table 6.9.6-11c. Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models.

Note: Reference results for content homogenized over volume of containment vessel are highlighted. Results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

hciabmt12	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$				
hciapbmflt12	**np (in.)**	**PF**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**hciapbmfdt12**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
content in flooded containment vessel, array packaging model for CSI=0.0														
no can spacers (np thickness = 0.0 in.)														
_4_1_5_3	0.0	80.0	3709	2967	10001	87.98	1.0E-04	0.92156	0.00160	0.92476				
_1_2_4_5	0.0	0.2	4000	3200	9443	82.26	1.0E-04	0.69676	0.00134	0.69944	_1_2_4_5	0.85244	0.00119	0.85481
_1_3_4_5	0.0	0.3	4000	3200	9443	82.26	1.0E-04	0.66231	0.00119	0.66469	_1_3_4_5	0.84158	0.00146	0.84451
_1_4_4_5	0.0	0.4	4000	3200	9443	82.26	1.0E-04	0.64127	0.00133	0.64392	_1_4_4_5	0.84036	0.00120	0.84276
_1_5_4_5	0.0	0.5	4000	3200	9443	82.26	1.0E-04	0.62704	0.00115	0.62934	_1_5_4_5	0.83647	0.00127	0.83901
_1_6_4_5	0.0	0.6	4000	3200	9443	82.26	1.0E-04	0.61943	0.00110	0.62164	_1_6_4_5	0.83721	0.00128	0.83977

Table 6.9.6-11c. Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models.

Note: Reference results for content homogenized over volume of containment vessel are highlighted. Results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

hciabmt12	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$				
hciapbmflt12	**np (in.)**	**PF**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**hciapbmfdt12**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
_5_1_4_3	0.0	70.0	4642	3249	9952	79.95	1.0E-04	0.92053	0.00147	0.92347				
_1_2_5_4	0.0	0.2	5000	3500	9390	74.82	1.0E-04	0.71271	0.00111	0.71494	_1_2_5_4	0.86056	0.00125	0.86305
_1_3_5_4	0.0	0.3	5000	3500	9390	74.82	1.0E-04	0.67372	0.00145	0.67662	_1_3_5_4	0.85614	0.00119	0.85851
_1_4_5_4	0.0	0.4	5000	3500	9390	74.82	1.0E-04	0.65481	0.00129	0.65738	_1_4_5_4	0.84829	0.00144	0.85117
_1_5_5_4	0.0	0.5	5000	3500	9390	74.82	1.0E-04	0.63822	0.00113	0.64047	_1_5_5_4	0.84683	0.00118	0.84919
_1_6_5_4	0.0	0.6	5000	3500	9390	74.82	1.0E-04	0.62688	0.00106	0.62899	_1_6_5_4	0.84497	0.00128	0.84754
_6_1_3_3	0.0	60.0	5577	3346	9903	77.24	1.0E-04	0.91017	0.00128	0.91274				
_1_2_6_3	0.0	0.2	6000	3600	9338	72.36	1.0E-04	0.71739	0.00119	0.71977	_1_2_6_3	0.85989	0.00142	0.86273
_1_3_6_3	0.0	0.3	6000	3600	9338	72.36	1.0E-04	0.68131	0.00126	0.68383	_1_3_6_3	0.85119	0.00113	0.85345
_1_4_6_3	0.0	0.4	6000	3600	9338	72.36	1.0E-04	0.65662	0.00118	0.65898	_1_4_6_3	0.84466	0.00126	0.84718
_1_5_6_3	0.0	0.5	6000	3600	9338	72.36	1.0E-04	0.63993	0.00109	0.64211	_1_5_6_3	0.84460	0.00144	0.84749
_1_6_6_3	0.0	0.6	6000	3600	9338	72.36	1.0E-04	0.62949	0.00119	0.63187	_1_6_6_3	0.84243	0.00125	0.84493
with can spacers (np thickness = 1.4 in.)														
_3_2_8_3	1.4	100.0	2774	2774	9436	88.78	1.0E-04	0.90243	0.00127	0.90497				
_2_2_3_8	1.4	0.2	3000	3000	8882	82.86	1.0E-04	0.57951	0.00103	0.58157	_2_2_3_8	0.81782	0.00115	0.82012
_2_3_3_8	1.4	0.3	3000	3000	8882	82.86	1.0E-04	0.55359	0.00094	0.55547	_2_3_3_8	0.81514	0.00148	0.81810
_2_4_3_8	1.4	0.4	3000	3000	8882	82.86	1.0E-04	0.53870	0.00102	0.54075	_2_4_3_8	0.81423	0.00122	0.81666
_2_5_3_8	1.4	0.5	3000	3000	8882	82.86	1.0E-04	0.52950	0.00097	0.53143	_2_5_3_8	0.81351	0.00131	0.81613
_2_6_3_8	1.4	0.6	3000	3000	8882	82.86	1.0E-04	0.52360	0.00120	0.52599	_2_6_3_8	0.81065	0.00127	0.81320

Table 6.9.6-11c. Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models.

Note: Reference results for content homogenized over volume of containment vessel are highlighted. Results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

hciabmt12	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$				
hciapbmflt12	**np (in.)**	**PF**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**hciapbmfdt12**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
_4_2_7_3	1.4	95.0	3701	3516	9387	69.68	1.0E-04	0.92094	0.00140	0.92374				
_2_2_4_7	1.4	0.2	4000	3800	8829	65.05	1.0E-04	0.62129	0.00113	0.62355	_2_2_4_7	0.85574	0.00150	0.85874
_2_3_4_7	1.4	0.3	4000	3800	8829	65.05	1.0E-04	0.59045	0.00106	0.59256	_2_3_4_7	0.85080	0.00142	0.85364
_2_4_4_7	1.4	0.4	4000	3800	8829	65.05	1.0E-04	0.57686	0.00095	0.57875	_2_4_4_7	0.84954	0.00126	0.85205
_2_5_4_7	1.4	0.5	4000	3800	8829	65.05	1.0E-04	0.56383	0.00096	0.56576	_2_5_4_7	0.84837	0.00159	0.85155
_2_6_4_7	1.4	0.6	4000	3800	8829	65.05	1.0E-04	0.55861	0.00120	0.56100	_2_6_4_7	0.85112	0.00127	0.85366
_4_2_6_3	1.4	90.0	3704	3333	9387	73.50	1.0E-04	0.90643	0.00133	0.90909				
_2_2_4_6	1.4	0.2	4000	3600	8829	68.67	1.0E-04	0.61197	0.00116	0.61429	_2_2_4_6	0.84318	0.00154	0.84626
_2_3_4_6	1.4	0.3	4000	3600	8829	68.67	1.0E-04	0.58023	0.00112	0.58248	_2_3_4_6	0.83944	0.00123	0.84190
_2_4_4_6	1.4	0.4	4000	3600	8829	68.67	1.0E-04	0.56418	0.00111	0.56641	_2_4_4_6	0.83754	0.00123	0.84000
_2_5_4_6	1.4	0.5	4000	3600	8829	68.67	1.0E-04	0.55222	0.00100	0.55423	_2_5_4_6	0.83876	0.00144	0.84163
_2_6_4_6	1.4	0.6	4000	3600	8829	68.67	1.0E-04	0.54866	0.00099	0.55063	_2_6_4_6	0.83719	0.00119	0.83958
_6_2_5_3	1.4	80.0	5563	4450	9289	54.48	1.0E-04	0.91987	0.00157	0.92301				
_2_2_6_5	1.4	0.2	6000	4800	8723	50.93	1.0E-04	0.67004	0.00099	0.67203	_2_2_6_5	0.87714	0.00150	0.88015
_2_3_6_5	1.4	0.3	6000	4800	8723	50.93	1.0E-04	0.63588	0.00098	0.63783	_2_3_6_5	0.87335	0.00149	0.87633
_2_4_6_5	1.4	0.4	6000	4800	8723	50.93	1.0E-04	0.61580	0.00114	0.61809	_2_4_6_5	0.87067	0.00120	0.87306
_2_5_6_5	1.4	0.5	6000	4800	8723	50.93	1.0E-04	0.60063	0.00111	0.60284	_2_5_6_5	0.87386	0.00137	0.87660
_2_6_6_5	1.4	0.6	6000	4800	8723	50.93	1.0E-04	0.59340	0.00097	0.59534	_2_6_6_5	0.87070	0.00141	0.87353

Table 6.9.6-11c. Comparison of HAC results for HEU broken metal content in ES-3100 HAC packaging calculation models.

Note: Reference results for content homogenized over volume of containment vessel are highlighted. Results are for modified cases where the HEU packaging fraction varies from 0.2 to 0.6 and the content is homogenized with 500 g polyethylene.

hciabmt12	np (in.)	enr. (wt %)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$				
hciapbmflt12	**np (in.)**	**PF**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**hciapbmfdt12**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
_8_2_4_3	1.4	70.0	7426	5198	9191	46.15	1.0E-04	0.91835	0.00126	0.92086				
_2_2_8_4	1.4	0.2	8000	5600	8618	43.16	1.0E-04	0.70405	0.00125	0.70655	_2_2_8_4	0.88804	0.00136	0.89077
_2_3_8_4	1.4	0.3	8000	5600	8618	43.16	1.0E-04	0.66628	0.00114	0.66856	_2_3_8_4	0.88503	0.00118	0.88740
_2_4_8_4	1.4	0.4	8000	5600	8618	43.16	1.0E-04	0.64431	0.00125	0.64681	_2_4_8_4	0.88186	0.00141	0.88467
_2_5_8_4	1.4	0.5	8000	5600	8618	43.16	1.0E-04	0.62989	0.00106	0.63201	_2_5_8_4	0.88416	0.00142	0.88701
_2_6_8_4	1.4	0.6	8000	5600	8618	43.16	1.0E-04	0.61934	0.00096	0.62126	_2_6_8_4	0.88358	0.00130	0.88618
_12_2_3_3	1.4	60.0	11154	6692	8995	35.08	1.0E-04	0.91776	0.00138	0.92053				
_2_2_12_3	1.4	0.2	12000	7200	8407	32.81	1.0E-04	0.75872	0.00115	0.76102	_2_2_12_3	0.90576	0.00134	0.90845
_2_3_12_3	1.4	0.3	12000	7200	8407	32.81	1.0E-04	0.71743	0.00106	0.71954	_2_3_12_3	0.90165	0.00138	0.90440
_2_4_12_3	1.4	0.4	12000	7200	8407	32.81	1.0E-04	0.69072	0.00115	0.69301	_2_4_12_3	0.90012	0.00124	0.90260
_2_5_12_3	1.4	0.5	12000	7200	8407	32.81	1.0E-04	0.67462	0.00099	0.67660	_2_5_12_3	0.89870	0.00124	0.90118
_2_6_12_3	1.4	0.6	12000	7200	8407	32.81	1.0E-04	0.66490	0.00106	0.66702	_2_6_12_3	0.90032	0.00117	0.90267

Table 6.9.6-11d. Comparison of results for the 277-4 canned spacer under the nominal and minimal acceptance criteria for HEU broken metal content in ES-3100 HAC packaging calculation models.

Note: Reference Cases **hciabmt12** selected from Table 6.9.6-11 are based for the nominal 277-4 canned spacer. These cases which establish loading limits were rerun with SCALE5, indicated as Cases **5hciabmt12** where case results are highlighted in yellow. The results for the corresponding Cases **5_401by131** for the 277-4 canned spacer sized per the minimal acceptance criteria are presented on the lines below. An absolute value of the quantity " **$(\Delta k_{eff}+2\sigma)/\sigma$** " >3 indicates that a statistically significant difference occurs between the case results.

5hciabmt12	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$		
5_401by131	**np (in.)**	**U (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**$\Delta k_{eff}+2\sigma$**	**$(\Delta k_{eff}+2\sigma)/\sigma$**
content in flooded containment vessel, array packaging model for CSI=0.0											
with can spacers											
_3_2_8_3	1.40	2774	2774	9436	88.78	1.0E-04	0.90362	0.00128	0.90619		
_3_2_8_3	1.31	2774	2774	9507	89.44	1.0E-04	0.90271	0.00146	0.90563	0.00056	0.38
_4_2_7_3	1.40	3701	3516	9387	69.68	1.0E-04	0.91873	0.00154	0.92182		
_4_2_7_3	1.31	3701	3516	9458	70.20	1.0E-04	0.91848	0.00149	0.92145	0.00037	0.25
_4_2_6_3	1.40	3704	3333	9387	73.50	1.0E-04	0.90865	0.00143	0.91151		
_4_2_6_3	1.31	3704	3333	9458	74.06	1.0E-04	0.90937	0.00139	0.91216	-0.00065	-0.47
_6_2_5_3	1.40	5563	4450	9289	54.48	1.0E-04	0.92059	0.00142	0.92344		
_6_2_5_3	1.31	5563	4450	9360	54.90	1.0E-04	0.92273	0.00125	0.92524	-0.00180	-1.44
_8_2_4_3	1.40	7426	5198	9191	46.15	1.0E-04	0.91790	0.00124	0.92039		
_8_2_4_3	1.31	7426	5198	9262	46.50	1.0E-04	0.92080	0.00183	0.92445	-0.00406	-2.22

Table 6.9.6-11d. Comparison of results for the 277-4 canned spacer under the nominal and minimal acceptance criteria for HEU broken metal content in ES-3100 HAC packaging calculation models.

Note: Reference Cases **hciabmt12** selected from Table 6.9.6-11 are based for the nominal 277-4 canned spacer. These cases which establish loading limits were rerun with SCALE5, indicated as Cases **5hciabmt12** where case results are highlighted in yellow. The results for the corresponding Cases **5_401by131** for the 277-4 canned spacer sized per the minimal acceptance criteria are presented on the lines below. An absolute value of the quantity " **$(\Delta k_{eff}+2\sigma)/\sigma$** " >3 indicates that a statistically significant difference occurs between the case results.

5hciabmt12	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$		
5_401by131	np (in.)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	$\Delta k_{eff}+2\sigma$	$(\Delta k_{eff}+2\sigma)/\sigma$
_12_2_3_3	1.40	11154	6692	8995	35.08	1.0E-04	0.91638	0.00127	0.91892		
_12_2_3_3	1.31	11154	6692	9065	35.36	1.0E-04	0.91711	0.00133	0.91978	-0.00086	-0.65

Table 6.9.6-12. Results for HEU oxide content in CV calculation model

case name (cvcrpdoxt11)	Ox (g)	^{235}U (g)	Ox density (g/cm^3)	Ox volume (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
UO_2 content, 500 g polyethylene, flooded containment vessel, reflected											
_1_3_24_15	24000	21125	4.00	6000	3803	3665	10.02	1.0E+00	0.91157	0.00138	0.91434
_1_4_24_15	24000	21125	5.00	4800	2606	4863	10.02	1.0E+00	0.90264	0.00139	0.90541
_1_5_24_15	24000	21125	6.54	5000	1477	5991	10.02	1.0E+00	0.89152	0.00115	0.89382
_1_2_20_15	20000	17604	3.00	6667	4833	3000	12.57	1.0E+00	0.90943	0.00117	0.91177
_1_3_20_15	20000	17604	4.00	5000	3170	4663	12.57	1.0E+00	0.89797	0.00129	0.90055
_1_4_20_15	20000	17604	5.00	4000	2171	5662	12.57	1.0E+00	0.89035	0.00121	0.89278
_1_5_20_15	20000	17604	6.54	3058	1231	6602	12.57	1.0E+00	0.87565	0.00112	0.87789
_1_2_15_15	15000	13203	3.00	5000	3625	4664	17.66	1.0E+00	0.89891	0.00138	0.90166

Table 6.9.6-12. Results for HEU oxide content in CV calculation model

case name (cvcrpdoxt11)	Ox (g)	^{235}U (g)	Ox density (g/cm^3)	Ox volume (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
_1_3_15_15	15000	13203	4.00	3750	2377	5911	17.66	1.0E+00	0.87963	0.00116	0.88195
_1_4_15_15	15000	13203	5.00	3000	1629	6660	17.66	1.0E+00	0.86309	0.00134	0.86578
_1_5_15_15	15000	13203	6.54	2294	923	7365	17.66	1.0E+00	0.84270	0.00121	0.84513
14,000 g UO_2 content, 500 g polyethylene, flooded containment vessel, reflected											
_1_1_14_15	14000	12323	2.00	7000	5712	2667	19.11	1.0E+00	0.90801	0.00154	0.91110
_1_2_14_15	14000	12323	3.00	4667	3383	4996	19.11	1.0E+00	0.89261	0.00124	0.89510
_1_3_14_15	14000	12323	4.00	3500	2219	6161	19.11	1.0E+00	0.87604	0.00119	0.87842
_1_4_14_15	14000	12323	5.00	2800	1520	6860	19.11	1.0E+00	0.85585	0.00139	0.85863
_1_5_14_15	14000	12323	6.54	2141	862	7518	19.11	1.0E+00	0.83530	0.00112	0.83755
14,000 g U_3O_8 content, 500 g polyethylene, flooded containment vessel, reflected											
_2_1_14_15	14000	11850	2.00	7000	5304	2667	18.97	1.0E+00	0.88331	0.00144	0.88620
_2_2_14_15	14000	11850	3.00	4667	2975	4996	18.97	1.0E+00	0.85075	0.00129	0.85333
_2_3_14_15	14000	11850	4.00	3500	1810	6161	18.97	1.0E+00	0.82386	0.00123	0.82632
_2_4_14_15	14000	11850	5.00	2800	1111	6860	18.97	1.0E+00	0.79922	0.00143	0.80209
_2_5_14_15	14000	11850	6.54	2141	453	7518	18.97	1.0E+00	0.76510	0.00114	0.76738
14,000 g UO_3 content, 500 g polyethylene, flooded containment vessel, reflected											
_3_1_14_15	14000	11627	2.00	7000	5071	2667	18.81	1.0E+00	0.86835	0.00122	0.87079
_3_2_14_15	14000	11627	3.00	4667	2741	4996	18.81	1.0E+00	0.83069	0.00119	0.83307
_3_3_14_15	14000	11627	4.00	3500	1577	6161	18.81	1.0E+00	0.79457	0.00132	0.79720
_3_4_14_15	14000	11627	5.00	2800	878	6860	18.81	1.0E+00	0.76399	0.00140	0.76679
_3_5_14_15	14000	11627	6.54	2141	220	7518	18.81	1.0E+00	0.72235	0.00127	0.72490

Table 6.9.6-12. Results for HEU oxide content in CV calculation model

case name (cvcrpdoxt11)	Ox (g)	^{235}U (g)	Ox density (g/cm^3)	Ox volume (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
14,000 g UO_2 content, 500 g polyethylene, dry containment vessel, reflected											
_1_1_14_1	14000	12323	2.00	7000	5712	0	13.46	1.0E-20	0.90869	0.00156	0.91180
_1_2_14_1	14000	12323	3.00	4667	3383	0	8.53	1.0E-20	0.88628	0.00144	0.88916
_1_3_14_1	14000	12323	4.00	3500	2219	0	6.06	1.0E-20	0.86750	0.00131	0.87012
_1_4_14_1	14000	12323	5.00	2800	1520	0	4.58	1.0E-20	0.84555	0.00151	0.84857
_1_5_14_1	14000	12323	6.54	2141	862	0	3.19	1.0E-20	0.82157	0.00109	0.82375
UO_2 content, 2.0 g/cm^3 oxide density, 500 g polyethylene, flooded containment vessel, reflected											
_1_1_14_15	14000	12323	2.00	7000	5712	2667	19.11	1.0E+00	0.90801	0.00154	0.91110
_1_1_13_15	13000	11443	2.00	6500	5304	3166	20.79	1.0E+00	0.91011	0.00123	0.91258
_1_1_12_15	12000	10562	2.00	6000	4896	3665	22.74	1.0E+00	0.90176	0.00141	0.90457
_1_1_11_15	11000	9682	2.00	5500	4488	4164	25.06	1.0E+00	0.89737	0.00154	0.90044
_1_1_10_15	10000	8802	2.00	5000	4080	4663	27.83	1.0E+00	0.89620	0.00130	0.89880
_1_1_9_15	9000	7922	2.00	4500	3672	5163	31.23	1.0E+00	0.88551	0.00161	0.88872
_1_1_8_15	8000	7042	2.00	4000	3264	5662	35.47	1.0E+00	0.87598	0.00157	0.87912
_1_1_7_15	7000	6162	2.00	3500	2856	6161	40.92	1.0E+00	0.86765	0.00148	0.87061
_1_1_6_15	6000	5281	2.00	3000	2448	6660	48.19	1.0E+00	0.85412	0.00120	0.85652
_1_1_5_15	5000	4401	2.00	2500	2040	7159	58.37	1.0E+00	0.83022	0.00138	0.83298
_1_1_4_15	4000	3521	2.00	2000	1632	7658	73.63	1.0E+00	0.80856	0.00156	0.81168
_1_1_3_15	3000	2641	2.00	1500	1224	8157	99.08	1.0E+00	0.77245	0.00147	0.77539
_1_1_2_15	2000	1761	2.00	1000	816	8656	149.96	1.0E+00	0.72062	0.00132	0.72326
_1_1_1_15	1000	880	2.00	500	408	9155	302.58	1.0E+00	0.63401	0.00126	0.63653

Table 6.9.6-13. Results for HEU product oxide content at 6.54 g/cm3 in single-unit packaging calculation model

case name	Ox (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
UO_2 content and 500 g polyethylene in flooded containment vessel, single package reflected													
NCT										**HAC**			
ncsrpoxt11_1_24_1	24000	21125	1477	5991	10.02	1.0E-20	0.72148	0.00120	0.72388				
ncsrpoxt11_1_24_2	24000	21125	1477	5991	10.02	1.0E-05	0.71942	0.00107	0.72156				
ncsrpoxt11_1_24_3	24000	21125	1477	5991	10.02	0.0E+00	0.71790	0.00122	0.72035				
ncsrpoxt11_1_24_4	24000	21125	1477	5991	10.02	1.0E-03	0.72072	0.00154	0.72380				
ncsrpoxt11_1_24_5	24000	21125	1477	5991	10.02	1.0E-02	0.71999	0.00123	0.72244				
ncsrpoxt11_1_24_6	24000	21125	1477	5991	10.02	1.0E-01	0.72828	0.00103	0.73035				
ncsrpoxt11_1_24_8	24000	21125	1477	5991	10.02	3.0E-01	0.74362	0.00123	0.74607				
ncsrpoxt11_1_24_15	24000	21125	1477	5991	10.02	1.0E+00	0.80222	0.00108	0.80438				

Table 6.9.6-13a. Results for HEU oxide content in single-unit packaging calculation model

case name (ncsrpdoxt11)	Ox (g)	^{235}U (g)	Ox den. (g/cm^3)	Ox vol. (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	k_{eff}	σ	$k_{eff}+2\sigma$	case name (hcsrpdoxt12)	k_{eff}	σ	$k_{eff}+2\sigma$
NCT											**HAC**			
UO_2 content and 500 g polyethylene in flooded containment vessel, flooded package														
_1_3_24	24000	21125	4.00	6000	3803	3665	10.02	0.81371	0.00144	0.81659	_1_3_24	0.81599	0.00133	0.81865
_1_4_24	24000	21125	5.00	4800	2606	4863	10.02	0.80666	0.00111	0.80887	_1_4_24	0.81112	0.00119	0.81350
_1_5_24	24000	21125	6.54	3670	1477	5991	10.02	0.80222	0.00108	0.80438	_1_5_24	0.80624	0.00114	0.80852
_1_2_20	20000	17604	3.00	6667	4833	3000	12.57	0.81352	0.00155	0.81662	_1_2_20	0.81200	0.00136	0.81472
_1_3_20	20000	17604	4.00	5000	3170	4663	12.57	0.80451	0.00124	0.80698	_1_3_20	0.80524	0.00118	0.80760

Table 6.9.6-13a. Results for HEU oxide content in single-unit packaging calculation model

case name (ncsrpdoxt11)	Ox (g)	^{235}U (g)	Ox den. (g/cm^3)	Ox vol. (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	k_{eff}	σ	$k_{eff}+2\sigma$	case name (hcsrpdoxt12)	k_{eff}	σ	$k_{eff}+2\sigma$
_1_4_20	20000	17604	5.00	4000	2171	5662	12.57	0.79655	0.00129	0.79914	_1_4_20	0.79813	0.00137	0.80087
_1_5_20	20000	17604	6.54	3058	1231	6602	12.57	0.78510	0.00133	0.78775	_1_5_20	0.78801	0.00121	0.79043
_1_2_15	15000	13203	3.00	5000	3625	4664	17.66	0.79666	0.00133	0.79933	_1_2_15	0.79891	0.00149	0.80189
_1_3_15	15000	13203	4.00	3750	2377	5911	17.66	0.78374	0.00123	0.78619	_1_3_15	0.78801	0.00130	0.79061
_1_4_15	15000	13203	5.00	3000	1629	6660	17.66	0.77585	0.00104	0.77794	_1_4_15	0.77767	0.00131	0.78028
_1_5_15	15000	13203	6.54	2294	923	7365	17.66	0.75988	0.00120	0.76228	_1_5_15	0.76047	0.00122	0.76291
UO_2, content and 500 g polyethylene in flooded containment vessel, flooded package														
_1_1_14	14000	12323	2.00	7000	5712	2667	19.11	0.81144	0.00130	0.81403	_1_1_14	0.80983	0.00147	0.81276
_1_2_14	14000	12323	3.00	4667	3383	4996	19.11	0.79632	0.00134	0.79900	_1_2_14	0.79412	0.00155	0.79722
_1_3_14	14000	12323	4.00	3500	2219	6161	19.11	0.78024	0.00138	0.78300	_1_3_14	0.78251	0.00141	0.78533
_1_4_14	14000	12323	5.00	2800	1520	6860	19.11	0.76867	0.00119	0.77106	_1_4_14	0.77186	0.00130	0.77446
_1_5_14	14000	12323	6.54	2141	862	7518	19.11	0.75106	0.00143	0.75393	_1_5_14	0.75712	0.00132	0.75975
UO_3 content and 500 g polyethylene in flooded containment vessel, flooded package														
_2_1_14	14000	11850	2.00	7000	5304	2667	18.97	0.77449	0.00162	0.77772	_2_1_14	0.77571	0.00138	0.77847
_2_2_14	14000	11850	3.00	4667	2975	4996	18.97	0.75132	0.00141	0.75415	_2_2_14	0.74985	0.00135	0.75256
_2_3_14	14000	11850	4.00	3500	1810	6161	18.97	0.72213	0.00119	0.72452	_2_3_14	0.72485	0.00112	0.72708
_2_4_14	14000	11850	5.00	2800	1111	6860	18.97	0.70025	0.00132	0.70289	_2_4_14	0.70229	0.00135	0.70498
_2_5_14	14000	11850	6.54	2141	453	7518	18.97	0.66897	0.00140	0.67177	_2_5_14	0.67431	0.00107	0.67645
U_3O_8 content and 500 g polyethylene in flooded containment vessel, flooded package														
_3_1_14	14000	11627	2.00	7000	5071	2667	18.81	0.75704	0.00138	0.75980	_3_1_14	0.75676	0.00139	0.75954
_3_2_14	14000	11627	3.00	4667	2741	4996	18.81	0.72097	0.00124	0.72345	_3_2_14	0.72300	0.00121	0.72542
_3_3_14	14000	11627	4.00	3500	1577	6161	18.81	0.69035	0.00114	0.69263	_3_3_14	0.69274	0.00112	0.69498
_3_4_14	14000	11627	5.00	2800	878	6860	18.81	0.66080	0.00123	0.66326	_3_4_14	0.66443	0.00115	0.66674
_3_5_14	14000	11627	6.54	2141	220	7518	18.81	0.62168	0.00129	0.62427	_3_5_14	0.62544	0.00118	0.62780

Table 6.9.6-13b. Results for HEU oxide content in array packaging calculation model

case name (nciapdoxt11)	Ox (g)	^{235}U (g)	Ox den. (g/cm^3)	Ox vol. (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	k_{eff}	σ	$k_{eff}+2\sigma$	case name (hciapdoxt12)	k_{eff}	σ	$k_{eff}+2\sigma$
UO_2 content and 500 g polyethylene in flooded containment vessel, array packaging model for CSI=0.0														
NCT											**HAC**			
_1_3_24_3	24000	21125	4.00	6000	3803	3665	10.02	0.96758	0.00121	0.97000	_1_3_24_3	0.96822	0.00124	0.97070
_1_4_24_3	24000	21125	5.00	4800	2606	4863	10.02	0.94340	0.00119	0.94578	_1_4_24_3	0.94131	0.00115	0.94360
_1_5_24_3	24000	21125	6.54	3670	1477	5991	10.02	0.91495	0.00134	0.91764	_1_5_24_3	0.91666	0.00106	0.91878
_1_2_20_3	20000	17604	3.00	6667	4833	3000	12.57	0.97118	0.00122	0.97363	_1_2_20_3	0.97255	0.00139	0.97532
_1_3_20_3	20000	17604	4.00	5000	3170	4663	12.57	0.93543	0.00122	0.93786	_1_3_20_3	0.93616	0.00141	0.93897
_1_4_20_3	20000	17604	5.00	4000	2171	5662	12.57	0.91167	0.00117	0.91401	_1_4_20_3	0.91202	0.00126	0.91453
_1_5_20_3	20000	17604	6.54	3058	1231	6602	12.57	0.88413	0.00124	0.88661	_1_5_20_3	0.88426	0.00137	0.88700
_1_2_15_3	15000	13203	3.00	5000	3625	4664	17.66	0.92181	0.00128	0.92438	_1_2_15_3	0.92129	0.00139	0.92407
_1_3_15_3	15000	13203	4.00	3750	2377	5911	17.66	0.88533	0.00117	0.88767	_1_3_15_3	0.88414	0.00125	0.88663
_1_4_15_3	15000	13203	5.00	3000	1628	6660	17.66	0.86168	0.00116	0.86400	_1_4_15_3	0.86039	0.00117	0.86273
_1_5_15_3	15000	13203	6.54	2294	923	7365	17.66	0.83434	0.00122	0.83678	_1_5_15_3	0.83140	0.00111	0.83363
_1_1_12_3	12000	10562	2.00	6000	4896	3665	22.74	0.93409	0.00140	0.93688	_1_1_12_3	0.93732	0.00137	0.94006
_1_2_12_3	12000	10562	3.00	4000	2900	5662	22.74	0.88391	0.00131	0.88652	_1_2_12_3	0.88387	0.00121	0.88630
_1_3_12_3	12000	10562	4.00	3000	1902	6660	22.74	0.85157	0.00111	0.85379	_1_3_12_3	0.84658	0.00133	0.84925
_1_4_12_3	12000	10562	5.00	2400	1303	7259	22.74	0.82574	0.00128	0.82831	_1_4_12_3	0.82349	0.00119	0.82587
_1_5_12_3	12000	10562	6.54	1835	739	7823	22.74	0.79328	0.00110	0.79548	_1_5_12_3	0.79233	0.00121	0.79475
_1_1_11_3	11000	9682	2.00	5500	4488	4164	25.06	0.91822	0.00129	0.92079	_1_1_11_3	0.92203	0.00134	0.92471
_1_2_11_3	11000	9682	3.00	3667	2658	5994	25.06	0.86689	0.00129	0.86946	_1_2_11_3	0.87093	0.00135	0.87364
_1_3_11_3	11000	9682	4.00	2750	1743	6909	25.06	0.83492	0.00133	0.83757	_1_3_11_3	0.83515	0.00124	0.83763

Table 6.9.6-13b. Results for HEU oxide content in array packaging calculation model

case name (nciapdoxt11)	Ox (g)	^{235}U (g)	Ox den. (g/cm^3)	Ox vol. (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	k_{eff}	σ	$k_{eff}+2\sigma$	case name (hciapdoxt12)	k_{eff}	σ	$k_{eff}+2\sigma$
_1_4_11_3	11000	9682	5.00	2200	1194	7458	25.06	0.80930	0.00149	0.81227	_1_4_11_3	0.80948	0.00129	0.81205
_1_5_11_3	11000	9682	6.54	1682	677	7976	25.06	0.77906	0.00100	0.78106	_1_5_11_3	0.77935	0.00118	0.78171
_1_1_10_3	10000	8802	2.00	5000	4080	4663	27.83	0.90471	0.00131	0.90733	_1_1_10_3	0.90600	0.00128	0.90856
_1_1_9_3	9000	7922	2.00	4500	3672	5163	31.23	0.88936	0.00137	0.89210	_1_1_9_3	0.88714	0.00123	0.88960
_1_1_8_3	8000	7042	2.00	4000	3264	5662	35.47	0.86854	0.00144	0.87141	_1_1_8_3	0.86980	0.00145	0.87270
_1_1_7_3	7000	6162	2.00	3500	2856	6161	40.92	0.84876	0.00125	0.85126	_1_1_7_3	0.84926	0.00133	0.85192
_1_1_6_3	6000	5281	2.00	3000	2448	6660	48.19	0.82546	0.00127	0.82800	_1_1_6_3	0.82275	0.00135	0.82544
UO_2, UO_3, or U_3O_8 content and 500 g polyethylene in flooded containment vessel, array packaging model for CSI=0.0														
_1_1_7_3	7000	6162	2.00	3500	2856	6161	40.92	0.84876	0.00125	0.85126	_1_1_7_3	0.84926	0.00133	0.85192
_2_1_7_3	7000	5925	2.00	3500	2652	6161	41.65	0.81721	0.00130	0.81980	_2_1_7_3	0.81943	0.00125	0.82194
_3_1_7_3	7000	5813	2.00	3500	2535	6161	41.93	0.80044	0.00129	0.80302	_3_1_7_3	0.80086	0.00134	0.80355

Table 6.9.6-14. Results for UNX crystal content in CV calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
UNH crystal content, 0 g polyethylene, flooded containment vessel, reflected										
cvcrunhct11_24_1	24000	11303	5197	1620	15.74	1106	1.0E+00	0.82007	0.00128	0.82262
cvcrunhct11_23_1	23000	10832	4980	1978	16.77	1060	1.0E+00	0.82120	0.00129	0.82378
cvcrunhct11_22_1	22000	10361	4764	2335	17.88	1014	1.0E+00	0.82675	0.00122	0.82919
cvcrunhct11_21_1	21000	9890	4547	2693	19.11	968	1.0E+00	0.82938	0.00118	0.83174
cvcrunhct11_20_1	20000	9419	4331	3050	20.45	922	1.0E+00	0.83221	0.00129	0.83480

Table 6.9.6-14. Results for UNX crystal content in CV calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrunhct11_19_1	19000	8948	4114	3407	21.94	876	1.0E+00	0.83423	0.00152	0.83728
cvcrunhct11_18_1	18000	8477	3898	3765	23.59	830	1.0E+00	0.83622	0.00128	0.83878
cvcrunhct11_17_1	17000	8006	3681	4122	25.44	784	1.0E+00	0.84032	0.00167	0.84365
cvcrunhct11_16_1	16000	7536	3464	4479	27.51	738	1.0E+00	0.84509	0.00151	0.84811
cvcrunhct11_15_1	15000	7064	3248	4837	29.87	692	1.0E+00	0.84402	0.00133	0.84667
cvcrunhct11_14_1	14000	6594	3031	5194	32.56	645	1.0E+00	0.84915	0.00130	0.85175
cvcrunhct11_13_1	13000	6123	2815	5551	35.67	599	1.0E+00	0.84986	0.00127	0.85241
cvcrunhct11_12_1	12000	5652	2598	5909	39.29	553	1.0E+00	0.85138	0.00159	0.85456
cvcrunhct11_11_1	11000	5181	2382	6266	43.57	507	1.0E+00	0.85137	0.00136	0.85408
cvcrunhct11_10_1	10000	4710	2165	6623	48.71	461	1.0E+00	0.85062	0.00149	0.85359
cvcrunhct11_9_1	9000	4239	1949	6981	54.99	415	1.0E+00	0.85423	0.00147	0.85718
cvcrunhct11_8_1	8000	3768	1732	7338	62.83	369	1.0E+00	0.84783	0.00152	0.85088
cvcrunhct11_7_1	7000	3297	1516	7695	72.92	323	1.0E+00	0.84713	0.00166	0.85044
cvcrunhct11_6_1	6000	2826	1299	8053	86.38	277	1.0E+00	0.83915	0.00151	0.84218
cvcrunhct11_5_1	5000	2355	1083	8410	105.2	231	1.0E+00	0.82865	0.00177	0.83220
cvcrunhct11_4_1	4000	1884	866	8768	133.5	184	1.0E+00	0.81158	0.00162	0.81483
cvcrunhct11_3_1	3000	1413	650	9125	180.6	138	1.0E+00	0.78282	0.00120	0.78522
cvcrunhct11_2_1	2000	942	433	9482	274.7	92	1.0E+00	0.73150	0.00114	0.73377
cvcrunhct11_1_1	1000	471	217	9840	557.2	46	1.0E+00	0.60716	0.00106	0.60927
UNH crystal content, 500 g polyethylene, flooded containment vessel, reflected										
cvcrpunhct11_24_15	24000	11303	5197	1078	15.97	1106	1.0E+00	0.82422	0.00129	0.82681
cvcrpunhct11_23_15	23000	10832	4980	1435	17.01	1060	1.0E+00	0.82842	0.00146	0.83134
cvcrpunhct11_22_15	22000	10361	4764	1793	18.13	1014	1.0E+00	0.83462	0.00156	0.83773
cvcrpunhct11_21_15	21000	9890	4547	2150	19.37	968	1.0E+00	0.83608	0.00149	0.83906

Table 6.9.6-14. Results for UNX crystal content in CV calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrpunhct11_20_15	20000	9419	4331	2507	20.73	922	1.0E+00	0.84111	0.00143	0.84397
cvcrpunhct11_19_15	19000	8948	4114	2865	22.23	876	1.0E+00	0.84084	0.00135	0.84355
cvcrpunhct11_18_15	18000	8477	3898	3222	23.90	830	1.0E+00	0.84379	0.00138	0.84654
cvcrpunhct11_17_15	17000	8006	3681	3579	25.76	784	1.0E+00	0.84513	0.00147	0.84807
cvcrpunhct11_16_15	16000	7536	3464	3937	27.86	738	1.0E+00	0.84809	0.00132	0.85072
cvcrpunhct11_15_15	15000	7064	3248	4294	30.24	692	1.0E+00	0.85178	0.00146	0.85470
cvcrpunhct11_14_15	14000	6594	3031	4652	32.96	645	1.0E+00	0.85473	0.00134	0.85741
cvcrpunhct11_13_15	13000	6123	2815	5009	36.09	599	1.0E+00	0.85544	0.00134	0.85812
cvcrpunhct11_12_15	12000	5652	2598	5366	39.75	553	1.0E+00	0.85658	0.00142	0.85941
cvcrpunhct11_11_15	11000	5181	2382	5724	44.07	507	1.0E+00	0.85830	0.00152	0.86133
cvcrpunhct11_10_15	10000	4710	2165	6081	49.26	461	1.0E+00	0.85943	0.00176	0.86296
cvcrpunhct11_9_15	9000	4239	1949	6438	55.60	415	1.0E+00	0.85882	0.00139	0.86161
cvcrpunhct11_8_15	8000	3768	1732	6796	63.53	369	1.0E+00	0.85472	0.00116	0.85705
cvcrpunhct11_7_15	7000	3297	1516	7153	73.72	323	1.0E+00	0.84975	0.00143	0.85261
cvcrpunhct11_6_15	6000	2826	1299	7510	87.31	277	1.0E+00	0.84484	0.00132	0.84748
cvcrpunhct11_5_15	5000	2355	1083	7868	106.33	231	1.0E+00	0.83459	0.00167	0.83793
cvcrpunhct11_4_15	4000	1884	866	8225	134.85	184	1.0E+00	0.82093	0.00142	0.82378
cvcrpunhct11_3_15	3000	1413	650	8582	182.42	138	1.0E+00	0.78968	0.00130	0.79228
cvcrpunhct11_2_15	2000	942	433	8940	277.51	92	1.0E+00	0.73500	0.00145	0.73791
cvcrpunhct11_1_15	1000	471	217	9297	562.74	46	1.0E+00	0.61053	0.00118	0.61289
UNH crystal content, 500 g polyethylene, dry containment vessel, reflected										
cvcrpunhct11_24_1	24000	11303	5197	0	13.48	1106.5	1.0E-20	0.76603	0.00145	0.76893
cvcrpunhct11_23_1	23000	10832	4980	0	13.55	1060.4	1.0E-20	0.75118	0.00132	0.75382
cvcrpunhct11_22_1	22000	10361	4764	0	13.62	1014.3	1.0E-20	0.73265	0.00133	0.73531

Table 6.9.6-14. Results for UNX crystal content in CV calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrpunhct11_21_1	21000	9890	4547	0	13.70	968.2	1.0E-20	0.71276	0.00125	0.71527
cvcrpunhct11_20_1	20000	9419	4331	0	13.78	922.1	1.0E-20	0.69662	0.00146	0.69955
cvcrpunhct11_19_1	19000	8948	4114	0	13.87	876.0	1.0E-20	0.67992	0.00144	0.68279
cvcrpunhct11_18_1	18000	8477	3898	0	13.98	829.9	1.0E-20	0.66144	0.00115	0.66374
cvcrpunhct11_17_1	17000	8006	3681	0	14.09	783.8	1.0E-20	0.64482	0.00128	0.64738
cvcrpunhct11_16_1	16000	7536	3464	0	14.23	737.7	1.0E-20	0.62404	0.00110	0.62624
cvcrpunhct11_15_1	15000	7064	3248	0	14.37	691.5	1.0E-20	0.60835	0.00125	0.61085
cvcrpunhct11_14_1	14000	6594	3031	0	14.54	645.5	1.0E-20	0.58778	0.00113	0.59003
cvcrpunhct11_13_1	13000	6123	2815	0	14.74	599.4	1.0E-20	0.56892	0.00115	0.57123
cvcrpunhct11_12_1	12000	5652	2598	0	14.97	553.2	1.0E-20	0.55059	0.00129	0.55317
cvcrpunhct11_11_1	11000	5181	2382	0	15.24	507.1	1.0E-20	0.53268	0.00108	0.53485
cvcrpunhct11_10_1	10000	4710	2165	0	15.56	461.0	1.0E-20	0.51381	0.00135	0.51650
cvcrpunhct11_9_1	9000	4239	1949	0	15.96	414.9	1.0E-20	0.49374	0.00111	0.49596
cvcrpunhct11_8_1	8000	3768	1732	0	16.45	368.8	1.0E-20	0.47312	0.00106	0.47524
cvcrpunhct11_7_1	7000	3297	1516	0	17.09	322.7	1.0E-20	0.45221	0.00108	0.45437
cvcrpunhct11_6_1	6000	2826	1299	0	17.93	276.6	1.0E-20	0.43063	0.00114	0.43290
cvcrpunhct11_5_1	5000	2355	1083	0	19.12	230.5	1.0E-20	0.40936	0.00103	0.41141
cvcrpunhct11_4_1	4000	1884	866	0	20.90	184.4	1.0E-20	0.38394	0.00105	0.38603
cvcrpunhct11_3_1	3000	1413	650	0	23.87	138.3	1.0E-20	0.35655	0.00096	0.35846
cvcrpunhct11_2_1	2000	942	433	0	29.80	92.2	1.0E-20	0.31381	0.00093	0.31566
cvcrpunhct11_1_1	1000	471	217	0	47.60	46.1	1.0E-20	0.24974	0.00079	0.25132
500 g polyethylene and undissolved UNH crystals, flooded containment vessel, reflected										
cvcrbpunhct11_24_15	24000	11303	5197	1078	15.97	NA	1.0E+00	0.81439	0.00135	0.81710
cvcrbpunhct11_23_15	23000	10832	4980	1435	17.01	NA	1.0E+00	0.81243	0.00128	0.81498

Table 6.9.6-14. Results for UNX crystal content in CV calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrbpunhct11_22_15	22000	10361	4764	1793	18.13	NA	1.0E+00	0.81092	0.00139	0.81369
cvcrbpunhct11_21_15	21000	9890	4547	2150	19.37	NA	1.0E+00	0.80901	0.00135	0.81172
cvcrbpunhct11_20_15	20000	9419	4331	2507	20.73	NA	1.0E+00	0.80864	0.00168	0.81200
cvcrbpunhct11_19_15	19000	8948	4114	2865	22.23	NA	1.0E+00	0.80344	0.00145	0.80635
cvcrbpunhct11_18_15	18000	8477	3898	3222	23.90	NA	1.0E+00	0.80646	0.00132	0.80911
cvcrbpunhct11_17_15	17000	8006	3681	3579	25.76	NA	1.0E+00	0.80294	0.00134	0.80563
cvcrbpunhct11_16_15	16000	7536	3465	3937	27.86	NA	1.0E+00	0.79909	0.00115	0.80139
cvcrbpunhct11_15_15	15000	7064	3248	4294	30.24	NA	1.0E+00	0.79593	0.00133	0.79858
cvcrbpunhct11_14_15	14000	6594	3031	4652	32.96	NA	1.0E+00	0.79487	0.00109	0.79705
cvcrbpunhct11_13_15	13000	6123	2815	5009	36.09	NA	1.0E+00	0.78728	0.00118	0.78964
cvcrbpunhct11_12_15	12000	5652	2598	5366	39.75	NA	1.0E+00	0.78337	0.00127	0.78592
cvcrbpunhct11_11_15	11000	5181	2382	5724	44.07	NA	1.0E+00	0.77773	0.00122	0.78017
cvcrbpunhct11_10_15	10000	4710	2165	6081	49.26	NA	1.0E+00	0.77009	0.00154	0.77317
cvcrbpunhct11_9_15	9000	4239	1949	6438	55.60	NA	1.0E+00	0.76494	0.00133	0.76760
cvcrbpunhct11_8_15	8000	3768	1732	6796	63.53	NA	1.0E+00	0.75339	0.00148	0.75635
cvcrbpunhct11_7_15	7000	3297	1516	7153	73.72	NA	1.0E+00	0.74139	0.00149	0.74437
cvcrbpunhct11_6_15	6000	2826	1299	7510	87.31	NA	1.0E+00	0.72740	0.00134	0.73009
cvcrbpunhct11_5_15	5000	2355	1083	7868	6.33	NA	1.0E+00	0.70988	0.00128	0.71244
cvcrbpunhct11_4_15	4000	1884	866	8225	34.85	NA	1.0E+00	0.68707	0.00137	0.68981
cvcrbpunhct11_3_15	3000	1413	650	8582	82.42	NA	1.0E+00	0.65613	0.00136	0.65885
cvcrbpunhct11_2_15	2000	942	433	8940	77.51	NA	1.0E+00	0.61167	0.00117	0.61402
cvcrbpunhct11_1_15	1000	471	217	9297	62.74	NA	1.0E+00	0.55043	0.00140	0.55324

Table 6.9.6-14. Results for UNX crystal content in CV calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
500 g polyethylene and undissolved UNH crystals, dry containment vessel, reflected										
cvcrbpunhct11_24_1	24000	11303	5197	0	13.48	NA	1.0E-20	0.81264	0.00142	0.81548
cvcrbpunhct11_23_1	23000	10832	4980	0	13.55	NA	1.0E-20	0.81127	0.00129	0.81384
cvcrbpunhct11_22_1	22000	10361	4764	0	13.62	NA	1.0E-20	0.80828	0.00121	0.81069
cvcrbpunhct11_21_1	21000	9890	4547	0	13.70	NA	1.0E-20	0.80873	0.00122	0.81117
cvcrbpunhct11_20_1	20000	9419	4331	0	13.78	NA	1.0E-20	0.80508	0.00132	0.80773
cvcrbpunhct11_19_1	19000	8948	4114	0	13.87	NA	1.0E-20	0.80364	0.00150	0.80664
cvcrbpunhct11_18_1	18000	8477	3898	0	13.98	NA	1.0E-20	0.80002	0.00170	0.80343
cvcrbpunhct11_17_1	17000	8006	3681	0	14.09	NA	1.0E-20	0.79969	0.00165	0.80298
cvcrbpunhct11_16_1	16000	7536	3465	0	14.23	NA	1.0E-20	0.79458	0.00144	0.79746
cvcrbpunhct11_15_1	15000	7064	3248	0	14.37	NA	1.0E-20	0.79130	0.00141	0.79411
cvcrbpunhct11_14_1	14000	6594	3031	0	14.54	NA	1.0E-20	0.78794	0.00127	0.79048
cvcrbpunhct11_13_1	13000	6123	2815	0	14.74	NA	1.0E-20	0.78506	0.00137	0.78781
cvcrbpunhct11_12_1	12000	5652	2598	0	14.97	NA	1.0E-20	0.78061	0.00121	0.78303
cvcrbpunhct11_11_1	11000	5181	2382	0	15.24	NA	1.0E-20	0.77102	0.00125	0.77352
cvcrbpunhct11_10_1	10000	4710	2165	0	15.56	NA	1.0E-20	0.76415	0.00129	0.76673
cvcrbpunhct11_9_1	9000	4239	1949	0	15.96	NA	1.0E-20	0.75589	0.00141	0.75872
cvcrbpunhct11_8_1	8000	3768	1732	0	16.45	NA	1.0E-20	0.74147	0.00151	0.74449
cvcrbpunhct11_7_1	7000	3297	1516	0	17.09	NA	1.0E-20	0.72828	0.00125	0.73077
cvcrbpunhct11_6_1	6000	2826	1299	0	17.93	NA	1.0E-20	0.71077	0.00122	0.71321
cvcrbpunhct11_5_1	5000	2355	1083	0	19.12	NA	1.0E-20	0.68823	0.00137	0.69096
cvcrbpunhct11_4_1	4000	1884	866	0	20.90	NA	1.0E-20	0.66016	0.00146	0.66309
cvcrbpunhct11_3_1	3000	1413	650	0	23.87	NA	1.0E-20	0.61922	0.00144	0.62211

Table 6.9.6-14. Results for UNX crystal content in CV calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrbpunhct11_2_1	2000	942	433	0	29.80	NA	1.0E-20	0.56205	0.00129	0.56462
cvcrbpunhct11_1_1	1000	471	217	0	47.60	NA	1.0E-20	0.47544	0.00110	0.47765

Table 6.9.6-15. Results for UNX crystal content in packaging calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
UNH crystal content, 0 g polyethylene in flooded containment vessel, single package reflected														
NCT											**HAC**			
ncsrunhct11_24_1_1	24000	11303	5197	1620	15.74	1106	1.0E-20	0.60250	0.00130	0.60510	hcsrunhct12_24_1_1	0.60528	0.00129	0.60786
ncsrunhct11_24_1_2	24000	11303	5197	1620	15.74	1106	1.0E-05	0.59895	0.00119	0.60134	hcsrunhct12_24_1_2	0.60289	0.00142	0.60574
ncsrunhct11_24_1_3	24000	11303	5197	1620	15.74	1106	1.0E-04	0.59947	0.00124	0.60194	hcsrunhct12_24_1_3	0.60552	0.00130	0.60812
ncsrunhct11_24_1_4	24000	11303	5197	1620	15.74	1106	1.0E-03	0.60331	0.00132	0.60595	hcsrunhct12_24_1_4	0.60265	0.00112	0.60489
ncsrunhct11_24_1_5	24000	11303	5197	1620	15.74	1106	1.0E-02	0.60398	0.00118	0.60635	hcsrunhct12_24_1_5	0.60426	0.00152	0.60731
ncsrunhct11_24_1_6	24000	11303	5197	1620	15.74	1106	1.0E-01	0.61004	0.00142	0.61287	hcsrunhct12_24_1_6	0.61378	0.00127	0.61632
ncsrunhct11_24_1_8	24000	11303	5197	1620	15.74	1106	3.0E-01	0.63238	0.00143	0.63524	hcsrunhct12_24_1_8	0.63556	0.00128	0.63813
ncsrunhct11_24_1_15	24000	11303	5197	1620	15.74	1106	1.0E+00	0.69882	0.00142	0.70166	hcsrunhct12_24_1_15	0.70190	0.00129	0.70448
ncsrunhct11_24_1_15	24000	11303	5197	1620	15.74	1106	1.0E+00	0.69882	0.00142	0.70166	hcsrunhct12_24_1_15	0.70190	0.00129	0.70448
ncsrunhct11_23_1_15	23000	10832	4980	1978	16.77	1060	1.0E+00	0.70360	0.00134	0.70628	hcsrunhct12_23_1_15	0.70555	0.00129	0.70813
ncsrunhct11_22_1_15	22000	10361	4764	2335	17.88	1014	1.0E+00	0.70899	0.00132	0.71163	hcsrunhct12_22_1_15	0.70899	0.00136	0.71171
ncsrunhct11_21_1_15	21000	9890	4547	2693	19.11	968	1.0E+00	0.71172	0.00133	0.71438	hcsrunhct12_21_1_15	0.71348	0.00158	0.71664

Table 6.9.6-15. Results for UNX crystal content in packaging calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrunhct11_20_1_15	20000	9419	4331	3050	20.45	922	1.0E+00	0.71256	0.00123	0.71501	hcsrunhct12_20_1_15	0.71623	0.00117	0.71858
ncsrunhct11_19_1_15	19000	8948	4114	3407	21.94	876	1.0E+00	0.71780	0.00132	0.72045	hcsrunhct12_19_1_15	0.71798	0.00132	0.72063
ncsrunhct11_18_1_15	18000	8477	3898	3765	23.59	830	1.0E+00	0.72130	0.00139	0.72407	hcsrunhct12_18_1_15	0.72545	0.00149	0.72843
ncsrunhct11_17_1_15	17000	8006	3681	4122	25.44	784	1.0E+00	0.72340	0.00161	0.72663	hcsrunhct12_17_1_15	0.72589	0.00134	0.72856
ncsrunhct11_16_1_15	16000	7536	3464	4479	27.51	738	1.0E+00	0.72816	0.00141	0.73098	hcsrunhct12_16_1_15	0.73042	0.00147	0.73336
ncsrunhct11_15_1_15	15000	7064	3248	4837	29.87	692	1.0E+00	0.73150	0.00149	0.73449	hcsrunhct12_15_1_15	0.73525	0.00151	0.73827
ncsrunhct11_14_1_15	14000	6594	3031	5194	32.56	645	1.0E+00	0.73255	0.00135	0.73524	hcsrunhct12_14_1_15	0.73405	0.00150	0.73704
ncsrunhct11_13_1_15	13000	6123	2815	5551	35.67	599	1.0E+00	0.73488	0.00128	0.73745	hcsrunhct12_13_1_15	0.73722	0.00159	0.74040
ncsrunhct11_12_1_15	12000	5652	2598	5909	39.29	553	1.0E+00	0.73982	0.00146	0.74274	hcsrunhct12_12_1_15	0.74114	0.00126	0.74366
ncsrunhct11_11_1_15	11000	5181	2382	6266	43.57	507	1.0E+00	0.74059	0.00156	0.74370	hcsrunhct12_11_1_15	0.74104	0.00187	0.74477
ncsrunhct11_10_1_15	10000	4710	2165	6623	48.71	461	1.0E+00	0.74238	0.00148	0.74533	hcsrunhct12_10_1_15	0.74247	0.00134	0.74514
ncsrunhct11_9_1_15	9000	4239	1949	6981	54.99	415	1.0E+00	0.74214	0.00135	0.74484	hcsrunhct12_9_1_15	0.74537	0.00150	0.74836
ncsrunhct11_8_1_15	8000	3768	1732	7338	62.83	369	1.0E+00	0.74436	0.00146	0.74728	hcsrunhct12_8_1_15	0.74169	0.00176	0.74521
ncsrunhct11_7_1_15	7000	3297	1516	7695	72.92	323	1.0E+00	0.73972	0.00146	0.74265	hcsrunhct12_7_1_15	0.74201	0.00129	0.74459
ncsrunhct11_6_1_15	6000	2826	1299	8053	86.38	277	1.0E+00	0.73458	0.00147	0.73752	hcsrunhct12_6_1_15	0.73491	0.00155	0.73802
ncsrunhct11_5_1_15	5000	2355	1083	8410	105.22	231	1.0E+00	0.72880	0.00143	0.73166	hcsrunhct12_5_1_15	0.72804	0.00151	0.73107
ncsrunhct11_4_1_15	4000	1884	866	8768	133.47	184	1.0E+00	0.71269	0.00158	0.71585	hcsrunhct12_4_1_15	0.71463	0.00147	0.71758
ncsrunhct11_3_1_15	3000	1413	650	9125	180.57	138	1.0E+00	0.68768	0.00137	0.69042	hcsrunhct12_3_1_15	0.69065	0.00121	0.69306
ncsrunhct11_2_1_15	2000	942	433	9482	274.74	92	1.0E+00	0.64383	0.00118	0.64619	hcsrunhct12_2_1_15	0.64813	0.00131	0.65076
UNH crystal content, 500 g polyethylene in flooded containment vessel, single package reflected														
ncsrpunhct11_24_1	24000	11303	5197	1078	15.97	1106	1E-20	0.60653	0.00140	0.60932	hcsrpunhct12_24_1	0.60988	0.00142	0.61273
ncsrpunhct11_24_15	24000	11303	5197	1078	15.97	1106	1E+00	0.70571	0.00135	0.70841	hcsrpunhct12_24_15	0.70886	0.00133	0.71152

Table 6.9.6-15. Results for UNX crystal content in packaging calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrpunhct11_24_15	24000	11303	5197	1078	15.97	1106	1E+00	0.70571	0.00135	0.70841	hcsrpunhct12_24_15	0.70886	0.00133	0.71152
ncsrpunhct11_23_15	23000	10832	4980	1435	17.01	1060	1E+00	0.71244	0.00130	0.71504	hcsrpunhct12_23_15	0.71209	0.00121	0.71452
ncsrpunhct11_22_15	22000	10361	4764	1793	18.13	1014	1E+00	0.71524	0.00158	0.71841	hcsrpunhct12_22_15	0.71753	0.00126	0.72006
ncsrpunhct11_21_15	21000	9890	4547	2150	19.37	968	1E+00	0.71747	0.00154	0.72055	hcsrpunhct12_21_15	0.71997	0.00137	0.72270
ncsrpunhct11_20_15	20000	9419	4331	2507	20.73	922	1E+00	0.72176	0.00151	0.72479	hcsrpunhct12_20_15	0.72403	0.00130	0.72663
ncsrpunhct11_19_15	19000	8948	4114	2865	22.23	876	1E+00	0.72616	0.00138	0.72891	hcsrpunhct12_19_15	0.72647	0.00141	0.72929
ncsrpunhct11_18_15	18000	8477	3898	3222	23.90	830	1E+00	0.72901	0.00163	0.73227	hcsrpunhct12_18_15	0.73343	0.00131	0.73606
ncsrpunhct11_17_15	17000	8006	3681	3579	25.76	784	1E+00	0.73255	0.00127	0.73508	hcsrpunhct12_17_15	0.73387	0.00128	0.73643
ncsrpunhct11_16_15	16000	7536	3465	3937	27.86	738	1E+00	0.73515	0.00152	0.73818	hcsrpunhct12_16_15	0.73768	0.00152	0.74073
ncsrpunhct11_15_15	15000	7064	3248	4294	30.24	692	1E+00	0.74097	0.00126	0.74349	hcsrpunhct12_15_15	0.74006	0.00132	0.74270
ncsrpunhct11_14_15	14000	6594	3031	4652	32.96	645	1E+00	0.74169	0.00135	0.74438	hcsrpunhct12_14_15	0.74240	0.00141	0.74522
ncsrpunhct11_13_15	13000	6123	2815	5009	36.09	599	1E+00	0.74466	0.00139	0.74744	hcsrpunhct12_13_15	0.74534	0.00141	0.74815
ncsrpunhct11_12_15	12000	5652	2598	5366	39.75	553	1E+00	0.74381	0.00142	0.74666	hcsrpunhct12_12_15	0.74529	0.00132	0.74794
ncsrpunhct11_11_15	11000	5181	2382	5724	44.07	507	1E+00	0.74858	0.00146	0.75151	hcsrpunhct12_11_15	0.74980	0.00139	0.75259
ncsrpunhct11_10_15	10000	4710	2165	6081	49.26	461	1E+00	0.74595	0.00140	0.74875	hcsrpunhct12_10_15	0.74967	0.00141	0.75249
ncsrpunhct11_9_15	9000	4239	1949	6438	55.60	415	1E+00	0.74868	0.00167	0.75202	hcsrpunhct12_9_15	0.75260	0.00164	0.75587
ncsrpunhct11_8_15	8000	3768	1732	6796	63.53	369	1E+00	0.74978	0.00139	0.75255	hcsrpunhct12_8_15	0.74914	0.00120	0.75155
ncsrpunhct11_7_15	7000	3297	1516	7153	73.72	323	1E+00	0.74628	0.00147	0.74922	hcsrpunhct12_7_15	0.74708	0.00155	0.75018
ncsrpunhct11_6_15	6000	2826	1299	7510	87.31	277	1E+00	0.74259	0.00122	0.74503	hcsrpunhct12_6_15	0.74481	0.00150	0.74781
ncsrpunhct11_5_15	5000	2355	1083	7868	106.33	231	1E+00	0.73226	0.00133	0.73492	hcsrpunhct12_5_15	0.73303	0.00153	0.73609
ncsrpunhct11_4_15	4000	1884	866	8225	134.85	184	1E+00	0.72045	0.00145	0.72334	hcsrpunhct12_4_15	0.71942	0.00168	0.72279
ncsrpunhct11_3_15	3000	1413	650	8582	182.42	138	1E+00	0.69669	0.00167	0.70003	hcsrpunhct12_3_15	0.69613	0.00139	0.69891
ncsrpunhct11_2_15	2000	942	433	8940	277.51	92	1E+00	0.65100	0.00112	0.65324	hcsrpunhct12_2_15	0.65137	0.00149	0.65436
ncsrpunhct11_1_15	1000	471	217	9297	562.74	46	1E+00	0.54270	0.00116	0.54501	hcsrpunhct12_1_15	0.54296	0.00099	0.54494

Table 6.9.6-15. Results for UNX crystal content in packaging calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
UNH crystal content, 0 g polyethylene in flooded containment vessel, array packaging calculation model for CSI=0.0														
NCT											**HAC**			
nciaunhct11_8_24_1_1	24000	11303	5197	1620	15.74	1106	1.0E-20	0.91485	0.00136	0.91756	hciaunhct12_8_24_1_1	0.91665	0.00134	0.91933
nciaunhct11_8_24_1_2	24000	11303	5197	1620	15.74	1106	1.0E-05	0.91420	0.00120	0.91659	hciaunhct12_8_24_1_2	0.91708	0.00131	0.91969
nciaunhct11_8_24_1_3	24000	11303	5197	1620	15.74	1106	1.0E-04	0.91426	0.00123	0.91672	hciaunhct12_8_24_1_3	0.91632	0.00112	0.91856
nciaunhct11_8_24_1_4	24000	11303	5197	1620	15.74	1106	1.0E-03	0.91095	0.00119	0.91333	hciaunhct12_8_24_1_4	0.91159	0.00120	0.91399
nciaunhct11_8_24_1_5	24000	11303	5197	1620	15.74	1106	1.0E-02	0.88904	0.00117	0.89138	hciaunhct12_8_24_1_5	0.89357	0.00127	0.89610
nciaunhct11_8_24_1_6	24000	11303	5197	1620	15.74	1106	1.0E-01	0.77132	0.00109	0.77350	hciaunhct12_8_24_1_6	0.78417	0.00129	0.78676
nciaunhct11_8_24_1_8	24000	11303	5197	1620	15.74	1106	3.0E-01	0.71012	0.00130	0.71272	hciaunhct12_8_24_1_8	0.71917	0.00135	0.72188
nciaunhct11_8_24_1_15	24000	11303	5197	1620	15.74	1106	1.0E+00	0.71873	0.00134	0.72140	hciaunhct12_8_24_1_15	0.72598	0.00147	0.72892
nciaunhct11_8_24_1_3	24000	11303	5197	1620	15.74	1106	1.0E-04	0.91426	0.00123	0.91672	hciaunhct12_8_24_1_3	0.91632	0.00112	0.91856
nciaunhct11_8_12_1_3	12000	5652	2598	5909	39.29	553	1.0E-04	0.93016	0.00130	0.93277	hciaunhct12_8_12_1_3	0.92942	0.00157	0.93256
nciaunhct11_8_11_1_3	11000	5181	2382	6266	43.57	507	1.0E-04	0.92825	0.00132	0.93090	hciaunhct12_8_11_1_3	0.92834	0.00152	0.93138
nciaunhct11_8_10_1_3	10000	4710	2165	6623	48.71	461	1.0E-04	0.92490	0.00152	0.92794	hciaunhct12_8_10_1_3	0.92555	0.00137	0.92828
nciaunhct11_8_9_1_3	9000	4239	1949	6981	54.99	415	1.0E-04	0.92044	0.00124	0.92293	hciaunhct12_8_9_1_3	0.92360	0.00136	0.92631
nciaunhct11_8_8_1_3	8000	3768	1732	7338	62.83	369	1.0E-04	0.91662	0.00121	0.91905	hciaunhct12_8_8_1_3	0.91875	0.00144	0.92163
nciaunhct11_8_7_1_3	7000	3297	1516	7695	72.92	323	1.0E-04	0.91132	0.00140	0.91411	hciaunhct12_8_7_1_3	0.90978	0.00135	0.91247
nciaunhct11_8_6_1_3	6000	2826	1299	8053	86.38	277	1.0E-04	0.90036	0.00128	0.90293	hciaunhct12_8_6_1_3	0.89938	0.00150	0.90238
nciaunhct11_8_5_1_3	5000	2355	1083	8410	105.22	231	1.0E-04	0.88578	0.00141	0.88860	hciaunhct12_8_5_1_3	0.88489	0.00149	0.88788
nciaunhct11_8_4_1_3	4000	1884	866	8768	133.47	184	1.0E-04	0.86530	0.00119	0.86769	hciaunhct12_8_4_1_3	0.86326	0.00139	0.86604
nciaunhct11_8_3_1_3	3000	1413	650	9125	180.57	138	1.0E-04	0.82655	0.00120	0.82895	hciaunhct12_8_3_1_3	0.83005	0.00118	0.83242
nciaunhct11_8_2_1_3	2000	942	433	9482	274.74	92	1.0E-04	0.76783	0.00123	0.77029	hciaunhct12_8_2_1_3	0.76545	0.00129	0.76804
nciaunhct11_8_1_1_3	1000	471	217	9840	557.20	46	1.0E-04	0.62610	0.00112	0.62834	hciaunhct12_8_1_1_3	0.62341	0.00104	0.62549

Table 6.9.6-15. Results for UNX crystal content in packaging calculation model

case name	unh (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	gU/l	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
UNH crystal content, 500 g polyethylene in flooded containment vessel, array packaging calculation model for CSI=0.0														
nciapunhct11_24_1	24000	11303	5197	1078	15.97	1106	1E-20	0.92205	0.00118	0.92442	hciapunhct12_24_1	0.92136	0.00123	0.92383
nciapunhct11_24_15	24000	11303	5197	1078	15.97	1106	1E+00	0.72649	0.00128	0.72905	hciapunhct12_24_15	0.73087	0.00128	0.73343
nciapunhct11_24_3	24000	11303	5197	1078	15.97	1106	1E-04	0.92258	0.00141	0.92539	hciapunhct12_24_3	0.92172	0.00124	0.92419
nciapunhct11_16_3	16000	7536	3465	3937	27.86	738	1E-04	0.93498	0.00131	0.93759	hciapunhct12_16_3	0.93544	0.00130	0.93804
nciapunhct11_15_3	15000	7064	3248	4294	30.24	692	1E-04	0.93400	0.00139	0.93678	hciapunhct12_15_3	0.93500	0.00136	0.93771
nciapunhct11_14_3	14000	6594	3031	4652	32.96	645	1E-04	0.93374	0.00153	0.93680	hciapunhct12_14_3	0.93539	0.00135	0.93810
nciapunhct11_8_3	8000	3768	1732	6796	63.53	369	1E-04	0.92190	0.00144	0.92478	hciapunhct12_8_3	0.92270	0.00159	0.92589
nciapunhct11_7_3	7000	3297	1516	7153	73.72	323	1E-04	0.91677	0.00157	0.91991	hciapunhct12_7_3	0.91538	0.00132	0.91803
nciapunhct11_1_3	1000	471	217	9297	562.74	46	1E-04	0.62819	0.00115	0.63049	hciapunhct12_1_3	0.62885	0.00109	0.63103
UNH crystal content, 0 g polyethylene in flooded containment vessel, array packaging calculation model for CSI=0.4														
NCT											**HAC**			
ncf1unhct11_8_24_1_3	24000	11303	5197	1620	15.74	1106	1.0E-04	0.86774	0.00127	0.87027	hcf2unhct12_8_24_1_3	0.82915	0.00145	0.83205
ncf1unhct11_8_12_1_3	12000	5652	2598	5909	39.29	553	1.0E-04	0.88287	0.00133	0.88554	hcf2unhct12_8_12_1_3	0.85267	0.00165	0.85597
ncf1unhct11_8_11_1_3	11000	5181	2382	6266	43.57	507	1.0E-04	0.88535	0.00133	0.88802	hcf2unhct12_8_11_1_3	0.85565	0.00134	0.85833
ncf1unhct11_8_10_1_3	10000	4710	2165	6623	48.71	461	1.0E-04	0.88182	0.00140	0.88461	hcf2unhct12_8_10_1_3	0.85153	0.00132	0.85416
ncf1unhct11_8_1_1_3	1000	471	217	9840	557.20	46	1.0E-04	0.60011	0.00143	0.60297	hcf2unhct12_8_1_1_3	0.58199	0.00107	0.58414
UNH crystal content, 500 g polyethylene in flooded containment vessel, array packaging calculation model for CSI=0.4														
ncf1punhct11_24_3	24000	11303	5197	1078	15.97	1106	1E-04	0.87035	0.00135	0.87304	hcf2punhct12_24_3	0.83958	0.00135	0.84227
ncf1punhct11_15_3	15000	7064	3248	4294	30.24	692	1E-04	0.89208	0.00154	0.89516	hcf2punhct12_15_3	0.86102	0.00149	0.86400
ncf1punhct11_14_3	14000	6594	3031	4652	32.96	645	1E-04	0.89354	0.00152	0.89658	hcf2punhct12_14_3	0.85954	0.00131	0.86216
ncf1punhct11_1_3	1000	471	217	9297	562.74	46	1E-04	0.60481	0.00118	0.60718	hcf2punhct12_1_3	0.58731	0.00119	0.58968

Table 6.9.6-16. Results for leakage of UNX crystal content out of containment vessel

case name	U (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	CV gU/l	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UNH crystal content, 0 g polyethylene in flooded containment vessel, out leakage, single package reflected										
HAC										
icsrunhct12_24_1_1	24000	11303	5197	4875	30.14	687	1.0E-20	0.78331	0.00139	0.78609
icsrunhct12_24_1_2	24000	11303	5197	4875	30.14	687	1.0E-05	0.78291	0.00159	0.78610
icsrunhct12_24_1_3	24000	11303	5197	4875	30.14	687	1.0E-04	0.78197	0.00153	0.78503
icsrunhct12_24_1_4	24000	11303	5197	4875	30.14	687	1.0E-03	0.78003	0.00145	0.78294
icsrunhct12_24_1_5	24000	11303	5197	4875	30.14	687	1.0E-02	0.78443	0.00140	0.78723
icsrunhct12_24_1_6	24000	11303	5197	4875	30.14	687	1.0E-01	0.78426	0.00151	0.78729
icsrunhct12_24_1_8	24000	11303	5197	4875	30.14	687	3.0E-01	0.78841	0.00153	0.79146
icsrunhct12_24_1_15	24000	11303	5197	4875	30.14	687	1.0E+00	0.79193	0.00164	0.79521
icsrunhct12_24_1_15	24000	11303	5197	4875	30.14	687	1.0E+00	0.79193	0.00164	0.79521
icsrunhct12_23_1_15	23000	10832	4980	5097	31.79	658	1.0E+00	0.79465	0.00130	0.79724
icsrunhct12_22_1_15	22000	10361	4764	5318	33.59	629	1.0E+00	0.79665	0.00145	0.79956
icsrunhct12_21_1_15	21000	9890	4547	5540	35.56	601	1.0E+00	0.79533	0.00156	0.79845
icsrunhct12_20_1_15	20000	9419	4331	5762	37.73	572	1.0E+00	0.79937	0.00179	0.80295
icsrunhct12_19_1_15	19000	8948	4114	5984	40.13	544	1.0E+00	0.80059	0.00135	0.80329
icsrunhct12_18_1_15	18000	8477	3898	6205	42.79	515	1.0E+00	0.79930	0.00144	0.80219
icsrunhct12_17_1_15	17000	8006	3681	6427	45.77	486	1.0E+00	0.80320	0.00153	0.80626
icsrunhct12_16_1_15	16000	7536	3464	6649	49.11	458	1.0E+00	0.80113	0.00142	0.80396
icsrunhct12_15_1_15	15000	7064	3248	6871	52.91	429	1.0E+00	0.80445	0.00148	0.80740
icsrunhct12_14_1_15	14000	6594	3031	7092	57.24	401	1.0E+00	0.79995	0.00124	0.80243
icsrunhct12_13_1_15	13000	6123	2815	7314	62.25	372	1.0E+00	0.80425	0.00139	0.80703

Table 6.9.6-16. Results for leakage of UNX crystal content out of containment vessel

case name	U (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	CV gU/l	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
icsrunhct12_12_1_15	12000	5652	2598	7536	68.09	343	1.0E+00	0.79843	0.00129	0.80100
icsrunhct12_11_1_15	11000	5181	2382	7758	74.98	315	1.0E+00	0.80002	0.00147	0.80297
icsrunhct12_10_1_15	10000	4710	2165	7979	83.26	286	1.0E+00	0.79540	0.00162	0.79864
icsrunhct12_9_1_15	9000	4239	1949	8201	93.38	257	1.0E+00	0.79147	0.00156	0.79459
icsrunhct12_8_1_15	8000	3768	1732	8423	106.03	229	1.0E+00	0.78224	0.00165	0.78553
icsrunhct12_7_1_15	7000	3297	1516	8645	122.29	200	1.0E+00	0.77559	0.00131	0.77821
icsrunhct12_6_1_15	6000	2826	1299	8866	143.98	172	1.0E+00	0.76261	0.00136	0.76532
icsrunhct12_5_1_15	5000	2355	1083	9088	174.33	143	1.0E+00	0.74504	0.00138	0.74781
icsrunhct12_4_1_15	4000	1884	866	9310	219.86	114	1.0E+00	0.72070	0.00131	0.72333
icsrunhct12_3_1_15	3000	1413	650	9532	295.76	86	1.0E+00	0.68185	0.00131	0.68447
icsrunhct12_2_1_15	2000	942	433	9753	447.52	57	1.0E+00	0.61401	0.00117	0.61635
icsrunhct12_1_1_15	1000	471	217	9975	902.71	29	1.0E+00	0.47625	0.00103	0.47831
UNH crystal content, 500 g polyethylene in flooded containment vessel, out leakage, single package reflected										
icsrpunhct12_24_1	24000	11303	5197	4444	30.37	710	1E-20	0.79145	0.00146	0.79436
icsrpunhct12_24_15	24000	11303	5197	4444	30.37	710	1E+00	0.80433	0.00145	0.80723
icsrpunhct12_24_15	24000	11303	5197	4444	30.37	710	1E+00	0.80433	0.00145	0.80723
icsrpunhct12_23_15	23000	10832	4980	4661	32.03	680	1E+00	0.80343	0.00127	0.80597
icsrpunhct12_22_15	22000	10361	4764	4878	33.84	651	1E+00	0.80375	0.00125	0.80625
icsrpunhct12_21_15	21000	9890	4547	5095	35.83	621	1E+00	0.80639	0.00161	0.80961
icsrpunhct12_20_15	20000	9419	4331	5312	38.01	592	1E+00	0.80696	0.00144	0.80984
icsrpunhct12_19_15	19000	8948	4114	5529	40.42	562	1E+00	0.80928	0.00157	0.81242
icsrpunhct12_18_15	18000	8477	3898	5746	43.10	533	1E+00	0.80687	0.00138	0.80963
icsrpunhct12_17_15	17000	8006	3681	5963	46.09	503	1E+00	0.80989	0.00164	0.81317

Table 6.9.6-16. Results for leakage of UNX crystal content out of containment vessel

case name	U (g)	^{235}U (g)	unh H_2O (g)	CV H_2O (g)	h/x	CV gU/l	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
icsrpunhct12_16_15	16000	7536	3464	6180	49.46	473	1E+00	0.80777	0.00162	0.81101
icsrpunhct12_15_15	15000	7064	3248	6398	53.28	444	1E+00	0.81131	0.00154	0.81439
icsrpunhct12_14_15	14000	6594	3031	6615	57.64	414	1E+00	0.80815	0.00162	0.81139
icsrpunhct12_13_15	13000	6123	2815	6832	62.67	385	1E+00	0.80680	0.00133	0.80947
icsrpunhct12_12_15	12000	5652	2598	7049	68.55	355	1E+00	0.80665	0.00151	0.80967
icsrpunhct12_11_15	11000	5181	2382	7266	75.49	325	1E+00	0.80422	0.00157	0.80736
icsrpunhct12_10_15	10000	4710	2165	7483	83.82	296	1E+00	0.80093	0.00148	0.80388
icsrpunhct12_9_15	9000	4239	1949	7700	94.00	266	1E+00	0.79650	0.00144	0.79937
icsrpunhct12_8_15	8000	3768	1732	7918	106.72	237	1E+00	0.79302	0.00182	0.79667
icsrpunhct12_7_15	7000	3297	1516	8135	123.08	207	1E+00	0.78234	0.00156	0.78546
icsrpunhct12_6_15	6000	2826	1299	8352	144.90	178	1E+00	0.76957	0.00175	0.77308
icsrpunhct12_5_15	5000	2355	1083	8569	175.44	148	1E+00	0.75295	0.00147	0.75588
icsrpunhct12_4_15	4000	1884	866	8786	221.24	118	1E+00	0.72610	0.00127	0.72864
icsrpunhct12_3_15	3000	1413	650	9003	297.61	89	1E+00	0.68788	0.00134	0.69055
icsrpunhct12_2_15	2000	942	433	9220	450.29	59	1E+00	0.61943	0.00119	0.62182
icsrpunhct12_1_15	1000	471	217	9437	908.25	30	1E+00	0.47924	0.00105	0.48134

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
flooded containment vessel, reflected														
513 g polyethylene, no can spacers														
cvcrsk3cc_1_15_17	11589	8063	4468	28.09	6828	4765	417	87518	4105	50.58	2596	0.82806	0.00135	0.83075
cvcrsk3cc_2_15_17	14934	11665	4015	17.79	9879	6858	504	73492	4105	33.41	2252	0.81716	0.00136	0.81989
cvcrsk3cc_3_15_17	13821	11876	4893	20.62	10058	7028	372	52930	3233	32.62	1060	0.82909	0.00144	0.83197
cvcrsk3cc_4_15_17	15246	14900	4599	15.52	12619	8842	60	6786	3235	25.07	-227	0.82622	0.00154	0.82930
cvcrsk3cc_5_15_17	21216	21036	3869	9.49	17815	12455	27	2168	3235	16.27	-360	0.81061	0.00116	0.81293
cvcrsk3cc_6_15_17	15111	12933	3765	28.02	10960	4122	921	223432	4105	54.01	744	0.75711	0.00110	0.75932
cvcrsk3cc_7_15_17	13155	11666	3989	32.68	9886	3712	609	164054	4106	61.55	367	0.76196	0.00136	0.76469
cvcrsk3cc_8_15_17	13650	11689	4068	33.01	9906	3737	261	69834	4106	61.69	1187	0.76713	0.00137	0.76988
cvcrsk3cc_9_15_17	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.84737	0.00114	0.84965
cvcrsk3cc_10_15_17	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.85155	0.00148	0.85451
cvcrsk3cc_4_1_1	15246	14900	0	1.95	12619	8842	0.00	0	0	1.95	-227	0.49030	0.00095	0.49220
cvcrsk3cc_4_1_2	15246	14900	0	1.95	12619	8842	3.75	424	0	1.95	-227	0.49148	0.00090	0.49328
cvcrsk3cc_4_1_3	15246	14900	0	1.95	12619	8842	7.50	848	0	1.95	-227	0.49081	0.00095	0.49270
cvcrsk3cc_4_1_4	15246	14900	0	1.95	12619	8842	11.25	1272	0	1.95	-227	0.49337	0.00123	0.49584
cvcrsk3cc_4_1_5	15246	14900	0	1.95	12619	8842	15.00	1696	0	1.95	-227	0.49100	0.00105	0.49309
cvcrsk3cc_4_1_6	15246	14900	0	1.95	12619	8842	18.75	2120	0	1.95	-227	0.49125	0.00112	0.49348
cvcrsk3cc_4_1_7	15246	14900	0	1.95	12619	8842	22.50	2545	0	1.95	-227	0.49155	0.00104	0.49363
cvcrsk3cc_4_1_8	15246	14900	0	1.95	12619	8842	26.25	2969	0	1.95	-227	0.49300	0.00105	0.49510
cvcrsk3cc_4_1_9	15246	14900	0	1.95	12619	8842	30.00	3393	0	1.95	-227	0.49295	0.00117	0.49530
cvcrsk3cc_4_1_10	15246	14900	0	1.95	12619	8842	33.75	3817	0	1.95	-227	0.49206	0.00092	0.49391
cvcrsk3cc_4_1_11	15246	14900	0	1.95	12619	8842	37.50	4241	0	1.95	-227	0.49004	0.00115	0.49233
cvcrsk3cc_4_1_12	15246	14900	0	1.95	12619	8842	41.25	4665	0	1.95	-227	0.49325	0.00116	0.49558

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsk3cc_4_1_13	15246	14900	0	1.95	12619	8842	45.00	5089	0	1.95	-227	0.49242	0.00093	0.49429
cvcrsk3cc_4_1_14	15246	14900	0	1.95	12619	8842	48.75	5513	0	1.95	-227	0.49328	0.00119	0.49566
cvcrsk3cc_4_1_15	15246	14900	0	1.95	12619	8842	52.50	5937	0	1.95	-227	0.49139	0.00117	0.49373
cvcrsk3cc_4_1_16	15246	14900	0	1.95	12619	8842	56.25	6362	0	1.95	-227	0.49068	0.00105	0.49278
cvcrsk3cc_4_1_17	15246	14900	0	1.95	12619	8842	60.00	6786	0	1.95	-227	0.49303	0.00100	0.49502
cvcrsk3cc_4_6_1	15246	14900	460	3.3	12619	8842	0.00	0	323.51	4.26	-227	0.52088	0.00109	0.52306
cvcrsk3cc_4_6_2	15246	14900	460	3.3	12619	8842	3.75	424	323.51	4.26	-227	0.52247	0.00114	0.52474
cvcrsk3cc_4_6_3	15246	14900	460	3.3	12619	8842	7.50	848	323.51	4.26	-227	0.52250	0.00116	0.52482
cvcrsk3cc_4_6_4	15246	14900	460	3.3	12619	8842	11.25	1272	323.51	4.26	-227	0.52325	0.00103	0.52531
cvcrsk3cc_4_6_5	15246	14900	460	3.3	12619	8842	15.00	1696	323.51	4.26	-227	0.52252	0.00116	0.52485
cvcrsk3cc_4_6_6	15246	14900	460	3.3	12619	8842	18.75	2120	323.51	4.26	-227	0.52123	0.00113	0.52348
cvcrsk3cc_4_6_7	15246	14900	460	3.3	12619	8842	22.50	2545	323.51	4.26	-227	0.52156	0.00098	0.52353
cvcrsk3cc_4_6_8	15246	14900	460	3.3	12619	8842	26.25	2969	323.51	4.26	-227	0.52048	0.00106	0.52260
cvcrsk3cc_4_6_9	15246	14900	460	3.3	12619	8842	30.00	3393	323.51	4.26	-227	0.52115	0.00100	0.52315
cvcrsk3cc_4_6_10	15246	14900	460	3.3	12619	8842	33.75	3817	323.51	4.26	-227	0.52271	0.00114	0.52500
cvcrsk3cc_4_6_11	15246	14900	460	3.3	12619	8842	37.50	4241	323.51	4.26	-227	0.52221	0.00127	0.52474
cvcrsk3cc_4_6_12	15246	14900	460	3.3	12619	8842	41.25	4665	323.51	4.26	-227	0.52079	0.00104	0.52287
cvcrsk3cc_4_6_13	15246	14900	460	3.3	12619	8842	45.00	5089	323.51	4.26	-227	0.52323	0.00110	0.52543
cvcrsk3cc_4_6_14	15246	14900	460	3.3	12619	8842	48.75	5513	323.51	4.26	-227	0.52202	0.00129	0.52459
cvcrsk3cc_4_6_15	15246	14900	460	3.3	12619	8842	52.50	5937	323.51	4.26	-227	0.52288	0.00094	0.52476
cvcrsk3cc_4_6_16	15246	14900	460	3.3	12619	8842	56.25	6362	323.51	4.26	-227	0.52179	0.00106	0.52391
cvcrsk3cc_4_6_17	15246	14900	460	3.3	12619	8842	60.00	6786	323.51	4.26	-227	0.52265	0.00108	0.52481
cvcrsk3cc_4_7_1	15246	14900	920	4.66	12619	8842	0.00	0	647.03	6.57	-227	0.55466	0.00117	0.55699
cvcrsk3cc_4_7_2	15246	14900	920	4.66	12619	8842	3.75	424	647.03	6.57	-227	0.55192	0.00105	0.55402

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsk3cc_4_7_3	15246	14900	920	4.66	12619	8842	7.50	848	647.03	6.57	-227	0.55432	0.00118	0.55668
cvcrsk3cc_4_7_4	15246	14900	920	4.66	12619	8842	11.25	1272	647.03	6.57	-227	0.55387	0.00107	0.55600
cvcrsk3cc_4_7_5	15246	14900	920	4.66	12619	8842	15.00	1696	647.03	6.57	-227	0.55390	0.00102	0.55595
cvcrsk3cc_4_7_6	15246	14900	920	4.66	12619	8842	18.75	2120	647.03	6.57	-227	0.55272	0.00112	0.55496
cvcrsk3cc_4_7_7	15246	14900	920	4.66	12619	8842	22.50	2545	647.03	6.57	-227	0.55292	0.00118	0.55529
cvcrsk3cc_4_7_8	15246	14900	920	4.66	12619	8842	26.25	2969	647.03	6.57	-227	0.55262	0.00111	0.55484
cvcrsk3cc_4_7_9	15246	14900	920	4.66	12619	8842	30.00	3393	647.03	6.57	-227	0.55242	0.00108	0.55457
cvcrsk3cc_4_7_10	15246	14900	920	4.66	12619	8842	33.75	3817	647.03	6.57	-227	0.55457	0.00137	0.55732
cvcrsk3cc_4_7_11	15246	14900	920	4.66	12619	8842	37.50	4241	647.03	6.57	-227	0.55376	0.00117	0.55610
cvcrsk3cc_4_7_12	15246	14900	920	4.66	12619	8842	41.25	4665	647.03	6.57	-227	0.55283	0.00131	0.55545
cvcrsk3cc_4_7_13	15246	14900	920	4.66	12619	8842	45.00	5089	647.03	6.57	-227	0.55393	0.00118	0.55630
cvcrsk3cc_4_7_14	15246	14900	920	4.66	12619	8842	48.75	5513	647.03	6.57	-227	0.55181	0.00107	0.55395
cvcrsk3cc_4_7_15	15246	14900	920	4.66	12619	8842	52.50	5937	647.03	6.57	-227	0.55425	0.00107	0.55640
cvcrsk3cc_4_7_16	15246	14900	920	4.66	12619	8842	56.25	6362	647.03	6.57	-227	0.55377	0.00105	0.55587
cvcrsk3cc_4_7_17	15246	14900	920	4.66	12619	8842	60.00	6786	647.03	6.57	-227	0.55425	0.00101	0.55628
cvcrsk3cc_4_8_1	15246	14900	1380	6.02	12619	8842	0.00	0	970.54	8.88	-227	0.58801	0.00133	0.59068
cvcrsk3cc_4_8_2	15246	14900	1380	6.02	12619	8842	3.75	424	970.54	8.88	-227	0.58867	0.00114	0.59095
cvcrsk3cc_4_8_3	15246	14900	1380	6.02	12619	8842	7.50	848	970.54	8.88	-227	0.58712	0.00112	0.58936
cvcrsk3cc_4_8_4	15246	14900	1380	6.02	12619	8842	11.25	1272	970.54	8.88	-227	0.58657	0.00115	0.58887
cvcrsk3cc_4_8_5	15246	14900	1380	6.02	12619	8842	15.00	1696	970.54	8.88	-227	0.58720	0.00105	0.58930
cvcrsk3cc_4_8_6	15246	14900	1380	6.02	12619	8842	18.75	2120	970.54	8.88	-227	0.58418	0.00122	0.58663
cvcrsk3cc_4_8_7	15246	14900	1380	6.02	12619	8842	22.50	2545	970.54	8.88	-227	0.58706	0.00118	0.58943
cvcrsk3cc_4_8_8	15246	14900	1380	6.02	12619	8842	26.25	2969	970.54	8.88	-227	0.58528	0.00110	0.58748
cvcrsk3cc_4_8_9	15246	14900	1380	6.02	12619	8842	30.00	3393	970.54	8.88	-227	0.58452	0.00119	0.58689
cvcrsk3cc_4_8_10	15246	14900	1380	6.02	12619	8842	33.75	3817	970.54	8.88	-227	0.58645	0.00113	0.58870

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsk3cc_4_8_11	15246	14900	1380	6.02	12619	8842	37.50	4241	970.54	8.88	-227	0.58475	0.00109	0.58694
cvcrsk3cc_4_8_12	15246	14900	1380	6.02	12619	8842	41.25	4665	970.54	8.88	-227	0.58633	0.00110	0.58853
cvcrsk3cc_4_8_13	15246	14900	1380	6.02	12619	8842	45.00	5089	970.54	8.88	-227	0.58553	0.00107	0.58766
cvcrsk3cc_4_8_14	15246	14900	1380	6.02	12619	8842	48.75	5513	970.54	8.88	-227	0.58632	0.00118	0.58869
cvcrsk3cc_4_8_15	15246	14900	1380	6.02	12619	8842	52.50	5937	970.54	8.88	-227	0.58543	0.00106	0.58756
cvcrsk3cc_4_8_16	15246	14900	1380	6.02	12619	8842	56.25	6362	970.54	8.88	-227	0.58716	0.00123	0.58962
cvcrsk3cc_4_8_17	15246	14900	1380	6.02	12619	8842	60.00	6786	970.54	8.88	-227	0.58845	0.00113	0.59071
cvcrsk3cc_4_9_1	15246	14900	1840	7.38	12619	8842	0.00	0	1294.06	11.2	-227	0.62013	0.00104	0.62220
cvcrsk3cc_4_9_2	15246	14900	1840	7.38	12619	8842	3.75	424	1294.06	11.2	-227	0.61947	0.00123	0.62193
cvcrsk3cc_4_9_3	15246	14900	1840	7.38	12619	8842	7.50	848	1294.06	11.2	-227	0.62178	0.00112	0.62402
cvcrsk3cc_4_9_4	15246	14900	1840	7.38	12619	8842	11.25	1272	1294.06	11.2	-227	0.62009	0.00108	0.62225
cvcrsk3cc_4_9_5	15246	14900	1840	7.38	12619	8842	15.00	1696	1294.06	11.2	-227	0.61950	0.00114	0.62178
cvcrsk3cc_4_9_6	15246	14900	1840	7.38	12619	8842	18.75	2120	1294.06	11.2	-227	0.62035	0.00102	0.62240
cvcrsk3cc_4_9_7	15246	14900	1840	7.38	12619	8842	22.50	2545	1294.06	11.2	-227	0.61820	0.00111	0.62042
cvcrsk3cc_4_9_8	15246	14900	1840	7.38	12619	8842	26.25	2969	1294.06	11.2	-227	0.62037	0.00127	0.62290
cvcrsk3cc_4_9_9	15246	14900	1840	7.38	12619	8842	30.00	3393	1294.06	11.2	-227	0.62084	0.00111	0.62306
cvcrsk3cc_4_9_10	15246	14900	1840	7.38	12619	8842	33.75	3817	1294.06	11.2	-227	0.61977	0.00114	0.62205
cvcrsk3cc_4_9_11	15246	14900	1840	7.38	12619	8842	37.50	4241	1294.06	11.2	-227	0.61997	0.00123	0.62243
cvcrsk3cc_4_9_12	15246	14900	1840	7.38	12619	8842	41.25	4665	1294.06	11.2	-227	0.62097	0.00112	0.62320
cvcrsk3cc_4_9_13	15246	14900	1840	7.38	12619	8842	45.00	5089	1294.06	11.2	-227	0.62013	0.00126	0.62266
cvcrsk3cc_4_9_14	15246	14900	1840	7.38	12619	8842	48.75	5513	1294.06	11.2	-227	0.62028	0.00109	0.62245
cvcrsk3cc_4_9_15	15246	14900	1840	7.38	12619	8842	52.50	5937	1294.06	11.2	-227	0.62003	0.00107	0.62216
cvcrsk3cc_4_9_16	15246	14900	1840	7.38	12619	8842	56.25	6362	1294.06	11.2	-227	0.62193	0.00107	0.62408
cvcrsk3cc_4_9_17	15246	14900	1840	7.38	12619	8842	60.00	6786	1294.06	11.2	-227	0.62122	0.00117	0.62356

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsk3cc_4_10_1	15246	14900	2300	8.73	12619	8842	0.00	0	1617.57	13.51	-227	0.65504	0.00131	0.65766
cvcrsk3cc_4_10_2	15246	14900	2300	8.73	12619	8842	3.75	424	1617.57	13.51	-227	0.65421	0.00099	0.65618
cvcrsk3cc_4_10_3	15246	14900	2300	8.73	12619	8842	7.50	848	1617.57	13.51	-227	0.65445	0.00123	0.65692
cvcrsk3cc_4_10_4	15246	14900	2300	8.73	12619	8842	11.25	1272	1617.57	13.51	-227	0.65392	0.00127	0.65646
cvcrsk3cc_4_10_5	15246	14900	2300	8.73	12619	8842	15.00	1696	1617.57	13.51	-227	0.65599	0.00134	0.65868
cvcrsk3cc_4_10_6	15246	14900	2300	8.73	12619	8842	18.75	2120	1617.57	13.51	-227	0.65239	0.00107	0.65454
cvcrsk3cc_4_10_7	15246	14900	2300	8.73	12619	8842	22.50	2545	1617.57	13.51	-227	0.65356	0.00101	0.65558
cvcrsk3cc_4_10_8	15246	14900	2300	8.73	12619	8842	26.25	2969	1617.57	13.51	-227	0.65451	0.00134	0.65719
cvcrsk3cc_4_10_9	15246	14900	2300	8.73	12619	8842	30.00	3393	1617.57	13.51	-227	0.65576	0.00140	0.65855
cvcrsk3cc_4_10_10	15246	14900	2300	8.73	12619	8842	33.75	3817	1617.57	13.51	-227	0.65386	0.00121	0.65629
cvcrsk3cc_4_10_11	15246	14900	2300	8.73	12619	8842	37.50	4241	1617.57	13.51	-227	0.65645	0.00113	0.65871
cvcrsk3cc_4_10_12	15246	14900	2300	8.73	12619	8842	41.25	4665	1617.57	13.51	-227	0.65406	0.00130	0.65666
cvcrsk3cc_4_10_13	15246	14900	2300	8.73	12619	8842	45.00	5089	1617.57	13.51	-227	0.65406	0.00120	0.65646
cvcrsk3cc_4_10_14	15246	14900	2300	8.73	12619	8842	48.75	5513	1617.57	13.51	-227	0.65484	0.00126	0.65736
cvcrsk3cc_4_10_15	15246	14900	2300	8.73	12619	8842	52.50	5937	1617.57	13.51	-227	0.65420	0.00128	0.65675
cvcrsk3cc_4_10_16	15246	14900	2300	8.73	12619	8842	56.25	6362	1617.57	13.51	-227	0.65433	0.00123	0.65679
cvcrsk3cc_4_10_17	15246	14900	2300	8.73	12619	8842	60.00	6786	1617.57	13.51	-227	0.65399	0.00123	0.65646
cvcrsk3cc_4_11_1	15246	14900	2760	10.09	12619	8842	0.00	0	1941.09	15.82	-227	0.68728	0.00114	0.68956
cvcrsk3cc_4_11_2	15246	14900	2760	10.09	12619	8842	3.75	424	1941.09	15.82	-227	0.68899	0.00121	0.69141
cvcrsk3cc_4_11_3	15246	14900	2760	10.09	12619	8842	7.50	848	1941.09	15.82	-227	0.68815	0.00113	0.69041
cvcrsk3cc_4_11_4	15246	14900	2760	10.09	12619	8842	11.25	1272	1941.09	15.82	-227	0.68967	0.00117	0.69200
cvcrsk3cc_4_11_5	15246	14900	2760	10.09	12619	8842	15.00	1696	1941.09	15.82	-227	0.68936	0.00133	0.69201
cvcrsk3cc_4_11_6	15246	14900	2760	10.09	12619	8842	18.75	2120	1941.09	15.82	-227	0.68713	0.00127	0.68966
cvcrsk3cc_4_11_7	15246	14900	2760	10.09	12619	8842	22.50	2545	1941.09	15.82	-227	0.68933	0.00141	0.69216
cvcrsk3cc_4_11_8	15246	14900	2760	10.09	12619	8842	26.25	2969	1941.09	15.82	-227	0.68808	0.00130	0.69068

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsk3cc_4_11_9	15246	14900	2760	10.09	12619	8842	30.00	3393	1941.09	15.82	-227	0.69012	0.00114	0.69239
cvcrsk3cc_4_11_10	15246	14900	2760	10.09	12619	8842	33.75	3817	1941.09	15.82	-227	0.68913	0.00148	0.69208
cvcrsk3cc_4_11_11	15246	14900	2760	10.09	12619	8842	37.50	4241	1941.09	15.82	-227	0.68961	0.00139	0.69239
cvcrsk3cc_4_11_12	15246	14900	2760	10.09	12619	8842	41.25	4665	1941.09	15.82	-227	0.68779	0.00113	0.69005
cvcrsk3cc_4_11_13	15246	14900	2760	10.09	12619	8842	45.00	5089	1941.09	15.82	-227	0.69197	0.00114	0.69425
cvcrsk3cc_4_11_14	15246	14900	2760	10.09	12619	8842	48.75	5513	1941.09	15.82	-227	0.68861	0.00114	0.69090
cvcrsk3cc_4_11_15	15246	14900	2760	10.09	12619	8842	52.50	5937	1941.09	15.82	-227	0.68815	0.00127	0.69069
cvcrsk3cc_4_11_16	15246	14900	2760	10.09	12619	8842	56.25	6362	1941.09	15.82	-227	0.69041	0.00131	0.69303
cvcrsk3cc_4_11_17	15246	14900	2760	10.09	12619	8842	60.00	6786	1941.09	15.82	-227	0.68744	0.00129	0.69003
cvcrsk3cc_4_12_1	15246	14900	3220	11.45	12619	8842	0.00	0	2264.6	18.13	-227	0.72168	0.00119	0.72405
cvcrsk3cc_4_12_2	15246	14900	3220	11.45	12619	8842	3.75	424	2264.6	18.13	-227	0.72398	0.00131	0.72660
cvcrsk3cc_4_12_3	15246	14900	3220	11.45	12619	8842	7.50	848	2264.6	18.13	-227	0.72501	0.00142	0.72786
cvcrsk3cc_4_12_4	15246	14900	3220	11.45	12619	8842	11.25	1272	2264.6	18.13	-227	0.72327	0.00132	0.72592
cvcrsk3cc_4_12_5	15246	14900	3220	11.45	12619	8842	15.00	1696	2264.6	18.13	-227	0.72278	0.00124	0.72526
cvcrsk3cc_4_12_6	15246	14900	3220	11.45	12619	8842	18.75	2120	2264.6	18.13	-227	0.72081	0.00142	0.72364
cvcrsk3cc_4_12_7	15246	14900	3220	11.45	12619	8842	22.50	2545	2264.6	18.13	-227	0.72286	0.00141	0.72568
cvcrsk3cc_4_12_8	15246	14900	3220	11.45	12619	8842	26.25	2969	2264.6	18.13	-227	0.72457	0.00118	0.72693
cvcrsk3cc_4_12_9	15246	14900	3220	11.45	12619	8842	30.00	3393	2264.6	18.13	-227	0.72295	0.00126	0.72547
cvcrsk3cc_4_12_10	15246	14900	3220	11.45	12619	8842	33.75	3817	2264.6	18.13	-227	0.71959	0.00131	0.72221
cvcrsk3cc_4_12_11	15246	14900	3220	11.45	12619	8842	37.50	4241	2264.6	18.13	-227	0.72351	0.00106	0.72563
cvcrsk3cc_4_12_12	15246	14900	3220	11.45	12619	8842	41.25	4665	2264.6	18.13	-227	0.72291	0.00139	0.72570
cvcrsk3cc_4_12_13	15246	14900	3220	11.45	12619	8842	45.00	5089	2264.6	18.13	-227	0.72324	0.00125	0.72574
cvcrsk3cc_4_12_14	15246	14900	3220	11.45	12619	8842	48.75	5513	2264.6	18.13	-227	0.72395	0.00143	0.72680
cvcrsk3cc_4_12_15	15246	14900	3220	11.45	12619	8842	52.50	5937	2264.6	18.13	-227	0.72591	0.00111	0.72814

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsk3cc_4_12_16	15246	14900	3220	11.45	12619	8842	56.25	6362	2264.6	18.13	-227	0.72242	0.00146	0.72535
cvcrsk3cc_4_12_17	15246	14900	3220	11.45	12619	8842	60.00	6786	2264.6	18.13	-227	0.72398	0.00117	0.72631
cvcrsk3cc_4_13_1	15246	14900	3679	12.81	12619	8842	0.00	0	2588.12	20.45	-227	0.75630	0.00133	0.75896
cvcrsk3cc_4_13_2	15246	14900	3679	12.81	12619	8842	3.75	424	2588.12	20.45	-227	0.75574	0.00132	0.75838
cvcrsk3cc_4_13_3	15246	14900	3679	12.81	12619	8842	7.50	848	2588.12	20.45	-227	0.75761	0.00136	0.76032
cvcrsk3cc_4_13_4	15246	14900	3679	12.81	12619	8842	11.25	1272	2588.12	20.45	-227	0.75747	0.00147	0.76042
cvcrsk3cc_4_13_5	15246	14900	3679	12.81	12619	8842	15.00	1696	2588.12	20.45	-227	0.75674	0.00120	0.75914
cvcrsk3cc_4_13_6	15246	14900	3679	12.81	12619	8842	18.75	2120	2588.12	20.45	-227	0.75883	0.00137	0.76157
cvcrsk3cc_4_13_7	15246	14900	3679	12.81	12619	8842	22.50	2545	2588.12	20.45	-227	0.75912	0.00125	0.76162
cvcrsk3cc_4_13_8	15246	14900	3679	12.81	12619	8842	26.25	2969	2588.12	20.45	-227	0.75690	0.00131	0.75952
cvcrsk3cc_4_13_9	15246	14900	3679	12.81	12619	8842	30.00	3393	2588.12	20.45	-227	0.75692	0.00123	0.75938
cvcrsk3cc_4_13_10	15246	14900	3679	12.81	12619	8842	33.75	3817	2588.12	20.45	-227	0.75676	0.00123	0.75923
cvcrsk3cc_4_13_11	15246	14900	3679	12.81	12619	8842	37.50	4241	2588.12	20.45	-227	0.75541	0.00134	0.75808
cvcrsk3cc_4_13_12	15246	14900	3679	12.81	12619	8842	41.25	4665	2588.12	20.45	-227	0.75894	0.00141	0.76176
cvcrsk3cc_4_13_13	15246	14900	3679	12.81	12619	8842	45.00	5089	2588.12	20.45	-227	0.75688	0.00137	0.75963
cvcrsk3cc_4_13_14	15246	14900	3679	12.81	12619	8842	48.75	5513	2588.12	20.45	-227	0.75618	0.00140	0.75898
cvcrsk3cc_4_13_15	15246	14900	3679	12.81	12619	8842	52.50	5937	2588.12	20.45	-227	0.75806	0.00143	0.76092
cvcrsk3cc_4_13_16	15246	14900	3679	12.81	12619	8842	56.25	6362	2588.12	20.45	-227	0.75838	0.00131	0.76100
cvcrsk3cc_4_13_17	15246	14900	3679	12.81	12619	8842	60.00	6786	2588.12	20.45	-227	0.75890	0.00130	0.76150
cvcrsk3cc_4_14_1	15246	14900	4139	14.16	12619	8842	0.00	0	2911.63	22.76	-227	0.78934	0.00142	0.79219
cvcrsk3cc_4_14_2	15246	14900	4139	14.16	12619	8842	3.75	424	2911.63	22.76	-227	0.79102	0.00153	0.79408
cvcrsk3cc_4_14_3	15246	14900	4139	14.16	12619	8842	7.50	848	2911.63	22.76	-227	0.78792	0.00140	0.79073
cvcrsk3cc_4_14_4	15246	14900	4139	14.16	12619	8842	11.25	1272	2911.63	22.76	-227	0.78817	0.00122	0.79061
cvcrsk3cc_4_14_5	15246	14900	4139	14.16	12619	8842	15.00	1696	2911.63	22.76	-227	0.79185	0.00133	0.79451

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsk3cc_4_14_6	15246	14900	4139	14.16	12619	8842	18.75	2120	2911.63	22.76	-227	0.78935	0.00155	0.79244
cvcrsk3cc_4_14_7	15246	14900	4139	14.16	12619	8842	22.50	2545	2911.63	22.76	-227	0.79031	0.00139	0.79310
cvcrsk3cc_4_14_8	15246	14900	4139	14.16	12619	8842	26.25	2969	2911.63	22.76	-227	0.79032	0.00119	0.79269
cvcrsk3cc_4_14_9	15246	14900	4139	14.16	12619	8842	30.00	3393	2911.63	22.76	-227	0.79075	0.00125	0.79326
cvcrsk3cc_4_14_10	15246	14900	4139	14.16	12619	8842	33.75	3817	2911.63	22.76	-227	0.78950	0.00127	0.79203
cvcrsk3cc_4_14_11	15246	14900	4139	14.16	12619	8842	37.50	4241	2911.63	22.76	-227	0.79226	0.00132	0.79490
cvcrsk3cc_4_14_12	15246	14900	4139	14.16	12619	8842	41.25	4665	2911.63	22.76	-227	0.79141	0.00129	0.79400
cvcrsk3cc_4_14_13	15246	14900	4139	14.16	12619	8842	45.00	5089	2911.63	22.76	-227	0.79226	0.00131	0.79488
cvcrsk3cc_4_14_14	15246	14900	4139	14.16	12619	8842	48.75	5513	2911.63	22.76	-227	0.79139	0.00140	0.79418
cvcrsk3cc_4_14_15	15246	14900	4139	14.16	12619	8842	52.50	5937	2911.63	22.76	-227	0.79157	0.00136	0.79429
cvcrsk3cc_4_14_16	15246	14900	4139	14.16	12619	8842	56.25	6362	2911.63	22.76	-227	0.78883	0.00118	0.79119
cvcrsk3cc_4_14_17	15246	14900	4139	14.16	12619	8842	60.00	6786	2911.63	22.76	-227	0.79251	0.00163	0.79576
cvcrsk3cc_4_15_1	15246	14900	4599	15.52	12619	8842	0.00	0	3235.15	25.07	-227	0.82370	0.00143	0.82655
cvcrsk3cc_4_15_2	15246	14900	4599	15.52	12619	8842	3.75	424	3235.15	25.07	-227	0.82249	0.00121	0.82491
cvcrsk3cc_4_15_3	15246	14900	4599	15.52	12619	8842	7.50	848	3235.15	25.07	-227	0.82289	0.00125	0.82539
cvcrsk3cc_4_15_4	15246	14900	4599	15.52	12619	8842	11.25	1272	3235.15	25.07	-227	0.82409	0.00117	0.82643
cvcrsk3cc_4_15_5	15246	14900	4599	15.52	12619	8842	15.00	1696	3235.15	25.07	-227	0.82541	0.00127	0.82794
cvcrsk3cc_4_15_6	15246	14900	4599	15.52	12619	8842	18.75	2120	3235.15	25.07	-227	0.82424	0.00123	0.82669
cvcrsk3cc_4_15_7	15246	14900	4599	15.52	12619	8842	22.50	2545	3235.15	25.07	-227	0.82476	0.00182	0.82841
cvcrsk3cc_4_15_8	15246	14900	4599	15.52	12619	8842	26.25	2969	3235.15	25.07	-227	0.82419	0.00142	0.82702
cvcrsk3cc_4_15_9	15246	14900	4599	15.52	12619	8842	30.00	3393	3235.15	25.07	-227	0.82530	0.00145	0.82820
cvcrsk3cc_4_15_10	15246	14900	4599	15.52	12619	8842	33.75	3817	3235.15	25.07	-227	0.82433	0.00155	0.82742
cvcrsk3cc_4_15_11	15246	14900	4599	15.52	12619	8842	37.50	4241	3235.15	25.07	-227	0.82379	0.00142	0.82663
cvcrsk3cc_4_15_12	15246	14900	4599	15.52	12619	8842	41.25	4665	3235.15	25.07	-227	0.82450	0.00146	0.82742
cvcrsk3cc_4_15_13	15246	14900	4599	15.52	12619	8842	45.00	5089	3235.15	25.07	-227	0.82666	0.00109	0.82883

Table 6.9.6-17. Results for skull oxide (SO) content in CV calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrsk3cc_4_15_14	15246	14900	4599	15.52	12619	8842	48.75	5513	3235.15	25.07	-227	0.82521	0.00125	0.82772
cvcrsk3cc_4_15_15	15246	14900	4599	15.52	12619	8842	52.50	5937	3235.15	25.07	-227	0.82544	0.00120	0.82784
cvcrsk3cc_4_15_16	15246	14900	4599	15.52	12619	8842	56.25	6362	3235.15	25.07	-227	0.82578	0.00133	0.82844
cvcrsk3cc_4_15_17	15246	14900	4599	15.52	12619	8842	60.00	6786	3235.15	25.07	-227	0.82622	0.00154	0.82930
cvcrsk3cc_6_1_17	15111	12933	0	4.17	10960	4122	921	223432	0	4.17	744	0.44158	0.00098	0.44355
cvcrsk3cc_6_6_17	15111	12933	377	6.56	10960	4122	921	223432	410	9.16	744	0.46812	0.00103	0.47018
cvcrsk3cc_6_7_17	15111	12933	753	8.94	10960	4122	921	223432	821	14.14	744	0.49580	0.00108	0.49797
cvcrsk3cc_6_8_17	15111	12933	1130	11.33	10960	4122	921	223432	1231	19.12	744	0.52824	0.00111	0.53046
cvcrsk3cc_6_9_17	15111	12933	1506	13.71	10960	4122	921	223432	1642	24.11	744	0.55880	0.00129	0.56139
cvcrsk3cc_6_10_17	15111	12933	1883	16.09	10960	4122	921	223432	2052	29.09	744	0.58946	0.00103	0.59153
cvcrsk3cc_6_11_17	15111	12933	2259	18.48	10960	4122	921	223432	2463	34.07	744	0.62334	0.00130	0.62593
cvcrsk3cc_6_12_17	15111	12933	2636	20.86	10960	4122	921	223432	2873	39.06	744	0.65813	0.00115	0.66044
cvcrsk3cc_6_13_17	15111	12933	3012	23.25	10960	4122	921	223432	3284	44.04	744	0.69032	0.00104	0.69240
cvcrsk3cc_6_14_17	15111	12933	3389	25.63	10960	4122	921	223432	3694	49.02	744	0.72104	0.00142	0.72388
cvcrsk3cc_6_15_17	15111	12933	3765	28.02	10960	4122	921	223432	4105	54.01	744	0.75711	0.00110	0.75932

Table 6.9.6-18a. NCT results for skull oxide (SO) content in packaging calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded CV, NCT single package, reflected														
513 g polyethylene, no can spacers														
ncsrsk_1_15	11589	8063	4468	28.09	6828	4765	417	87518	4105	50.58	2596	0.71933	0.00154	0.72241
ncsrsk_2_15	14934	11665	4015	17.79	9879	6858	504	73492	4105	33.41	2252	0.70319	0.00144	0.70606
ncsrsk_3_15	13821	11876	4893	20.62	10058	7028	372	52930	3233	32.62	1060	0.71916	0.00128	0.72172
ncsrsk_4_15	15246	14900	4599	15.52	12619	8842	60	6786	3235	25.07	-227	0.71123	0.00145	0.71413
ncsrsk_5_15	21216	21036	3869	9.49	17815	12455	27	2168	3235	16.27	-360	0.69577	0.00139	0.69855
ncsrsk_6_15	15111	12933	3765	28.02	10960	4122	921	223432	4105	54.01	744	0.63803	0.00171	0.64146
ncsrsk_7_15	13155	11666	3989	32.68	9886	3712	609	164054	4106	61.55	367	0.65018	0.00127	0.65271
ncsrsk_8_15	13650	11689	4068	33.01	9906	3737	261	69834	4106	61.69	1187	0.65349	0.00128	0.65604
ncsrsk_9_15	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.73837	0.00130	0.74096
ncsrsk_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.74201	0.00149	0.74499
ncsrsk_9_1	21300	19865	0	1.10	16816	15673	921	58764	0	1.10	1	0.40142	0.00078	0.40297
ncsrsk_9_6	21300	19865	380	1.73	16816	15673	921	58764	324	2.27	1	0.43142	0.00096	0.43334
ncsrsk_9_7	21300	19865	760	2.36	16816	15673	921	58764	647	3.44	1	0.46578	0.00099	0.46776
ncsrsk_9_8	21300	19865	1140	3.00	16816	15673	921	58764	971	4.61	1	0.49839	0.00107	0.50053
ncsrsk_9_9	21300	19865	1521	3.63	16816	15673	921	58764	1294	5.79	1	0.53148	0.00124	0.53397
ncsrsk_9_10	21300	19865	1901	4.26	16816	15673	921	58764	1618	6.96	1	0.56633	0.00122	0.56877
ncsrsk_9_11	21300	19865	2281	4.90	16816	15673	921	58764	1941	8.13	1	0.60204	0.00118	0.60441
ncsrsk_9_12	21300	19865	2661	5.53	16816	15673	921	58764	2265	9.30	1	0.63600	0.00119	0.63839
ncsrsk_9_13	21300	19865	3041	6.16	16816	15673	921	58764	2588	10.47	1	0.67128	0.00130	0.67389
ncsrsk_9_14	21300	19865	3421	6.80	16816	15673	921	58764	2912	11.64	1	0.70363	0.00130	0.70623
ncsrsk_9_15	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.73837	0.00130	0.74096

Table 6.9.6-18a. NCT results for skull oxide (SO) content in packaging calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrsk_10_1	21300	20786	0	1.05	17596	16399	0	0	0	1.05	1	0.40278	0.00079	0.40436
ncsrsk_10_6	21300	20786	391	1.67	17596	16399	0	0	324	2.19	1	0.43497	0.00093	0.43683
ncsrsk_10_7	21300	20786	781	2.29	17596	16399	0	0	647	3.32	1	0.46764	0.00104	0.46971
ncsrsk_10_8	21300	20786	1172	2.91	17596	16399	0	0	971	4.46	1	0.50067	0.00103	0.50274
ncsrsk_10_9	21300	20786	1562	3.54	17596	16399	0	0	1294	5.60	1	0.53570	0.00129	0.53828
ncsrsk_10_10	21300	20786	1953	4.16	17596	16399	0	0	1618	6.73	1	0.57116	0.00119	0.57355
ncsrsk_10_11	21300	20786	2343	4.78	17596	16399	0	0	1941	7.87	1	0.60642	0.00131	0.60904
ncsrsk_10_12	21300	20786	2734	5.40	17596	16399	0	0	2265	9.00	1	0.63938	0.00118	0.64175
ncsrsk_10_13	21300	20786	3124	6.02	17596	16399	0	0	2588	10.14	1	0.67610	0.00123	0.67856
ncsrsk_10_14	21300	20786	3515	6.64	17596	16399	0	0	2912	11.28	1	0.70857	0.00115	0.71087
ncsrsk_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.74201	0.00149	0.74499
content in flooded containment vessel, NCT array packaging calculation model for CSI=0.0														
513 g polyethylene, no can spacers														
nciask_1_15	11589	8063	4468	28.09	6828	4765	417	87518	4105	50.58	2596	0.73555	0.00130	0.73814
nciask_2_15	14934	11665	4015	17.79	9879	6858	504	73492	4105	33.41	2252	0.72258	0.00122	0.72503
nciask_3_15	13821	11876	4893	20.62	10058	7028	372	52930	3233	32.62	1060	0.73483	0.00120	0.73724
nciask_4_15	15246	14900	4599	15.52	12619	8842	60	6786	3235	25.07	-227	0.72783	0.00122	0.73027
nciask_5_15	21216	21036	3869	9.49	17815	12455	27	2168	3235	16.27	-360	0.71163	0.00123	0.71409
nciask_6_15	15111	12933	3765	28.02	10960	4122	921	223432	4105	54.01	744	0.65333	0.00109	0.65551
nciask_7_15	13155	11666	3989	32.68	9886	3712	609	164054	4106	61.55	367	0.66124	0.00107	0.66339
nciask_8_15	13650	11689	4068	33.01	9906	3737	261	69834	4106	61.69	1187	0.66664	0.00124	0.66912
nciask_9_15	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.75365	0.00127	0.75620
nciask_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.76141	0.00140	0.76422

Table 6.9.6-18a. NCT results for skull oxide (SO) content in packaging calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
nciask_6_1	15111	12933	0	4.17	10960	4122	921	223432	0	4.17	744	0.26223	0.00069	0.26361
nciask_6_6	15111	12933	377	6.56	10960	4122	921	223432	410	9.16	744	0.29333	0.00078	0.29489
nciask_6_7	15111	12933	753	8.94	10960	4122	921	223432	821	14.14	744	0.32968	0.00084	0.33136
nciask_6_8	15111	12933	1130	11.33	10960	4122	921	223432	1231	19.12	744	0.36777	0.00088	0.36953
nciask_6_9	15111	12933	1506	13.71	10960	4122	921	223432	1642	24.11	744	0.40621	0.00127	0.40874
nciask_6_10	15111	12933	1883	16.09	10960	4122	921	223432	2052	29.09	744	0.44807	0.00116	0.45039
nciask_6_11	15111	12933	2259	18.48	10960	4122	921	223432	2463	34.07	744	0.49212	0.00111	0.49435
nciask_6_12	15111	12933	2636	20.86	10960	4122	921	223432	2873	39.06	744	0.53233	0.00122	0.53477
nciask_6_13	15111	12933	3012	23.25	10960	4122	921	223432	3284	44.04	744	0.57192	0.00123	0.57439
nciask_6_14	15111	12933	3389	25.63	10960	4122	921	223432	3694	49.02	744	0.61188	0.00136	0.61460
nciask_6_15	15111	12933	3765	28.02	10960	4122	921	223432	4105	54.01	744	0.65333	0.00109	0.65551
nciask_9_1	21300	19865	0	1.1	16816	15673	921	58764	0	1.10	1	0.41949	0.00093	0.42134
nciask_9_6	21300	19865	380	1.73	16816	15673	921	58764	324	2.27	1	0.45272	0.00092	0.45456
nciask_9_7	21300	19865	760	2.36	16816	15673	921	58764	647	3.44	1	0.48472	0.00116	0.48704
nciask_9_8	21300	19865	1140	3	16816	15673	921	58764	971	4.61	1	0.51805	0.00111	0.52027
nciask_9_9	21300	19865	1521	3.63	16816	15673	921	58764	1294	5.79	1	0.55105	0.00116	0.55336
nciask_9_10	21300	19865	1901	4.26	16816	15673	921	58764	1618	6.96	1	0.58571	0.00105	0.58780
nciask_9_11	21300	19865	2281	4.9	16816	15673	921	58764	1941	8.13	1	0.62158	0.00114	0.62386
nciask_9_12	21300	19865	2661	5.53	16816	15673	921	58764	2265	9.30	1	0.65700	0.00141	0.65983
nciask_9_13	21300	19865	3041	6.16	16816	15673	921	58764	2588	10.47	1	0.68964	0.00125	0.69214
nciask_9_14	21300	19865	3421	6.8	16816	15673	921	58764	2912	11.64	1	0.72169	0.00141	0.72451
nciask_9_15	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.75365	0.00127	0.75620
nciask_10_1	21300	20786	0	1.05	17596	16399	0	0	0	1.05	1	0.42530	0.00082	0.42693
nciask_10_6	21300	20786	391	1.67	17596	16399	0	0	324	2.19	1	0.45517	0.00080	0.45677

Table 6.9.6-18a. NCT results for skull oxide (SO) content in packaging calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
nciask_10_7	21300	20786	781	2.29	17596	16399	0	0	647	3.32	1	0.48754	0.00099	0.48952
nciask_10_8	21300	20786	1172	2.91	17596	16399	0	0	971	4.46	1	0.52247	0.00101	0.52448
nciask_10_9	21300	20786	1562	3.54	17596	16399	0	0	1294	5.60	1	0.55799	0.00107	0.56013
nciask_10_10	21300	20786	1953	4.16	17596	16399	0	0	1618	6.73	1	0.59209	0.00104	0.59416
nciask_10_11	21300	20786	2343	4.78	17596	16399	0	0	1941	7.87	1	0.62721	0.00107	0.62935
nciask_10_12	21300	20786	2734	5.4	17596	16399	0	0	2265	9.00	1	0.65769	0.00115	0.65999
nciask_10_13	21300	20786	3124	6.02	17596	16399	0	0	2588	10.14	1	0.69394	0.00131	0.69655
nciask_10_14	21300	20786	3515	6.64	17596	16399	0	0	2912	11.28	1	0.72808	0.00150	0.73109
nciask_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.76141	0.00140	0.76422

Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded CV, HAC single package, reflected														
513 g polyethylene, no can spacers														
hcsrsk_1_15	11589	8063	4468	28.09	6828	4765	417	87518	4105	50.58	2596	0.72049	0.00145	0.72339
hcsrsk_2_15	14934	11665	4015	17.79	9879	6858	504	73492	4105	33.41	2252	0.70717	0.00140	0.70997
hcsrsk_3_15	13821	11876	4893	20.62	10058	7028	372	52930	3233	32.62	1060	0.72081	0.00136	0.72353
hcsrsk_4_15	15246	14900	4599	15.52	12619	8842	60	6786	3235	25.07	-227	0.71449	0.00128	0.71706
hcsrsk_5_15	21216	21036	3869	9.49	17815	12455	27	2168	3235	16.27	-360	0.69845	0.00134	0.70113
hcsrsk_6_15	15111	12933	3765	28.02	10960	4122	921	223432	4105	54.01	744	0.63787	0.00140	0.64066
hcsrsk_7_15	13155	11666	3989	32.68	9886	3712	609	164054	4106	61.55	367	0.64910	0.00150	0.65210
hcsrsk_8_15	13650	11689	4068	33.01	9906	3737	261	69834	4106	61.69	1187	0.65332	0.00140	0.65613

Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
hcsrsk_9_15	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.73855	0.00121	0.74096
hcsrsk_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.74359	0.00118	0.74595
hcsrsk_9_1	21300	19865	0	1.10	16816	15673	921	58764	0	1.10	1	0.40344	0.00080	0.40505
hcsrsk_9_6	21300	19865	380	1.73	16816	15673	921	58764	324	2.27	1	0.43432	0.00091	0.43614
hcsrsk_9_7	21300	19865	760	2.36	16816	15673	921	58764	647	3.44	1	0.46617	0.00090	0.46796
hcsrsk_9_8	21300	19865	1140	3.00	16816	15673	921	58764	971	4.61	1	0.49951	0.00104	0.50160
hcsrsk_9_9	21300	19865	1521	3.63	16816	15673	921	58764	1294	5.79	1	0.53428	0.00114	0.53656
hcsrsk_9_10	21300	19865	1901	4.26	16816	15673	921	58764	1618	6.96	1	0.57081	0.00102	0.57286
hcsrsk_9_11	21300	19865	2281	4.90	16816	15673	921	58764	1941	8.13	1	0.60569	0.00111	0.60792
hcsrsk_9_12	21300	19865	2661	5.53	16816	15673	921	58764	2265	9.30	1	0.63704	0.00125	0.63955
hcsrsk_9_13	21300	19865	3041	6.16	16816	15673	921	58764	2588	10.47	1	0.67153	0.00139	0.67431
hcsrsk_9_14	21300	19865	3421	6.80	16816	15673	921	58764	2912	11.64	1	0.70545	0.00113	0.70770
hcsrsk_9_15	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.73855	0.00121	0.74096
hcsrsk_10_1	21300	20786	0	1.05	17596	16399	0	0	0	1.05	1	0.40569	0.00088	0.40745
hcsrsk_10_6	21300	20786	391	1.67	17596	16399	0	0	324	2.19	1	0.43659	0.00086	0.43832
hcsrsk_10_7	21300	20786	781	2.29	17596	16399	0	0	647	3.32	1	0.47008	0.00095	0.47198
hcsrsk_10_8	21300	20786	1172	2.91	17596	16399	0	0	971	4.46	1	0.50524	0.00097	0.50717
hcsrsk_10_9	21300	20786	1562	3.54	17596	16399	0	0	1294	5.60	1	0.53928	0.00102	0.54133
hcsrsk_10_10	21300	20786	1953	4.16	17596	16399	0	0	1618	6.73	1	0.57494	0.00115	0.57724
hcsrsk_10_11	21300	20786	2343	4.78	17596	16399	0	0	1941	7.87	1	0.60702	0.00111	0.60924
hcsrsk_10_12	21300	20786	2734	5.40	17596	16399	0	0	2265	9.00	1	0.64205	0.00132	0.64469
hcsrsk_10_13	21300	20786	3124	6.02	17596	16399	0	0	2588	10.14	1	0.67634	0.00138	0.67911
hcsrsk_10_14	21300	20786	3515	6.64	17596	16399	0	0	2912	11.28	1	0.71259	0.00144	0.71547
hcsrsk_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.74359	0.00118	0.74595

Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, HAC array packaging calculation model for CSI=0.0														
513 g polyethylene, no can spacers														
hciask_1_15	11589	8063	4468	28.09	6828	4765	417	87518	4105	50.58	2596	0.73896	0.00132	0.74159
hciask_2_15	14934	11665	4015	17.79	9879	6858	504	73492	4105	33.41	2252	0.72435	0.00127	0.72689
hciask_3_15	13821	11876	4893	20.62	10058	7028	372	52930	3233	32.62	1060	0.73900	0.00130	0.74160
hciask_4_15	15246	14900	4599	15.52	12619	8842	60	6786	3235	25.07	-227	0.73199	0.00123	0.73445
hciask_5_15	21216	21036	3869	9.49	17815	12455	27	2168	3235	16.27	-360	0.71601	0.00117	0.71835
hciask_6_15	15111	12933	3765	28.02	10960	4122	921	223432	4105	54.01	744	0.65587	0.00125	0.65837
hciask_7_15	13155	11666	3989	32.68	9886	3712	609	164054	4106	61.55	367	0.66608	0.00159	0.66925
hciask_8_15	13650	11689	4068	33.01	9906	3737	261	69834	4106	61.69	1187	0.66948	0.00153	0.67255
hciask_9_15	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.75757	0.00116	0.75989
hciask_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.76462	0.00131	0.76725
hciask_6_1	15111	12933	0	4.17	10960	4122	921	223432	0	4.17	744	0.26620	0.00075	0.26769
hciask_6_6	15111	12933	377	6.56	10960	4122	921	223432	411	9.16	744	0.29787	0.00085	0.29957
hciask_6_7	15111	12933	753	8.94	10960	4122	921	223432	821	14.14	744	0.33370	0.00085	0.33539
hciask_6_8	15111	12933	1130	11.33	10960	4122	921	223432	1231	19.12	744	0.37226	0.00098	0.37422
hciask_6_9	15111	12933	1506	13.71	10960	4122	921	223432	1642	24.11	744	0.41300	0.00083	0.41465
hciask_6_10	15111	12933	1883	16.09	10960	4122	921	223432	2052	29.09	744	0.45192	0.00106	0.45403
hciask_6_11	15111	12933	2259	18.48	10960	4122	921	223432	2463	34.07	744	0.49341	0.00113	0.49566
hciask_6_12	15111	12933	2636	20.86	10960	4122	921	223432	2873	39.06	744	0.53469	0.00111	0.53691
hciask_6_13	15111	12933	3012	23.25	10960	4122	921	223432	3284	44.04	744	0.57324	0.00123	0.57571
hciask_6_14	15111	12933	3389	25.63	10960	4122	921	223432	3694	49.02	744	0.61596	0.00125	0.61847
hciask_6_15	15111	12933	3765	28.02	10960	4122	921	223432	4105	54.01	744	0.65587	0.00125	0.65837

Table 6.9.6-18b. HAC results for skull oxide (SO) content in packaging calculation model

case name	SO (g)	U_3O_8 (g)	Sat. H_2O (g)	SO h/x	U (g)	^{235}U (g)	C (g)	mg C/ g ^{235}U	CV H_2O (g)	CV h/x	Unident. (g)	k_{eff}	σ	$k_{eff}+2\sigma$
hciask_9_1	21300	19865	0	1.10	16816	15673	921	58764	0	1.10	1	0.42753	0.00091	0.42935
hciask_9_6	21300	19865	380	1.73	16816	15673	921	58764	324	2.27	1	0.45603	0.00103	0.45808
hciask_9_7	21300	19865	760	2.36	16816	15673	921	58764	647	3.44	1	0.48912	0.00101	0.49114
hciask_9_8	21300	19865	1140	3.00	16816	15673	921	58764	971	4.61	1	0.52104	0.00109	0.52322
hciask_9_9	21300	19865	1521	3.63	16816	15673	921	58764	1294	5.79	1	0.55643	0.00104	0.55851
hciask_9_10	21300	19865	1901	4.26	16816	15673	921	58764	1618	6.96	1	0.59193	0.00105	0.59403
hciask_9_11	21300	19865	2281	4.90	16816	15673	921	58764	1941	8.13	1	0.62726	0.00109	0.62945
hciask_9_12	21300	19865	2661	5.53	16816	15673	921	58764	2265	9.30	1	0.65952	0.00106	0.66163
hciask_9_13	21300	19865	3041	6.16	16816	15673	921	58764	2588	10.47	1	0.69094	0.00127	0.69348
hciask_9_14	21300	19865	3421	6.80	16816	15673	921	58764	2912	11.64	1	0.72863	0.00116	0.73095
hciask_9_15	21300	19865	3801	7.43	16816	15673	921	58764	3235	12.82	1	0.75757	0.00116	0.75989
hciask_10_1	21300	20786	0	1.05	17596	16399	0	0	0	1.05	1	0.43087	0.00111	0.43308
hciask_10_6	21300	20786	391	1.67	17596	16399	0	0	324	2.19	1	0.46066	0.00092	0.46250
hciask_10_7	21300	20786	781	2.29	17596	16399	0	0	647	3.32	1	0.49381	0.00097	0.49574
hciask_10_8	21300	20786	1172	2.91	17596	16399	0	0	971	4.46	1	0.52679	0.00113	0.52906
hciask_10_9	21300	20786	1562	3.54	17596	16399	0	0	1294	5.60	1	0.56200	0.00121	0.56442
hciask_10_10	21300	20786	1953	4.16	17596	16399	0	0	1618	6.73	1	0.59673	0.00118	0.59908
hciask_10_11	21300	20786	2343	4.78	17596	16399	0	0	1941	7.87	1	0.63042	0.00109	0.63260
hciask_10_12	21300	20786	2734	5.40	17596	16399	0	0	2265	9.00	1	0.66502	0.00116	0.66735
hciask_10_13	21300	20786	3124	6.02	17596	16399	0	0	2588	10.14	1	0.69780	0.00108	0.69997
hciask_10_14	21300	20786	3515	6.64	17596	16399	0	0	2912	11.28	1	0.73223	0.00123	0.73470
hciask_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.76462	0.00131	0.76725
nciask_10_14	21300	20786	3515	6.64	17596	16399	0	0	2912	11.28	1	0.72808	0.00150	0.73109
nciask_10_15	21300	20786	3905	7.27	17596	16399	0	0	3235	12.41	1	0.76141	0.00140	0.76422

Table 6.9.6-19a. Results for $UZrH_x$ content in CV calculation model

case name	np	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
TRIGA ($UZrH_x$) fuel content at 19.7 wt % ^{235}U, 500 g CH_2, containment vessel, reflected									
no can spacers (np thickness = 0.0 in.)									
cvcrtriga_1_1	0.0	10,400	921	0	0.00	1.0E-20	0.34219	0.00107	0.34432
cvcrtriga_1_6	0.0	10,400	921	900	25.50	1.0E-01	0.34704	0.00101	0.34905
cvcrtriga_1_7	0.0	10,400	921	1,800	51.00	2.0E-01	0.35869	0.00094	0.36057
cvcrtriga_1_8	0.0	10,400	921	2,700	76.50	3.0E-01	0.37291	0.00103	0.37496
cvcrtriga_1_9	0.0	10,400	921	3,599	102.00	4.0E-01	0.38978	0.00115	0.39209
cvcrtriga_1_10	0.0	10,400	921	4,499	127.50	5.0E-01	0.41521	0.00099	0.41719
cvcrtriga_1_11	0.0	10,400	921	5,399	153.00	6.0E-01	0.43399	0.00108	0.43616
cvcrtriga_1_12	0.0	10,400	921	6,299	178.50	7.0E-01	0.45681	0.00116	0.45914
cvcrtriga_1_13	0.0	10,400	921	7,199	204.00	8.0E-01	0.48121	0.00136	0.48393
cvcrtriga_1_14	0.0	10,400	921	8,098	229.51	9.0E-01	0.50284	0.00114	0.50511
cvcrtriga_1_15	0.0	10,400	921	8,998	255.01	1.0E+00	0.52494	0.00120	0.52735
can spacers (np thickness = 1.4 in.)									
cvcrtriga_2_15	1.4	10,400	921	8,385	237.62	1.0E+00	0.42157	0.00099	0.42354
TRIGA ($UZrH_x$) fuel content at 70.1 wt % ^{235}U, 500 g CH_2, containment vessel, reflected									
no can spacers (np thickness = 0.0 in.)									
cvcrtriga_70_1_1	0.0	6,847	408	0	0.00	1.0E+00	0.29196	0.00097	0.29391
cvcrtriga_70_1_6	0.0	6,847	408	900	57.56	1.0E+00	0.30096	0.00102	0.30300
cvcrtriga_70_1_7	0.0	6,847	408	1,800	115.13	1.0E+00	0.31496	0.00089	0.31674
cvcrtriga_70_1_8	0.0	6,847	408	2,700	172.69	1.0E+00	0.33376	0.00106	0.33588
cvcrtriga_70_1_9	0.0	6,847	408	3,599	230.26	1.0E+00	0.35363	0.00100	0.35564
cvcrtriga_70_1_10	0.0	6,847	408	4,499	287.82	1.0E+00	0.37761	0.00098	0.37956
cvcrtriga_70_1_11	0.0	6,847	408	5,399	345.38	1.0E+00	0.40017	0.00120	0.40257

Table 6.9.6-19a. Results for $UZrH_x$ content in CV calculation model

case name	np	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvcrtriga_70_1_12	0.0	6,847	408	6,299	402.95	1.0E+00	0.42263	0.00109	0.42481
cvcrtriga_70_1_13	0.0	6,847	408	7,199	460.51	1.0E+00	0.44607	0.00120	0.44848
cvcrtriga_70_1_14	0.0	6,847	408	8,098	518.07	1.0E+00	0.46618	0.00104	0.46827
cvcrtriga_70_1_15	0.0	6,847	408	8,998	575.64	1.0E+00	0.48847	0.00130	0.49107
can spacers (np thickness = 1.4 in.)									
cvcrtriga_70_2_15	1.4	6,847	408	8,385	536.39	1.0E+00	0.38372	0.00112	0.38596

Table 6.9.6-19b. Results for $UZrH_x$ content spacing in CV calculation model

case name	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	pitch (cm)	pitch (in.)	k_{eff}	σ	$k_{eff}+2\sigma$
TRIGA ($UZrH_x$) fuel content at 19.7 wt % ^{235}U, triangular pitch spacing from touching sections to sections touching convenience can									
500 g CH_2 in cc, no can spacers (np thickness = 0.0 in.), containment vessel, reflected									
mocfr=1.0									
cvT20ptch_1_15_1	10,400	921	8,998	255.01	2.11201	1.440	0.48176	0.00106	0.48387
cvT20ptch_1_15_2	10,400	921	8,998	255.01	2.25466	1.537	0.49373	0.00119	0.49612
cvT20ptch_1_15_3	10,400	921	8,998	255.01	2.39731	1.635	0.50012	0.00131	0.50274
cvT20ptch_1_15_4	10,400	921	8,998	255.01	2.53996	1.732	0.50823	0.00110	0.51044
cvT20ptch_1_15_5	10,400	921	8,998	255.01	2.68261	1.829	0.51676	0.00126	0.51928
cvT20ptch_1_15_6	10,400	921	8,998	255.01	2.82526	1.927	0.52300	0.00115	0.52530
cvT20ptch_1_15_7	10,400	921	8,998	255.01	2.96791	2.024	0.52511	0.00127	0.52766
cvT20ptch_1_15_8	10,400	921	8,998	255.01	3.11056	2.121	0.52789	0.00116	0.53022
cvT20ptch_1_15_9	10,400	921	8,998	255.01	3.25321	2.218	0.52959	0.00109	0.53177

Table 6.9.6-19b. Results for $UZrH_x$ content spacing in CV calculation model

case name	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	pitch (cm)	pitch (in.)	k_{eff}	σ	$k_{eff}+2\sigma$
cvT20ptch_1_15_10	10,400	921	8,998	255.01	3.39586	2.316	0.52841	0.00115	0.53072
cvT20ptch_1_15_11	10,400	921	8,998	255.01	3.53851	2.413	0.52767	0.00109	0.52985
mocfr=0.9									
cvT20ptch_1_14_1	10,400	921	8,098	229.51	2.11201	1.440	0.46727	0.00112	0.46951
cvT20ptch_1_14_6	10,400	921	8,098	229.51	2.82526	1.927	0.50042	0.00110	0.50263
cvT20ptch_1_14_11	10,400	921	8,098	229.51	3.53851	2.413	0.51015	0.00114	0.51244
mocfr=0.8									
cvT20ptch_1_13_1	10,400	921	7,199	204.00	2.11201	1.440	0.44680	0.00107	0.44894
cvT20ptch_1_13_6	10,400	921	7,199	204.00	2.82526	1.927	0.47920	0.00102	0.48124
cvT20ptch_1_13_11	10,400	921	7,199	204.00	3.53851	2.413	0.49183	0.00115	0.49413
mocfr=0.7									
cvT20ptch_1_12_1	10,400	921	6,299	178.50	2.11201	1.440	0.43179	0.00117	0.43413
cvT20ptch_1_12_6	10,400	921	6,299	178.50	2.82526	1.927	0.45630	0.00123	0.45875
cvT20ptch_1_12_11	10,400	921	6,299	178.50	3.53851	2.413	0.46790	0.00112	0.47014
mocfr=0.6									
cvT20ptch_1_11_1	10,400	921	5,399	153.00	2.11201	1.440	0.41313	0.00109	0.41531
cvT20ptch_1_11_6	10,400	921	5,399	153.00	2.82526	1.927	0.43561	0.00115	0.43792
cvT20ptch_1_11_11	10,400	921	5,399	153.00	3.53851	2.413	0.44764	0.00100	0.44964
mocfr=0.5									
cvT20ptch_1_10_1	10,400	921	4,499	127.50	2.11201	1.440	0.39451	0.00106	0.39664
cvT20ptch_1_10_6	10,400	921	4,499	127.50	2.82526	1.927	0.41120	0.00128	0.41376
cvT20ptch_1_10_11	10,400	921	4,499	127.50	3.53851	2.413	0.42438	0.00120	0.42678

Table 6.9.6-19b. Results for $UZrH_x$ content spacing in CV calculation model

case name	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	pitch (cm)	pitch (in.)	k_{eff}	σ	$k_{eff}+2\sigma$
mocfr=0.4									
cvT20ptch_1_9_1	10,400	921	3,599	102.00	2.11201	1.440	0.38008	0.00097	0.38203
cvT20ptch_1_9_6	10,400	921	3,599	102.00	2.82526	1.927	0.39106	0.00098	0.39303
cvT20ptch_1_9_11	10,400	921	3,599	102.00	3.53851	2.413	0.40267	0.00126	0.40519
mocfr=0.3									
cvT20ptch_1_8_1	10,400	921	2,700	76.50	2.11201	1.440	0.36348	0.00091	0.36531
cvT20ptch_1_8_6	10,400	921	2,700	76.50	2.82526	1.927	0.37106	0.00102	0.37309
cvT20ptch_1_8_11	10,400	921	2,700	76.50	3.53851	2.413	0.38210	0.00098	0.38406
mocfr=0.2									
cvT20ptch_1_7_1	10,400	921	1,800	51.00	2.11201	1.440	0.35255	0.00094	0.35443
cvT20ptch_1_7_6	10,400	921	1,800	51.00	2.82526	1.927	0.35542	0.00089	0.35721
cvT20ptch_1_7_11	10,400	921	1,800	51.00	3.53851	2.413	0.36444	0.00091	0.36627
mocfr=0.1									
cvT20ptch_1_6_1	10,400	921	900	25.50	2.11201	1.440	0.34383	0.00115	0.34612
cvT20ptch_1_6_6	10,400	921	900	25.50	2.82526	1.927	0.34516	0.00093	0.34703
cvT20ptch_1_6_11	10,400	921	900	25.50	3.53851	2.413	0.35189	0.00102	0.35394
mocfr=1.0E-20									
cvT20ptch_1_1_1	10,400	921	0	0.00	2.11201	1.440	0.34314	0.00084	0.34482
cvT20ptch_1_1_6	10,400	921	0	0.00	2.82526	1.927	0.34273	0.00089	0.34452
cvT20ptch_1_1_11	10,400	921	0	0.00	3.53851	2.413	0.34291	0.00087	0.34466

Table 6.9.6-19c. Results for $UZrH_x$ content uranium weight fraction in CV calculation model

case name	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
TRIGA ($UZrH_x$) fuel content at 19.7 wt % ^{235}U, variation of uranium weight fraction in content								
500 g CH_2 in cc, no can spacers (np thickness = 0.0 in.), containment vessel, reflected								
45 wt % U								
cvTE20U45_1_15	10,400	921	8,998	255.01	1.0E+00	0.52494	0.00120	0.52735
cvTE20U45_1_14	10,400	921	8,098	229.51	9.0E-01	0.50284	0.00114	0.50511
cvTE20U45_1_13	10,400	921	7,199	204.00	8.0E-01	0.48121	0.00136	0.48393
cvTE20U45_1_12	10,400	921	6,299	178.50	7.0E-01	0.45681	0.00116	0.45914
cvTE20U45_1_11	10,400	921	5,399	153.00	6.0E-01	0.43399	0.00108	0.43616
cvTE20U45_1_10	10,400	921	4,499	127.50	5.0E-01	0.41521	0.00099	0.41719
cvTE20U45_1_9	10,400	921	3,599	102.00	4.0E-01	0.38978	0.00115	0.39209
cvTE20U45_1_8	10,400	921	2,700	76.50	3.0E-01	0.37291	0.00103	0.37496
cvTE20U45_1_7	10,400	921	1,800	51.00	2.0E-01	0.35869	0.00094	0.36057
cvTE20U45_1_6	10,400	921	900	25.50	1.0E-01	0.34704	0.00101	0.34905
cvTE20U45_1_1	10,400	921	0	0.00	1.0E-20	0.34219	0.00107	0.34432
30 wt % U								
cvTE20U30_1_15	8,250	489	8,998	480.29	1.0E+00	0.47671	0.00135	0.47942
cvTE20U30_1_14	8,250	489	8,098	432.26	9.0E-01	0.45562	0.00105	0.45772
cvTE20U30_1_13	8,250	489	7,199	384.23	8.0E-01	0.43218	0.00113	0.43445
cvTE20U30_1_12	8,250	489	6,299	336.20	7.0E-01	0.41165	0.00096	0.41356
cvTE20U30_1_11	8,250	489	5,399	288.17	6.0E-01	0.38706	0.00099	0.38903
cvTE20U30_1_10	8,250	489	4,499	240.14	5.0E-01	0.36759	0.00092	0.36944
cvTE20U30_1_9	8,250	489	3,599	192.11	4.0E-01	0.34766	0.00094	0.34954
cvTE20U30_1_8	8,250	489	2,700	144.09	3.0E-01	0.33073	0.00086	0.33245
cvTE20U30_1_7	8,250	489	1,800	96.06	2.0E-01	0.31555	0.00082	0.31720

Table 6.9.6-19c. Results for $UZrH_x$ content uranium weight fraction in CV calculation model

case name	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvTE20U30_1_6	8,250	489	900	48.03	1.0E-01	0.31018	0.00092	0.31202
cvTE20U30_1_01	8,250	489	0	0.00	1.0E-20	0.30488	0.00083	0.30654
20 wt % U								
cvTE20U20_1_15	7,545	297	8,998	790.78	1.0E+00	0.46046	0.00121	0.46289
cvTE20U20_1_14	7,545	297	8,098	711.70	9.0E-01	0.43928	0.00114	0.44156
cvTE20U20_1_13	7,545	297	7,199	632.62	8.0E-01	0.41486	0.00108	0.41702
cvTE20U20_1_12	7,545	297	6,299	553.54	7.0E-01	0.39584	0.00113	0.39809
cvTE20U20_1_11	7,545	297	5,399	474.47	6.0E-01	0.37399	0.00106	0.37612
cvTE20U20_1_10	7,545	297	4,499	395.39	5.0E-01	0.35345	0.00100	0.35545
cvTE20U20_1_9	7,545	297	3,599	316.31	4.0E-01	0.33290	0.00098	0.33486
cvTE20U20_1_8	7,545	297	2,700	237.23	3.0E-01	0.31513	0.00103	0.31719
cvTE20U20_1_7	7,545	297	1,800	158.16	2.0E-01	0.30148	0.00101	0.30350
cvTE20U20_1_6	7,545	297	900	79.08	1.0E-01	0.29354	0.00089	0.29532
cvTE20U20_1_1	7,545	297	0	0.00	1.0E-20	0.29227	0.00083	0.29392
12 wt % U								
cvTE20U12_1_15	7,125	168	8,998	1397.90	1.0E+00	0.44948	0.00108	0.45163
cvTE20U12_1_14	7,125	168	8,098	1258.10	9.0E-01	0.43067	0.00106	0.43280
cvTE20U12_1_13	7,125	168	7,199	1118.30	8.0E-01	0.40699	0.00098	0.40894
cvTE20U12_1_12	7,125	168	6,299	978.59	7.0E-01	0.38549	0.00098	0.38744
cvTE20U12_1_11	7,125	168	5,399	838.79	6.0E-01	0.36416	0.00089	0.36595
cvTE20U12_1_10	7,125	168	4,499	698.99	5.0E-01	0.34375	0.00106	0.34586
cvTE20U12_1_9	7,125	168	3,599	559.19	4.0E-01	0.32505	0.00108	0.32721
cvTE20U12_1_8	7,125	168	2,700	419.40	3.0E-01	0.30767	0.00087	0.30940
cvTE20U12_1_7	7,125	168	1,800	279.60	2.0E-01	0.29545	0.00076	0.29698

Table 6.9.6-19c. Results for $UZrH_x$ content uranium weight fraction in CV calculation model

case name	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
cvTE20U12_1_6	7,125	168	900	139.80	1.0E-01	0.28602	0.00086	0.28774
cvTE20U12_1_1	7,125	168	0	0.00	1.0E-20	0.28442	0.00079	0.28601
8.5 wt % U								
cvTE20U8p5_1_15	6,953	117	8,998	2007.30	1.0E+00	0.44412	0.00115	0.44643
cvTE20U8p5_1_14	6,953	117	8,098	1806.60	9.0E-01	0.42328	0.00110	0.42549
cvTE20U8p5_1_13	6,953	117	7,199	1605.80	8.0E-01	0.40452	0.00100	0.40652
cvTE20U8p5_1_12	6,953	117	6,299	1405.10	7.0E-01	0.38253	0.00122	0.38496
cvTE20U8p5_1_11	6,953	117	5,399	1204.40	6.0E-01	0.35988	0.00111	0.36209
cvTE20U8p5_1_10	6,953	117	4,499	1003.60	5.0E-01	0.33974	0.00099	0.34173
cvTE20U8p5_1_9	6,953	117	3,599	802.94	4.0E-01	0.31938	0.00090	0.32118
cvTE20U8p5_1_8	6,953	117	2,700	602.20	3.0E-01	0.30560	0.00084	0.30729
cvTE20U8p5_1_7	6,953	117	1,800	401.47	2.0E-01	0.29237	0.00085	0.29407
cvTE20U8p5_1_6	6,953	117	900	200.73	1.0E-01	0.28287	0.00104	0.28495
cvTE20U8p5_1_1	6,953	117	0	0.00	1.0E-20	0.28060	0.00080	0.28219
500 g CH_2 in cc, can spacers (np thickness = 1.4 in.), containment vessel, reflected								
cvTE20U45_02_15	10,400	921	8,385	237.62	1.0E+00	0.42157	0.00099	0.42354
cvTE20U30_02_15	8,250	489	8,385	447.54	1.0E+00	0.37862	0.00092	0.38046
cvTE20U20_02_15	7,545	297	8,385	736.86	1.0E+00	0.36052	0.00089	0.36229
cvTE20U12_02_15	7,125	168	8,385	1302.60	1.0E+00	0.35193	0.00100	0.35392
cvTE20U8p5_02_15	6,953	117	8,385	1870.40	1.0E+00	0.34847	0.00108	0.35064

Table 6.9.6-20a. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, single package reflected													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
						mocfr							
ncsrtriga_1_1_15	0.0	10,400	921	0	0.00	1.0E-20	0.19699	0.00072	0.19844	hcsrtriga_1_1_15	0.19912	0.00071	0.20055
ncsrtriga_1_6_15	0.0	10,400	921	900	25.50	1.0E-01	0.22100	0.00077	0.22253	hcsrtriga_1_6_15	0.22405	0.00077	0.22559
ncsrtriga_1_7_15	0.0	10,400	921	1,800	51.00	2.0E-02	0.25006	0.00081	0.25167	hcsrtriga_1_7_15	0.25119	0.00075	0.25268
ncsrtriga_1_8_15	0.0	10,400	921	2,700	76.50	3.0E-01	0.27901	0.00083	0.28067	hcsrtriga_1_8_15	0.28071	0.00086	0.28243
ncsrtriga_1_9_15	0.0	10,400	921	3,599	102.00	4.0E-01	0.31206	0.00097	0.31399	hcsrtriga_1_9_15	0.31333	0.00093	0.31520
ncsrtriga_1_10_15	0.0	10,400	921	4,499	127.50	5.0E-01	0.34408	0.00096	0.34601	hcsrtriga_1_10_15	0.34576	0.00103	0.34781
ncsrtriga_1_11_15	0.0	10,400	921	5,399	153.00	6.0E-01	0.37488	0.00093	0.37674	hcsrtriga_1_11_15	0.37800	0.00111	0.38023
ncsrtriga_1_12_15	0.0	10,400	921	6,299	178.50	7.0E-01	0.40792	0.00107	0.41006	hcsrtriga_1_12_15	0.40683	0.00105	0.40893
ncsrtriga_1_13_15	0.0	10,400	921	7,199	204.00	8.0E-01	0.43782	0.00116	0.44013	hcsrtriga_1_13_15	0.43867	0.00123	0.44113
ncsrtriga_1_14_15	0.0	10,400	921	8,098	229.51	9.0E-01	0.46460	0.00106	0.46672	hcsrtriga_1_14_15	0.46627	0.00120	0.46867
ncsrtriga_1_15_15	0.0	10,400	921	8,998	255.01	1.0E+00	0.49295	0.00104	0.49503	hcsrtriga_1_15_15	0.49247	0.00103	0.49454
						moifr							
ncsrtriga_1_15_1	0.0	10,400	921	8,998	255.01	1.0E-20	0.44499	0.00100	0.44700	hcsrtriga_1_15_1	0.44706	0.00104	0.44914
ncsrtriga_1_15_2	0.0	10,400	921	8,998	255.01	1.0E-05	0.44282	0.00109	0.44500	hcsrtriga_1_15_2	0.44626	0.00100	0.44825
ncsrtriga_1_15_3	0.0	10,400	921	8,998	255.01	1.0E-04	0.44454	0.00120	0.44693	hcsrtriga_1_15_3	0.44469	0.00125	0.44719
ncsrtriga_1_15_4	0.0	10,400	921	8,998	255.01	1.0E-03	0.44553	0.00111	0.44774	hcsrtriga_1_15_4	0.44692	0.00113	0.44918
ncsrtriga_1_15_5	0.0	10,400	921	8,998	255.01	1.0E-02	0.44389	0.00121	0.44631	hcsrtriga_1_15_5	0.44565	0.00104	0.44773
ncsrtriga_1_15_6	0.0	10,400	921	8,998	255.01	1.0E-01	0.44801	0.00104	0.45008	hcsrtriga_1_15_6	0.45115	0.00120	0.45356
ncsrtriga_1_15_8	0.0	10,400	921	8,998	255.01	3.0E-01	0.45921	0.00143	0.46207	hcsrtriga_1_15_8	0.46090	0.00112	0.46314
ncsrtriga_1_15_15	0.0	10,400	921	8,998	255.01	1.0E+00	0.49295	0.00104	0.49503	hcsrtriga_1_15_15	0.49247	0.00103	0.49454

Table 6.9.6-20a. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
with can spacers (np thickness = 1.4 in.)													
						mocfr							
ncsrtriga_2_1_15	1.4	10,400	921	0	0.00	1.0E-20	0.16519	0.00060	0.16640	hcsrtriga_2_1_15	0.16449	0.00062	0.16573
ncsrtriga_2_6_15	1.4	10,400	921	839	23.76	1.0E-01	0.18078	0.00063	0.18204	hcsrtriga_2_6_15	0.18163	0.00061	0.18284
ncsrtriga_2_7_15	1.4	10,400	921	1,677	47.52	2.0E-01	0.20001	0.00066	0.20133	hcsrtriga_2_7_15	0.20112	0.00072	0.20256
ncsrtriga_2_8_15	1.4	10,400	921	2,515	71.29	3.0E-01	0.22235	0.00085	0.22405	hcsrtriga_2_8_15	0.22446	0.00079	0.22603
ncsrtriga_2_9_15	1.4	10,400	921	3,354	95.05	4.0E-01	0.24785	0.00076	0.24936	hcsrtriga_2_9_15	0.24932	0.00079	0.25090
ncsrtriga_2_10_15	1.4	10,400	921	4,192	118.81	5.0E-01	0.27336	0.00091	0.27517	hcsrtriga_2_10_15	0.27427	0.00084	0.27595
ncsrtriga_2_11_15	1.4	10,400	921	5,031	142.57	6.0E-01	0.29864	0.00105	0.30075	hcsrtriga_2_11_15	0.30007	0.00090	0.30188
ncsrtriga_2_12_15	1.4	10,400	921	5,869	166.33	7.0E-01	0.32492	0.00094	0.32680	hcsrtriga_2_12_15	0.32594	0.00113	0.32820
ncsrtriga_2_13_15	1.4	10,400	921	6,708	190.09	8.0E-01	0.35137	0.00101	0.35339	hcsrtriga_2_13_15	0.35174	0.00101	0.35375
ncsrtriga_2_14_15	1.4	10,400	921	7,546	213.86	9.0E-01	0.37602	0.00105	0.37812	hcsrtriga_2_14_15	0.37666	0.00093	0.37852
ncsrtriga_2_15_15	1.4	10,400	921	8,385	237.62	1.0E+00	0.40040	0.00106	0.40252	hcsrtriga_2_15_15	0.40020	0.00112	0.40244
						moifr							
ncsrtriga_2_15_1	1.4	10,400	921	8,385	237.62	1.0E-20	0.36082	0.00102	0.36286	hcsrtriga_2_15_1	0.36370	0.00103	0.36576
ncsrtriga_2_15_2	1.4	10,400	921	8,385	237.62	1.0E-05	0.36163	0.00105	0.36373	hcsrtriga_2_15_2	0.36457	0.00097	0.36651
ncsrtriga_2_15_3	1.4	10,400	921	8,385	237.62	1.0E-04	0.36349	0.00115	0.36579	hcsrtriga_2_15_3	0.36369	0.00107	0.36584
ncsrtriga_2_15_4	1.4	10,400	921	8,385	237.62	1.0E-03	0.36368	0.00093	0.36554	hcsrtriga_2_15_4	0.36290	0.00107	0.36503
ncsrtriga_2_15_5	1.4	10,400	921	8,385	237.62	1.0E-02	0.36298	0.00111	0.36520	hcsrtriga_2_15_5	0.36275	0.00112	0.36498
ncsrtriga_2_15_6	1.4	10,400	921	8,385	237.62	1.0E-01	0.36587	0.00090	0.36766	hcsrtriga_2_15_6	0.37015	0.00095	0.37205
ncsrtriga_2_15_8	1.4	10,400	921	8,385	237.62	3.0E-01	0.37454	0.00104	0.37662	hcsrtriga_2_15_8	0.37482	0.00099	0.37680
ncsrtriga_2_15_15	1.4	10,400	921	8,385	237.62	1.0E+00	0.40040	0.00106	0.40252	hcsrtriga_2_15_15	0.40020	0.00112	0.40244

Table 6.9.6-20a. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, array packaging model for CSI=0.0													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
						moifr							
nciatriga_1_1_3	0.0	10,400	921	0	0.00	1.0E-04	0.21653	0.00055	0.21763	hciatriga_1_1_3	0.21640	0.00062	0.21763
nciatriga_1_6_3	0.0	10,400	921	900	25.50	1.0E-04	0.24325	0.00064	0.24453	hciatriga_1_6_3	0.24355	0.00069	0.24493
nciatriga_1_7_3	0.0	10,400	921	1,800	51.00	1.0E-04	0.27402	0.00079	0.27561	hciatriga_1_7_3	0.27398	0.00073	0.27544
nciatriga_1_8_3	0.0	10,400	921	2,700	76.50	1.0E-04	0.30790	0.00105	0.30999	hciatriga_1_8_3	0.30795	0.00081	0.30958
nciatriga_1_9_3	0.0	10,400	921	3,599	102.00	1.0E-04	0.34171	0.00109	0.34390	hciatriga_1_9_3	0.34285	0.00108	0.34500
nciatriga_1_10_3	0.0	10,400	921	4,499	127.50	1.0E-04	0.37614	0.00108	0.37830	hciatriga_1_10_3	0.37487	0.00101	0.37689
nciatriga_1_11_3	0.0	10,400	921	5,399	153.00	1.0E-04	0.40944	0.00101	0.41146	hciatriga_1_11_3	0.40922	0.00099	0.41120
nciatriga_1_12_3	0.0	10,400	921	6,299	178.50	1.0E-04	0.44034	0.00116	0.44267	hciatriga_1_12_3	0.44217	0.00104	0.44426
nciatriga_1_13_3	0.0	10,400	921	7,199	204.00	1.0E-04	0.46949	0.00102	0.47153	hciatriga_1_13_3	0.46841	0.00104	0.47049
nciatriga_1_14_3	0.0	10,400	921	8,098	229.51	1.0E-04	0.49678	0.00102	0.49881	hciatriga_1_14_3	0.49952	0.00113	0.50179
nciatriga_1_15_3	0.0	10,400	921	8,998	255.01	1.0E-04	0.52325	0.00109	0.52543	hciatriga_1_15_3	0.52373	0.00117	0.52606
with can spacers (np thickness = 1.4 in.)													
nciatriga_2_1_3	1.4	10,400	921	0	0.00	1.0E-04	0.19663	0.00056	0.19775	hciatriga_2_1_3	0.19533	0.00058	0.19648
nciatriga_2_6_3	1.4	10,400	921	839	23.76	1.0E-04	0.21458	0.00063	0.21583	hciatriga_2_6_3	0.21404	0.00062	0.21528
nciatriga_2_7_3	1.4	10,400	921	1,677	47.52	1.0E-04	0.23878	0.00069	0.24017	hciatriga_2_7_3	0.23939	0.00065	0.24068
nciatriga_2_8_3	1.4	10,400	921	2,515	71.29	1.0E-04	0.26268	0.00095	0.26458	hciatriga_2_8_3	0.26265	0.00073	0.26410
nciatriga_2_9_3	1.4	10,400	921	3,354	95.05	1.0E-04	0.28930	0.00075	0.29081	hciatriga_2_9_3	0.29016	0.00077	0.29169
nciatriga_2_10_3	1.4	10,400	921	4,192	118.81	1.0E-04	0.31695	0.00092	0.31879	hciatriga_2_10_3	0.31775	0.00088	0.31951
nciatriga_2_11_3	1.4	10,400	921	5,031	142.57	1.0E-04	0.34183	0.00090	0.34364	hciatriga_2_11_3	0.34164	0.00096	0.34355
nciatriga_2_12_3	1.4	10,400	921	5,869	166.33	1.0E-04	0.36766	0.00092	0.36949	hciatriga_2_12_3	0.36733	0.00102	0.36937
nciatriga_2_13_3	1.4	10,400	921	6,708	190.09	1.0E-04	0.39176	0.00122	0.39420	hciatriga_2_13_3	0.39342	0.00103	0.39547

Table 6.9.6-20a. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciatriga_2_14_3	1.4	10,400	921	7,546	213.86	1.0E-04	0.41783	0.00101	0.41986	hciatriga_2_14_3	0.41760	0.00108	0.41976
nciatriga_2_15_3	1.4	10,400	921	8,385	237.62	1.0E-04	0.43993	0.00109	0.44211	hciatriga_2_15_3	0.44034	0.00119	0.44271

Table 6.9.6-20b. Results for $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
content in flooded containment vessel, single package reflected													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
						moifr							
ncsrtriga70_1_1_15	0.0	6,847	408	0	0.00	1.0E+00	0.15814	0.00073	0.15960	hcsrtriga70_1_1_15	0.15823	0.00062	0.15947
ncsrtriga70_1_6_15	0.0	6,847	408	900	57.56	1.0E+00	0.18268	0.00068	0.18403	hcsrtriga70_1_6_15	0.18526	0.00075	0.18676
ncsrtriga70_1_7_15	0.0	6,847	408	1,800	115.13	1.0E+00	0.21248	0.00074	0.21396	hcsrtriga70_1_7_15	0.21376	0.00082	0.21540
ncsrtriga70_1_8_15	0.0	6,847	408	2,700	172.69	1.0E+00	0.24596	0.00086	0.24769	hcsrtriga70_1_8_15	0.24666	0.00081	0.24829
ncsrtriga70_1_9_15	0.0	6,847	408	3,599	230.26	1.0E+00	0.27756	0.00103	0.27963	hcsrtriga70_1_9_15	0.27837	0.00085	0.28007
ncsrtriga70_1_10_15	0.0	6,847	408	4,499	287.82	1.0E+00	0.30903	0.00102	0.31107	hcsrtriga70_1_10_15	0.31172	0.00101	0.31374
ncsrtriga70_1_11_15	0.0	6,847	408	5,399	345.38	1.0E+00	0.34331	0.00121	0.34573	hcsrtriga70_1_11_15	0.34406	0.00110	0.34626
ncsrtriga70_1_12_15	0.0	6,847	408	6,299	402.95	1.0E+00	0.37320	0.00129	0.37578	hcsrtriga70_1_12_15	0.37419	0.00109	0.37637
ncsrtriga70_1_13_15	0.0	6,847	408	7,199	460.51	1.0E+00	0.40369	0.00106	0.40581	hcsrtriga70_1_13_15	0.40592	0.00110	0.40811
ncsrtriga70_1_14_15	0.0	6,847	408	8,098	518.07	1.0E+00	0.43096	0.00129	0.43353	hcsrtriga70_1_14_15	0.42993	0.00109	0.43212
ncsrtriga70_1_15_15	0.0	6,847	408	8,998	575.64	1.0E+00	0.45846	0.00117	0.46080	hcsrtriga70_1_15_15	0.45656	0.00108	0.45872

Table 6.9.6-20b. Results for $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
						moifr							
ncsrtriga70_1_15_1	0.0	6,847	408	8,998	575.64	1.0E-20	0.40894	0.00119	0.41131	hcsrtriga70_1_15_1_	0.41076	0.00122	0.41320
ncsrtriga70_1_15_2	0.0	6,847	408	8,998	575.64	1.0E-05	0.40806	0.00115	0.41036	hcsrtriga70_1_15_2	0.41073	0.00130	0.41332
ncsrtriga70_1_15_3	0.0	6,847	408	8,998	575.64	1.0E-04	0.40992	0.00118	0.41228	hcsrtriga70_1_15_3	0.41080	0.00120	0.41319
ncsrtriga70_1_15_4	0.0	6,847	408	8,998	575.64	1.0E-03	0.41084	0.00110	0.41304	hcsrtriga70_1_15_4	0.41181	0.00115	0.41412
ncsrtriga70_1_15_5	0.0	6,847	408	8,998	575.64	1.0E-02	0.41069	0.00116	0.41300	hcsrtriga70_1_15_5	0.41159	0.00124	0.41407
ncsrtriga70_1_15_6	0.0	6,847	408	8,998	575.64	1.0E-01	0.41431	0.00107	0.41644	hcsrtriga70_1_15_6	0.41621	0.00123	0.41868
ncsrtriga70_1_15_8	0.0	6,847	408	8,998	575.64	3.0E-01	0.42523	0.00129	0.42780	hcsrtriga70_1_15_8	0.42893	0.00120	0.43133
ncsrtriga70_1_15_15	0.0	6,847	408	8,998	575.64	1.0E+00	0.45846	0.00117	0.46080	hcsrtriga70_1_15_15	0.45656	0.00108	0.45872
with can spacers (np thickness = 1.4 in.)													
						moifr							
ncsrtriga70_2_1_15	1.4	6,847	408	0	0.00	1.0E+00	0.12174	0.00059	0.12291	hcsrtriga70_2_1_15	0.12413	0.00057	0.12528
ncsrtriga70_2_6_15	1.4	6,847	408	839	53.64	1.0E+00	0.14017	0.00063	0.14143	hcsrtriga70_2_6_15	0.14097	0.00061	0.14220
ncsrtriga70_2_7_15	1.4	6,847	408	1,677	107.28	1.0E+00	0.16109	0.00066	0.16241	hcsrtriga70_2_7_15	0.16260	0.00068	0.16396
ncsrtriga70_2_8_15	1.4	6,847	408	2,515	160.92	1.0E+00	0.18174	0.00080	0.18335	hcsrtriga70_2_8_15	0.18552	0.00067	0.18686
ncsrtriga70_2_9_15	1.4	6,847	408	3,354	214.55	1.0E+00	0.20707	0.00076	0.20859	hcsrtriga70_2_9_15	0.20911	0.00077	0.21064
ncsrtriga70_2_10_15	1.4	6,847	408	4,192	268.19	1.0E+00	0.23324	0.00089	0.23503	hcsrtriga70_2_10_15	0.23447	0.00074	0.23595
ncsrtriga70_2_11_15	1.4	6,847	408	5,031	321.83	1.0E+00	0.26093	0.00080	0.26254	hcsrtriga70_2_11_15	0.26039	0.00085	0.26209
ncsrtriga70_2_12_15	1.4	6,847	408	5,869	375.47	1.0E+00	0.28710	0.00084	0.28878	hcsrtriga70_2_12_15	0.28784	0.00093	0.28970
ncsrtriga70_2_13_15	1.4	6,847	408	6,708	429.11	1.0E+00	0.30929	0.00098	0.31124	hcsrtriga70_2_13_15	0.31105	0.00093	0.31291
ncsrtriga70_2_14_15	1.4	6,847	408	7,546	482.75	1.0E+00	0.33473	0.00114	0.33702	hcsrtriga70_2_14_15	0.33634	0.00094	0.33822
ncsrtriga70_2_15_15	1.4	6,847	408	8,385	536.39	1.0E+00	0.35776	0.00116	0.36008	hcsrtriga70_2_15_15	0.35922	0.00110	0.36142
						moifr							
ncsrtriga70_2_15_1	1.4	6,847	408	8,385	536.39	1.0E-20	0.32321	0.00094	0.32508	hcsrtriga70_2_15_1	0.32561	0.00106	0.32774
ncsrtriga70_2_15_2	1.4	6,847	408	8,385	536.39	1.0E-05	0.32283	0.00092	0.32467	hcsrtriga70_2_15_2	0.32441	0.00099	0.32639

Table 6.9.6-20b. Results for $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrtriga70_2_15_3	1.4	6,847	408	8,385	536.39	1.0E-04	0.32432	0.00088	0.32608	hcsrtriga70_2_15_3	0.32423	0.00102	0.32628
ncsrtriga70_2_15_4	1.4	6,847	408	8,385	536.39	1.0E-03	0.32279	0.00104	0.32488	hcsrtriga70_2_15_4	0.32600	0.00111	0.32822
ncsrtriga70_2_15_5	1.4	6,847	408	8,385	536.39	1.0E-02	0.32448	0.00105	0.32658	hcsrtriga70_2_15_5	0.32622	0.00093	0.32808
ncsrtriga70_2_15_6	1.4	6,847	408	8,385	536.39	1.0E-01	0.32871	0.00097	0.33065	hcsrtriga70_2_15_6	0.32929	0.00110	0.33150
ncsrtriga70_2_15_8	1.4	6,847	408	8,385	536.39	3.0E-01	0.33627	0.00091	0.33809	hcsrtriga70_2_15_8	0.33709	0.00106	0.33920
ncsrtriga70_2_15_15	1.4	6,847	408	8,385	536.39	1.0E+00	0.35776	0.00116	0.36008	hcsrtriga70_2_15_15	0.35922	0.00110	0.36142
content in flooded containment vessel, array packaging model for CSI=0.0													
NCT										**HAC**			
no can spacers (np thickness = 0.0 in.)													
						moifr							
nciatriga70_1_1_3	0.0	6,847	408	0	0.00	1.0E-04	0.16525	0.00063	0.16651	hciatriga70_1_1_3	0.16514	0.00067	0.16648
nciatriga70_1_6_3	0.0	6,847	408	900	57.56	1.0E-04	0.19360	0.00070	0.19500	hciatriga70_1_6_3	0.19280	0.00066	0.19411
nciatriga70_1_7_3	0.0	6,847	408	1,800	115.13	1.0E-04	0.22946	0.00076	0.23099	hciatriga70_1_7_3	0.23027	0.00076	0.23179
nciatriga70_1_8_3	0.0	6,847	408	2,700	172.69	1.0E-04	0.26461	0.00087	0.26635	hciatriga70_1_8_3	0.26463	0.00074	0.26612
nciatriga70_1_9_3	0.0	6,847	408	3,599	230.26	1.0E-04	0.30186	0.00095	0.30375	hciatriga70_1_9_3	0.30020	0.00084	0.30187
nciatriga70_1_10_3	0.0	6,847	408	4,499	287.82	1.0E-04	0.33608	0.00095	0.33798	hciatriga70_1_10_3	0.33776	0.00089	0.33954
nciatriga70_1_11_3	0.0	6,847	408	5,399	345.38	1.0E-04	0.37069	0.00105	0.37279	hciatriga70_1_11_3	0.37191	0.00104	0.37400
nciatriga70_1_12_3	0.0	6,847	408	6,299	402.95	1.0E-04	0.40431	0.00110	0.40651	hciatriga70_1_12_3	0.40368	0.00099	0.40567
nciatriga70_1_13_3	0.0	6,847	408	7,199	460.51	1.0E-04	0.43185	0.00143	0.43472	hciatriga70_1_13_3	0.43386	0.00141	0.43668
nciatriga70_1_14_3	0.0	6,847	408	8,098	518.07	1.0E-04	0.46029	0.00122	0.46272	hciatriga70_1_14_3	0.46036	0.00120	0.46277
nciatriga70_1_15_3	0.0	6,847	408	8,998	575.64	1.0E-04	0.48628	0.00123	0.48875	hciatriga70_1_15_3	0.48653	0.00107	0.48868
with can spacers (np thickness = 1.4 in.)													
nciatriga70_2_1_3	1.4	6,847	408	0	0.00	1.0E-04	0.14342	0.00054	0.14450	hciatriga70_2_1_3	0.14299	0.00055	0.14410
nciatriga70_2_6_3	1.4	6,847	408	839	53.64	1.0E-04	0.16333	0.00057	0.16446	hciatriga70_2_6_3	0.16444	0.00071	0.16586
nciatriga70_2_7_3	1.4	6,847	408	1,677	107.28	1.0E-04	0.18886	0.00069	0.19024	hciatriga70_2_7_3	0.18870	0.00075	0.19020

Table 6.9.6-20b. Results for $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
nciatriga70_2_8_3	1.4	6,847	408	2,515	160.92	1.0E-04	0.21548	0.00077	0.21703	hciatriga70_2_8_3	0.21709	0.00079	0.21867
nciatriga70_2_9_3	1.4	6,847	408	3,354	214.55	1.0E-04	0.24403	0.00092	0.24587	hciatriga70_2_9_3	0.24443	0.00082	0.24606
nciatriga70_2_10_3	1.4	6,847	408	4,192	268.19	1.0E-04	0.27230	0.00090	0.27410	hciatriga70_2_10_3	0.27167	0.00077	0.27321
nciatriga70_2_11_3	1.4	6,847	408	5,031	321.83	1.0E-04	0.29818	0.00092	0.30003	hciatriga70_2_11_3	0.29902	0.00096	0.30093
nciatriga70_2_12_3	1.4	6,847	408	5,869	375.47	1.0E-04	0.32583	0.00081	0.32745	hciatriga70_2_12_3	0.32607	0.00087	0.32781
nciatriga70_2_13_3	1.4	6,847	408	6,708	429.11	1.0E-04	0.35008	0.00102	0.35212	hciatriga70_2_13_3	0.34964	0.00088	0.35140
nciatriga70_2_14_3	1.4	6,847	408	7,546	482.75	1.0E-04	0.37201	0.00116	0.37434	hciatriga70_2_14_3	0.37167	0.00099	0.37364
nciatriga70_2_15_3	1.4	6,847	408	8,385	536.39	1.0E-04	0.39529	0.00120	0.39769	hciatriga70_2_15_3	0.39403	0.00109	0.39622

Table 6.9.6-20c. Results for 1.31 in. smaller diameter $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$
1.31 in. diameter content in flooded containment vessel, single package reflected									
NCT									
no can spacers (np thickness = 0.0 in.)									
						mocfr			
ncsrT70_131_1_1_15	0.0	5,667	338	0	0.00	1.0E+00	0.12864	0.00055	0.12974
ncsrT70_131_1_6_15	0.0	5,667	338	920	71.15	1.0E+00	0.15144	0.00066	0.15276
ncsrT70_131_1_7_15	0.0	5,667	338	1,841	142.31	1.0E+00	0.18245	0.00065	0.18375
ncsrT70_131_1_8_15	0.0	5,667	338	2,762	213.46	1.0E+00	0.21360	0.00085	0.21530
ncsrT70_131_1_9_15	0.0	5,667	338	3,682	284.61	1.0E+00	0.24688	0.00096	0.24880
ncsrT70_131_1_10_15	0.0	5,667	338	4,602	355.77	1.0E+00	0.28138	0.00101	0.28340
ncsrT70_131_1_11_15	0.0	5,667	338	5,523	426.92	1.0E+00	0.31377	0.00098	0.31574

Table 6.9.6-20c. Results for 1.31 in. smaller diameter $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrT70_131_1_12_15	0.0	5,667	338	6,443	498.07	1.0E+00	0.34582	0.00107	0.34797
ncsrT70_131_1_13_15	0.0	5,667	338	7,364	569.23	1.0E+00	0.37661	0.00103	0.37867
ncsrT70_131_1_14_15	0.0	5,667	338	8,284	640.38	1.0E+00	0.40376	0.00110	0.40597
ncsrT70_131_1_15_15	0.0	5,667	338	9,205	711.53	1.0E+00	0.43000	0.00103	0.43206
						moifr			
ncsrT70_131_1_15_1	0.0	5,667	338	9,205	711.53	1.0E-20	0.38521	0.00136	0.38793
ncsrT70_131_1_15_2	0.0	5,667	338	9,205	711.53	1.0E-05	0.38339	0.00098	0.38536
ncsrT70_131_1_15_3	0.0	5,667	338	9,205	711.53	1.0E-04	0.38633	0.00100	0.38834
ncsrT70_131_1_15_4	0.0	5,667	338	9,205	711.53	1.0E-03	0.38417	0.00096	0.38610
ncsrT70_131_1_15_5	0.0	5,667	338	9,205	711.53	1.0E-02	0.38613	0.00108	0.38829
ncsrT70_131_1_15_6	0.0	5,667	338	9,205	711.53	1.0E-01	0.39026	0.00098	0.39222
ncsrT70_131_1_15_8	0.0	5,667	338	9,205	711.53	3.0E-01	0.40187	0.00122	0.40430
ncsrT70_131_1_15_15	0.0	5,667	338	9,205	711.53	1.0E+00	0.43000	0.00103	0.43206
1.31 in. diameter content content in flooded containment vessel, array packaging model for CSI=0.0									
NCT									
no can spacers (np thickness = 0.0 in.)									
						moifr			
nciaT70_131_1_1_3	0.0	5,667	338	0	0.00	1.0E-04	0.12954	0.00047	0.13048
nciaT70_131_1_6_3	0.0	5,667	338	920	71.15	1.0E-04	0.15804	0.00057	0.15918
nciaT70_131_1_7_3	0.0	5,667	338	1,841	142.31	1.0E-04	0.19290	0.00064	0.19417
nciaT70_131_1_8_3	0.0	5,667	338	2,762	213.46	1.0E-04	0.22844	0.00085	0.23015
nciaT70_131_1_9_3	0.0	5,667	338	3,682	284.61	1.0E-04	0.26752	0.00081	0.26914
nciaT70_131_1_10_3	0.0	5,667	338	4,602	355.77	1.0E-04	0.30500	0.00096	0.30692
nciaT70_131_1_11_3	0.0	5,667	338	5,523	426.92	1.0E-04	0.33850	0.00107	0.34064
nciaT70_131_1_12_3	0.0	5,667	338	6,443	498.07	1.0E-04	0.37139	0.00102	0.37342

Table 6.9.6-20c. Results for 1.31 in. smaller diameter $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$
nciaT70_131_1_13_3	0.0	5,667	338	7,364	569.23	1.0E-04	0.40245	0.00098	0.40441
nciaT70_131_1_14_3	0.0	5,667	338	8,284	640.38	1.0E-04	0.43010	0.00115	0.43241
nciaT70_131_1_15_3	0.0	5,667	338	9,205	711.53	1.0E-04	0.45804	0.00122	0.46047

Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$
homogenized content in flooded containment vessel, single package reflected [10 CFR 71.55(d)(2)]									
NCT									
no can spacers (np thickness = 0.0 in.)									
						mocfr			
ncsrt55d2_1_1_15	0.0	10,400	921	0	0.00	1.0E+00	0.11370	0.00054	0.11477
ncsrt55d2_1_6_15	0.0	10,400	921	900	25.50	1.0E+00	0.15074	0.00061	0.15196
ncsrt55d2_1_7_15	0.0	10,400	921	1,800	51.00	1.0E+00	0.19298	0.00070	0.19439
ncsrt55d2_1_8_15	0.0	10,400	921	2,700	76.50	1.0E+00	0.24182	0.00082	0.24346
ncsrt55d2_1_9_15	0.0	10,400	921	3,599	102.00	1.0E+00	0.29424	0.00084	0.29591
ncsrt55d2_1_10_15	0.0	10,400	921	4,499	127.50	1.0E+00	0.34858	0.00100	0.35059
ncsrt55d2_1_11_15	0.0	10,400	921	5,399	153.00	1.0E+00	0.40341	0.00119	0.40579
ncsrt55d2_1_12_15	0.0	10,400	921	6,299	178.50	1.0E+00	0.45802	0.00109	0.46020
ncsrt55d2_1_13_15	0.0	10,400	921	7,199	204.00	1.0E+00	0.51163	0.00121	0.51404
ncsrt55d2_1_14_15	0.0	10,400	921	8,098	229.51	1.0E+00	0.56264	0.00129	0.56521
ncsrt55d2_1_15_15	0.0	10,400	921	8,998	255.01	1.0E+00	0.60824	0.00136	0.61095
						moifr			
ncsrt55d2_1_15_15	0.0	10,400	921	8,998	255.01	1.0E+00	0.60824	0.00136	0.61095
ncsrt55d2_1_15_8	0.0	10,400	921	8,998	255.01	3.0E-01	0.55284	0.00122	0.55528

Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrt55d2_1_15_6	0.0	10,400	921	8,998	255.01	1.0E-01	0.53397	0.00114	0.53626
ncsrt55d2_1_15_5	0.0	10,400	921	8,998	255.01	1.0E-02	0.52373	0.00115	0.52604
ncsrt55d2_1_15_4	0.0	10,400	921	8,998	255.01	1.0E-03	0.52361	0.00124	0.52609
ncsrt55d2_1_15_3	0.0	10,400	921	8,998	255.01	1.0E-04	0.52050	0.00116	0.52283
ncsrt55d2_1_15_2	0.0	10,400	921	8,998	255.01	1.0E-05	0.52366	0.00123	0.52611
ncsrt55d2_1_15_1	0.0	10,400	921	8,998	255.01	1.0E-20	0.52390	0.00120	0.52631
with can spacers (np thickness = 1.4 in.)									
						mocfr			
ncsrt55d2_2_1_15	1.4	10,400	921	0	0.00	1.0E+00	0.10877	0.00048	0.10972
ncsrt55d2_2_6_15	1.4	10,400	921	839	23.76	1.0E+00	0.14519	0.00062	0.14643
ncsrt55d2_2_7_15	1.4	10,400	921	1,677	47.52	1.0E+00	0.18564	0.00082	0.18729
ncsrt55d2_2_8_15	1.4	10,400	921	2,515	71.29	1.0E+00	0.23269	0.00095	0.23459
ncsrt55d2_2_9_15	1.4	10,400	921	3,354	95.05	1.0E+00	0.28305	0.00082	0.28469
ncsrt55d2_2_10_15	1.4	10,400	921	4,192	118.81	1.0E+00	0.33734	0.00105	0.33944
ncsrt55d2_2_11_15	1.4	10,400	921	5,031	142.57	1.0E+00	0.39111	0.00128	0.39367
ncsrt55d2_2_12_15	1.4	10,400	921	5,869	166.33	1.0E+00	0.44324	0.00114	0.44553
ncsrt55d2_2_13_15	1.4	10,400	921	6,708	190.09	1.0E+00	0.49696	0.00128	0.49951
ncsrt55d2_2_14_15	1.4	10,400	921	7,546	213.86	1.0E+00	0.54756	0.00093	0.54942
ncsrt55d2_2_15_15	1.4	10,400	921	8,385	237.62	1.0E+00	0.59538	0.00144	0.59825
						moifr			
ncsrt55d2_2_15_15	1.4	10,400	921	8,385	237.62	1.0E+00	0.59538	0.00144	0.59825
ncsrt55d2_2_15_8	1.4	10,400	921	8,385	237.62	3.0E-01	0.53671	0.00112	0.53895
ncsrt55d2_2_15_6	1.4	10,400	921	8,385	237.62	1.0E-01	0.52002	0.00107	0.52217
ncsrt55d2_2_15_5	1.4	10,400	921	8,385	237.62	1.0E-02	0.50958	0.00123	0.51204
ncsrt55d2_2_15_4	1.4	10,400	921	8,385	237.62	1.0E-03	0.50803	0.00111	0.51024

Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$
ncsrt55d2_2_15_3	1.4	10,400	921	8,385	237.62	1.0E-04	0.50785	0.00116	0.51018
ncsrt55d2_2_15_2	1.4	10,400	921	8,385	237.62	1.0E-05	0.50851	0.00117	0.51086
ncsrt55d2_2_15_1	1.4	10,400	921	8,385	237.62	1.0E-20	0.50763	0.00113	0.50989
homogenized content in flooded containment vessel, array packaging model for CSI=0.0 [10 CFR 71.55(d)(2)]									
NCT									
no can spacers (np thickness = 0.0 in.)									
						moifr			
nciat55d2_1_1_3	0.0	10400	921	0	0.00	1.0E-04	0.13090	0.00039	0.13168
nciat55d2_1_6_3	0.0	10400	921	900	25.50	1.0E-04	0.18600	0.00056	0.18713
nciat55d2_1_7_3	0.0	10400	921	1,800	51.00	1.0E-04	0.24841	0.00078	0.24997
nciat55d2_1_8_3	0.0	10400	921	2,700	76.50	1.0E-04	0.31679	0.00074	0.31826
nciat55d2_1_9_3	0.0	10400	921	3,599	102.00	1.0E-04	0.38338	0.00097	0.38531
nciat55d2_1_10_3	0.0	10400	921	4,499	127.50	1.0E-04	0.44808	0.00093	0.44993
nciat55d2_1_11_3	0.0	10400	921	5,399	153.00	1.0E-04	0.51062	0.00096	0.51254
nciat55d2_1_12_3	0.0	10400	921	6,299	178.50	1.0E-04	0.56869	0.00104	0.57076
nciat55d2_1_13_3	0.0	10400	921	7,198	204.00	1.0E-04	0.62259	0.00112	0.62484
nciat55d2_1_14_3	0.0	10400	921	8,098	229.51	1.0E-04	0.67077	0.00100	0.67276
nciat55d2_1_15_3	0.0	10400	921	8,998	255.01	1.0E-04	0.71379	0.00131	0.71641
with can spacers (np thickness = 1.4 in.)									
nciat55d2_02_1_3	1.4	10400	921	0	0.00	1.0E-04	0.12620	0.00039	0.12697
nciat55d2_02_6_3	1.4	10400	921	838	23.76	1.0E-04	0.17224	0.00043	0.17310
nciat55d2_02_7_3	1.4	10400	921	1,677	47.52	1.0E-04	0.22779	0.00057	0.22894
nciat55d2_02_8_3	1.4	10400	921	2,515	71.29	1.0E-04	0.28723	0.00081	0.28884
nciat55d2_02_9_3	1.4	10400	921	3,354	95.05	1.0E-04	0.34934	0.00079	0.35091
nciat55d2_02_10_3	1.4	10400	921	4,192	118.81	1.0E-04	0.40899	0.00097	0.41094

Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in.)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	$k_{eff}+2\sigma$
nciat55d2_02_11_3	1.4	10400	921	5,031	142.57	1.0E-04	0.46775	0.00101	0.46977
nciat55d2_02_12_3	1.4	10400	921	5,869	166.33	1.0E-04	0.52454	0.00105	0.52664
nciat55d2_02_13_3	1.4	10400	921	6,708	190.09	1.0E-04	0.57561	0.00105	0.57771
nciat55d2_02_14_3	1.4	10400	921	7,546	213.86	1.0E-04	0.62437	0.00100	0.62637
nciat55d2_02_15_3	1.4	10400	921	8,385	237.62	1.0E-04	0.66968	0.00118	0.67203

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff}+2\sigma$
	core						shell							
compromised package, HEU-poly core in spherical configuration, 20.0 cm water reflector														
10,000 g HEU														
atdmr_10_8	10,000	500	na	na	1.68	6.3550	na	na	na	na	0.0703	0.84682	0.00132	0.84946
atdmr_10_7	9,500	500	na	na	1.77	6.3544	na	na	na	na	0.0708	0.82979	0.00121	0.83220
atdmr_10_6	9,000	500	na	na	1.86	6.3537	na	na	na	na	0.0704	0.81840	0.00105	0.82051
atdmr_10_5	8,000	500	na	na	2.10	6.3524	na	na	na	na	0.0705	0.79201	0.00116	0.79433
atdmr_10_4	7,000	500	na	na	2.40	6.3511	na	na	na	na	0.0706	0.76698	0.00108	0.76915
atdmr_10_3	6,000	500	na	na	2.80	6.3497	na	na	na	na	0.0713	0.73619	0.00111	0.73841
atdmr_10_2	4,000	500	na	na	4.19	6.3471	na	na	na	na	0.0715	0.67188	0.00126	0.67440
atdmr_10_1	1,900	500	na	na	8.83	6.3443	na	na	na	na	0.0718	0.58417	0.00103	0.58623
9,000 g HEU														
atdmr_9_8	9,000	500	na	na	1.86	6.2485	na	na	na	na	0.0710	0.82672	0.00113	0.82898
atdmr_9_7	8,550	500	na	na	1.96	6.2479	na	na	na	na	0.0716	0.81253	0.00143	0.81540

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
atdmr_9_6	8,100	500	na	na	2.07	6.2473	na	na	na	na	0.0712	0.80165	0.00110	0.80385
atdmr_9_5	7,200	500	na	na	2.33	6.2460	na	na	na	na	0.0710	0.77728	0.00120	0.77967
atdmr_9_4	6,300	500	na	na	2.66	6.2448	na	na	na	na	0.0716	0.75139	0.00124	0.75387
atdmr_9_3	5,400	500	na	na	3.11	6.2436	na	na	na	na	0.0724	0.72346	0.00126	0.72598
atdmr_9_2	3,600	500	na	na	4.66	6.2411	na	na	na	na	0.0724	0.65951	0.00101	0.66152
atdmr_9_1	1,710	500	na	na	9.81	6.2385	na	na	na	na	0.0734	0.57813	0.00106	0.58024
8,000 g HEU														
atdmr_8_8	8,000	500	na	na	2.10	6.1382	na	na	na	na	0.0718	0.80824	0.00110	0.81045
atdmr_8_7	7,600	500	na	na	2.21	6.1377	na	na	na	na	0.0724	0.79414	0.00125	0.79663
atdmr_8_6	7,200	500	na	na	2.33	6.1371	na	na	na	na	0.0722	0.78358	0.00124	0.78606
atdmr_8_5	6,400	500	na	na	2.62	6.1360	na	na	na	na	0.0723	0.76006	0.00119	0.76244
atdmr_8_4	5,600	500	na	na	2.99	6.1348	na	na	na	na	0.0719	0.73542	0.00116	0.73773
atdmr_8_3	4,800	500	na	na	3.49	6.1337	na	na	na	na	0.0726	0.70911	0.00113	0.71138
atdmr_8_2	3,200	500	na	na	5.24	6.1314	na	na	na	na	0.0733	0.65087	0.00120	0.65326
atdmr_8_1	1,520	500	na	na	11.03	6.1290	na	na	na	na	0.0731	0.57072	0.00116	0.57304
7,000 g HEU														
atdmr_7_8	7,000	500	na	na	2.40	6.0238	na	na	na	na	0.0732	0.78837	0.00130	0.79098
atdmr_7_7	6,650	500	na	na	2.52	6.0233	na	na	na	na	0.0727	0.77467	0.00108	0.77683
atdmr_7_6	6,300	500	na	na	2.66	6.0228	na	na	na	na	0.0735	0.76362	0.00120	0.76603
atdmr_7_5	5,600	500	na	na	2.99	6.0218	na	na	na	na	0.0735	0.74073	0.00115	0.74302
atdmr_7_4	4,900	500	na	na	3.42	6.0207	na	na	na	na	0.0731	0.71741	0.00120	0.71982
atdmr_7_3	4,200	500	na	na	3.99	6.0197	na	na	na	na	0.0740	0.69409	0.00108	0.69624
atdmr_7_2	2,800	500	na	na	5.99	6.0176	na	na	na	na	0.0735	0.63885	0.00113	0.64111
atdmr_7_1	1,330	500	na	na	12.61	6.0155	na	na	na	na	0.0745	0.56445	0.00108	0.56660

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
compromised package, HEU-poly core in spherical configuration, stainless steel shell, 20.0 cm water reflector														
7,000 g HEU 100% enrichment														
atdmsr_7_8_11	7,000	500	na	na	2.40	6.0238	na	na	66,133.1	13.0198	0.0297	0.76607	0.00120	0.76847
atdmsr_7_8_10	7,000	500	na	na	2.40	6.0238	na	na	59,519.8	12.6164	0.0313	0.76407	0.00104	0.76615
atdmsr_7_8_9	7,000	500	na	na	2.40	6.0238	na	na	52,906.5	12.1855	0.0329	0.76034	0.00112	0.76259
atdmsr_7_8_8	7,000	500	na	na	2.40	6.0238	na	na	46,293.2	11.7217	0.0348	0.75468	0.00126	0.75720
atdmsr_7_8_7	7,000	500	na	na	2.40	6.0238	na	na	39,679.9	11.2179	0.0370	0.75125	0.00130	0.75384
atdmsr_7_8_6	7,000	500	na	na	2.40	6.0238	na	na	33,066.6	10.6643	0.0396	0.74580	0.00123	0.74827
atdmsr_7_8_5	7,000	500	na	na	2.40	6.0238	na	na	26,453.3	10.0464	0.0428	0.73992	0.00122	0.74235
atdmsr_7_8_4	7,000	500	na	na	2.40	6.0238	na	na	19,839.9	9.3414	0.0464	0.73585	0.00164	0.73913
atdmsr_7_8_3	7,000	500	na	na	2.40	6.0238	na	na	13,226.6	8.5100	0.0517	0.73131	0.00121	0.73373
atdmsr_7_8_2	7,000	500	na	na	2.40	6.0238	na	na	6,613.3	7.4736	0.0594	0.73612	0.00125	0.73863
atdmsr_7_8_1	7,000	500	na	na	2.40	6.0238	na	na	0.0	6.0239	0.0730	0.78843	0.00113	0.79069
7,000 g HEU 95% enrichment														
atdmsr_7_7_11	6,650	500	na	na	2.52	6.0233	na	na	66,133.1	13.0197	0.0297	0.75217	0.00105	0.75427
atdmsr_7_7_10	6,650	500	na	na	2.52	6.0233	na	na	59,519.8	12.6163	0.0311	0.74832	0.00120	0.75072
atdmsr_7_7_9	6,650	500	na	na	2.52	6.0233	na	na	52,906.5	12.1854	0.0330	0.74504	0.00122	0.74749
atdmsr_7_7_8	6,650	500	na	na	2.52	6.0233	na	na	46,293.2	11.7215	0.0350	0.74113	0.00139	0.74391
atdmsr_7_7_7	6,650	500	na	na	2.52	6.0233	na	na	39,679.9	11.2178	0.0367	0.73518	0.00113	0.73745
atdmsr_7_7_6	6,650	500	na	na	2.52	6.0233	na	na	33,066.6	10.6642	0.0398	0.73061	0.00114	0.73289
atdmsr_7_7_5	6,650	500	na	na	2.52	6.0233	na	na	26,453.3	10.0462	0.0424	0.72581	0.00115	0.72811
atdmsr_7_7_4	6,650	500	na	na	2.52	6.0233	na	na	19,839.9	9.3412	0.0465	0.72114	0.00114	0.72341
atdmsr_7_7_3	6,650	500	na	na	2.52	6.0233	na	na	13,226.6	8.5097	0.0513	0.71750	0.00128	0.72006
atdmsr_7_7_2	6,650	500	na	na	2.52	6.0233	na	na	6,613.3	7.4733	0.0595	0.72179	0.00125	0.72429
atdmsr_7_7_1	6,650	500	na	na	2.52	6.0233	na	na	0.0	6.0234	0.0731	0.77710	0.00130	0.77970

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
7,000 g HEU 90% enrichment														
atdmsr_7_6_11	6,300	500	na	na	2.66	6.0228	na	na	66,133.1	13.0196	0.0300	0.73788	0.00105	0.73999
atdmsr_7_6_10	6,300	500	na	na	2.66	6.0228	na	na	59,519.8	12.6162	0.0308	0.73548	0.00108	0.73763
atdmsr_7_6_9	6,300	500	na	na	2.66	6.0228	na	na	52,906.5	12.1852	0.0327	0.73014	0.00125	0.73263
atdmsr_7_6_8	6,300	500	na	na	2.66	6.0228	na	na	46,293.2	11.7214	0.0349	0.72624	0.00124	0.72873
atdmsr_7_6_7	6,300	500	na	na	2.66	6.0228	na	na	39,679.9	11.2176	0.0371	0.72341	0.00126	0.72594
atdmsr_7_6_6	6,300	500	na	na	2.66	6.0228	na	na	33,066.6	10.6640	0.0393	0.71807	0.00109	0.72025
atdmsr_7_6_5	6,300	500	na	na	2.66	6.0228	na	na	26,453.3	10.0460	0.0423	0.71292	0.00108	0.71507
atdmsr_7_6_4	6,300	500	na	na	2.66	6.0228	na	na	19,839.9	9.3409	0.0462	0.70851	0.00126	0.71103
atdmsr_7_6_3	6,300	500	na	na	2.66	6.0228	na	na	13,226.6	8.5095	0.0515	0.70125	0.00118	0.70361
atdmsr_7_6_2	6,300	500	na	na	2.66	6.0228	na	na	6,613.3	7.4730	0.0595	0.70829	0.00122	0.71074
atdmsr_7_6_1	6,300	500	na	na	2.66	6.0228	na	na	0.0	6.0229	0.0731	0.76522	0.00130	0.76782
7,000 g HEU 80% enrichment														
atdmsr_7_5_11	5,600	500	na	na	2.99	6.0218	na	na	66,133.1	13.0194	0.0300	0.70826	0.00130	0.71086
atdmsr_7_5_10	5,600	500	na	na	2.99	6.0218	na	na	59,519.8	12.6160	0.0313	0.70615	0.00122	0.70860
atdmsr_7_5_9	5,600	500	na	na	2.99	6.0218	na	na	52,906.5	12.1850	0.0332	0.70259	0.00104	0.70468
atdmsr_7_5_8	5,600	500	na	na	2.99	6.0218	na	na	46,293.2	11.7211	0.0351	0.69758	0.00113	0.69985
atdmsr_7_5_7	5,600	500	na	na	2.99	6.0218	na	na	39,679.9	11.2173	0.0371	0.69312	0.00126	0.69564
atdmsr_7_5_6	5,600	500	na	na	2.99	6.0218	na	na	33,066.6	10.6637	0.0394	0.69094	0.00100	0.69295
atdmsr_7_5_5	5,600	500	na	na	2.99	6.0218	na	na	26,453.3	10.0457	0.0430	0.68484	0.00109	0.68701
atdmsr_7_5_4	5,600	500	na	na	2.99	6.0218	na	na	19,839.9	9.3405	0.0467	0.67851	0.00126	0.68102
atdmsr_7_5_3	5,600	500	na	na	2.99	6.0218	na	na	13,226.6	8.5089	0.0520	0.67622	0.00128	0.67878
atdmsr_7_5_2	5,600	500	na	na	2.99	6.0218	na	na	6,613.3	7.4723	0.0596	0.68260	0.00122	0.68505
atdmsr_7_5_1	5,600	500	na	na	2.99	6.0218	na	na	0.0	6.0219	0.0729	0.74067	0.00120	0.74307

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
7,000 g HEU 70% enrichment														
atdmsr_7_4_11	4,900	500	na	na	3.42	6.0207	na	na	66,133.1	13.0192	0.0298	0.67942	0.00111	0.68164
atdmsr_7_4_10	4,900	500	na	na	3.42	6.0207	na	na	59,519.8	12.6157	0.0315	0.67468	0.00108	0.67683
atdmsr_7_4_9	4,900	500	na	na	3.42	6.0207	na	na	52,906.5	12.1847	0.0329	0.67332	0.00107	0.67547
atdmsr_7_4_8	4,900	500	na	na	3.42	6.0207	na	na	46,293.2	11.7208	0.0344	0.66696	0.00109	0.66915
atdmsr_7_4_7	4,900	500	na	na	3.42	6.0207	na	na	39,679.9	11.2170	0.0371	0.66405	0.00102	0.66610
atdmsr_7_4_6	4,900	500	na	na	3.42	6.0207	na	na	33,066.6	10.6633	0.0396	0.65978	0.00133	0.66244
atdmsr_7_4_5	4,900	500	na	na	3.42	6.0207	na	na	26,453.3	10.0453	0.0430	0.65491	0.00111	0.65714
atdmsr_7_4_4	4,900	500	na	na	3.42	6.0207	na	na	19,839.9	9.3401	0.0461	0.65283	0.00115	0.65513
atdmsr_7_4_3	4,900	500	na	na	3.42	6.0207	na	na	13,226.6	8.5084	0.0519	0.64816	0.00119	0.65053
atdmsr_7_4_2	4,900	500	na	na	3.42	6.0207	na	na	6,613.3	7.4716	0.0592	0.65866	0.00129	0.66124
atdmsr_7_4_1	4,900	500	na	na	3.42	6.0207	na	na	0.0	6.0208	0.0735	0.71618	0.00119	0.71855
7,000 g HEU 60% enrichment														
atdmsr_7_3_11	4,200	500	na	na	3.99	6.0197	na	na	66,133.1	13.0189	0.0301	0.64937	0.00120	0.65177
atdmsr_7_3_10	4,200	500	na	na	3.99	6.0197	na	na	59,519.8	12.6155	0.0314	0.64512	0.00109	0.64731
atdmsr_7_3_9	4,200	500	na	na	3.99	6.0197	na	na	52,906.5	12.1845	0.0331	0.64112	0.00108	0.64328
atdmsr_7_3_8	4,200	500	na	na	3.99	6.0197	na	na	46,293.2	11.7206	0.0347	0.63750	0.00100	0.63951
atdmsr_7_3_7	4,200	500	na	na	3.99	6.0197	na	na	39,679.9	11.2167	0.0378	0.63266	0.00109	0.63483
atdmsr_7_3_6	4,200	500	na	na	3.99	6.0197	na	na	33,066.6	10.6630	0.0400	0.62892	0.00118	0.63129
atdmsr_7_3_5	4,200	500	na	na	3.99	6.0197	na	na	26,453.3	10.0449	0.0432	0.62395	0.00111	0.62617
atdmsr_7_3_4	4,200	500	na	na	3.99	6.0197	na	na	19,839.9	9.3397	0.0468	0.62020	0.00121	0.62262
atdmsr_7_3_3	4,200	500	na	na	3.99	6.0197	na	na	13,226.6	8.5079	0.0521	0.61780	0.00100	0.61980
atdmsr_7_3_2	4,200	500	na	na	3.99	6.0197	na	na	6,613.3	7.4710	0.0597	0.62719	0.00106	0.62931
atdmsr_7_3_1	4,200	500	na	na	3.99	6.0197	na	na	0.0	6.0198	0.0734	0.69368	0.00104	0.69575

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
7,000 g HEU 40% enrichment														
atdmsr_7_2_11	2,800	500	na	na	5.99	6.0176	na	na	66,133.1	13.0185	0.0298	0.57617	0.00095	0.57807
atdmsr_7_2_10	2,800	500	na	na	5.99	6.0176	na	na	59,519.8	12.6150	0.0319	0.57141	0.00113	0.57367
atdmsr_7_2_9	2,800	500	na	na	5.99	6.0176	na	na	52,906.5	12.1840	0.0329	0.56944	0.00094	0.57132
atdmsr_7_2_8	2,800	500	na	na	5.99	6.0176	na	na	46,293.2	11.7200	0.0351	0.56671	0.00107	0.56885
atdmsr_7_2_7	2,800	500	na	na	5.99	6.0176	na	na	39,679.9	11.2161	0.0373	0.56408	0.00108	0.56623
atdmsr_7_2_6	2,800	500	na	na	5.99	6.0176	na	na	33,066.6	10.6624	0.0400	0.56030	0.00098	0.56225
atdmsr_7_2_5	2,800	500	na	na	5.99	6.0176	na	na	26,453.3	10.0442	0.0427	0.55427	0.00096	0.55618
atdmsr_7_2_4	2,800	500	na	na	5.99	6.0176	na	na	19,839.9	9.3388	0.0468	0.55088	0.00103	0.55294
atdmsr_7_2_3	2,800	500	na	na	5.99	6.0176	na	na	13,226.6	8.5069	0.0518	0.55147	0.00094	0.55335
atdmsr_7_2_2	2,800	500	na	na	5.99	6.0176	na	na	6,613.3	7.4696	0.0598	0.56246	0.00099	0.56444
atdmsr_7_2_1	2,800	500	na	na	5.99	6.0176	na	na	0.0	6.0177	0.0741	0.63782	0.00112	0.64006
7,000 g HEU 19% enrichment														
atdmsr_7_1_11	1,330	500	na	na	12.61	6.0155	na	na	66,133.1	13.0180	0.0303	0.47486	0.00104	0.47693
atdmsr_7_1_10	1,330	500	na	na	12.61	6.0155	na	na	59,519.8	12.6145	0.0319	0.47397	0.00122	0.47641
atdmsr_7_1_9	1,330	500	na	na	12.61	6.0155	na	na	52,906.5	12.1834	0.0332	0.47151	0.00104	0.47360
atdmsr_7_1_8	1,330	500	na	na	12.61	6.0155	na	na	46,293.2	11.7195	0.0349	0.46786	0.00095	0.46975
atdmsr_7_1_7	1,330	500	na	na	12.61	6.0155	na	na	39,679.9	11.2155	0.0376	0.46514	0.00108	0.46730
atdmsr_7_1_6	1,330	500	na	na	12.61	6.0155	na	na	33,066.6	10.6617	0.0398	0.46144	0.00102	0.46347
atdmsr_7_1_5	1,330	500	na	na	12.61	6.0155	na	na	26,453.3	10.0434	0.0428	0.45904	0.00094	0.46093
atdmsr_7_1_4	1,330	500	na	na	12.61	6.0155	na	na	19,839.9	9.3379	0.0465	0.45553	0.00100	0.45753
atdmsr_7_1_3	1,330	500	na	na	12.61	6.0155	na	na	13,226.6	8.5058	0.0528	0.45536	0.00100	0.45737
atdmsr_7_1_2	1,330	500	na	na	12.61	6.0155	na	na	6,613.3	7.4682	0.0598	0.46993	0.00112	0.47216
atdmsr_7_1_1	1,330	500	na	na	12.61	6.0155	na	na	0.0	6.0156	0.0742	0.56352	0.00123	0.56598

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
compromised package, HEU-poly core in spherical configuration, dry (bound water) Kaolite shell, 20.0 cm water reflector														
7,000 g HEU 100% enrichment														
atdmdkr_7_8_6	7,000	500	na	na	2.40	6.0238	51,214.9	2,204.2	53,419.1	31.0802	0.0493	0.58882	0.00117	0.59116
atdmdkr_7_8_5	7,000	500	na	na	2.40	6.0238	40,971.9	1,763.4	42,735.3	28.8698	0.0508	0.59271	0.00122	0.59516
atdmdkr_7_8_4	7,000	500	na	na	2.40	6.0238	30,729.0	1,322.5	32,051.5	26.2565	0.0530	0.59911	0.00118	0.60147
atdmdkr_7_8_3	7,000	500	na	na	2.40	6.0238	20,485.9	881.7	21,367.6	22.9832	0.0559	0.60599	0.00101	0.60801
atdmdkr_7_8_2	7,000	500	na	na	2.40	6.0238	10,243.0	440.8	10,683.8	18.3506	0.0604	0.62729	0.00116	0.62962
atdmdkr_7_8_1	7,000	500	na	na	2.40	6.0238	0.0	0.0	0.0	6.0239	0.0733	0.78590	0.00118	0.78826
compromised package, HEU-poly core in spherical configuration, wet (bound plus 15 lb free water) Kaolite shell, 20.0 cm water reflector														
7,000 g HEU 100% enrichment														
atdm15kr_7_8_6	7,000	500	na	na	2.40	6.0238	51,214.9	9,008.1	60,223.0	31.0802	0.0402	0.59780	0.00113	0.60006
atdm15kr_7_8_5	7,000	500	na	na	2.40	6.0238	40,971.9	7,206.5	48,178.4	28.8698	0.0425	0.60257	0.00108	0.60473
atdm15kr_7_8_4	7,000	500	na	na	2.40	6.0238	30,728.9	5,404.9	36,133.8	26.2565	0.0452	0.60526	0.00112	0.60750
atdm15kr_7_8_3	7,000	500	na	na	2.40	6.0238	20,486.0	3,603.2	24,089.2	22.9832	0.0487	0.61255	0.00103	0.61461
atdm15kr_7_8_2	7,000	500	na	na	2.40	6.0238	10,243.0	1,801.6	12,044.6	18.3506	0.0546	0.63083	0.00104	0.63292
atdm15kr_7_8_1	7,000	500	na	na	2.40	6.0238	0.0	0.0	0.0	6.0239	0.0735	0.78760	0.00130	0.79020
7,000 g HEU 95% enrichment														
atdm15kr_7_7_6	6,650	500	na	na	2.52	6.0233	51,214.9	9,008.1	60,223.0	31.0802	0.0405	0.58499	0.00117	0.58733
atdm15kr_7_7_5	6,650	500	na	na	2.52	6.0233	40,971.8	7,206.6	48,178.4	28.8698	0.0427	0.58888	0.00102	0.59093
atdm15kr_7_7_4	6,650	500	na	na	2.52	6.0233	30,728.9	5,404.9	36,133.8	26.2564	0.0451	0.59189	0.00101	0.59391
atdm15kr_7_7_3	6,650	500	na	na	2.52	6.0233	20,485.9	3,603.3	24,089.2	22.9832	0.0490	0.59837	0.00098	0.60034
atdm15kr_7_7_2	6,650	500	na	na	2.52	6.0233	10,243.0	1,801.6	12,044.6	18.3506	0.0553	0.61938	0.00126	0.62190
atdm15kr_7_7_1	6,650	500	na	na	2.52	6.0233	0.0	0.0	0.0	6.0234	0.0727	0.77397	0.00119	0.77636

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
7,000 g HEU 90% enrichment														
atdm15kr_7_6_6	6,300	500	na	na	2.66	6.0228	51,214.9	9,008.1	60,223.0	31.0802	0.0404	0.57465	0.00119	0.57703
atdm15kr_7_6_5	6,300	500	na	na	2.66	6.0228	40,971.8	7,206.6	48,178.4	28.8698	0.0425	0.57735	0.00128	0.57991
atdm15kr_7_6_4	6,300	500	na	na	2.66	6.0228	30,728.9	5,404.9	36,133.8	26.2564	0.0450	0.57926	0.00117	0.58159
atdm15kr_7_6_3	6,300	500	na	na	2.66	6.0228	20,485.9	3,603.3	24,089.2	22.9831	0.0487	0.58806	0.00114	0.59034
atdm15kr_7_6_2	6,300	500	na	na	2.66	6.0228	10,243.0	1,801.6	12,044.6	18.3505	0.0554	0.60486	0.00116	0.60718
atdm15kr_7_6_1	6,300	500	na	na	2.66	6.0228	0.0	0.0	0.0	6.0229	0.0730	0.76331	0.00116	0.76563
7,000 g HEU 80% enrichment														
atdm15kr_7_5_6	5,600	500	na	na	2.99	6.0218	51,214.9	9,008.1	60,223.0	31.0802	0.0408	0.54645	0.00099	0.54842
atdm15kr_7_5_5	5,600	500	na	na	2.99	6.0218	40,971.8	7,206.6	48,178.4	28.8698	0.0423	0.54984	0.00093	0.55170
atdm15kr_7_5_4	5,600	500	na	na	2.99	6.0218	30,728.9	5,404.9	36,133.8	26.2563	0.0446	0.55606	0.00114	0.55834
atdm15kr_7_5_3	5,600	500	na	na	2.99	6.0218	20,485.9	3,603.3	24,089.2	22.9831	0.0487	0.56202	0.00110	0.56422
atdm15kr_7_5_2	5,600	500	na	na	2.99	6.0218	10,243.0	1,801.6	12,044.6	18.3504	0.0552	0.58092	0.00102	0.58295
atdm15kr_7_5_1	5,600	500	na	na	2.99	6.0218	0.0	0.0	0.0	6.0219	0.0730	0.74103	0.00130	0.74363
7,000 g HEU 70% enrichment														
atdm15kr_7_4_6	4,900	500	na	na	3.42	6.0207	51,214.9	9,008.1	60,223.0	31.0801	0.0409	0.52118	0.00095	0.52308
atdm15kr_7_4_5	4,900	500	na	na	3.42	6.0207	40,971.8	7,206.6	48,178.4	28.8697	0.0426	0.52194	0.00095	0.52385
atdm15kr_7_4_4	4,900	500	na	na	3.42	6.0207	30,728.9	5,404.9	36,133.8	26.2563	0.0452	0.52781	0.00096	0.52973
atdm15kr_7_4_3	4,900	500	na	na	3.42	6.0207	20,485.9	3,603.3	24,089.2	22.9830	0.0487	0.53753	0.00090	0.53933
atdm15kr_7_4_2	4,900	500	na	na	3.42	6.0207	10,243.0	1,801.6	12,044.6	18.3503	0.0550	0.55570	0.00095	0.55760
atdm15kr_7_4_1	4,900	500	na	na	3.42	6.0207	0.0	0.0	0.0	6.0208	0.0732	0.71662	0.00127	0.71916

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
7,000 g HEU 60% enrichment														
atdm15kr_7_3_6	4,200	500	na	na	3.99	6.0197	51,214.9	9,008.1	60,223.0	31.0801	0.0403	0.49438	0.00093	0.49623
atdm15kr_7_3_5	4,200	500	na	na	3.99	6.0197	40,971.8	7,206.6	48,178.4	28.8697	0.0424	0.49599	0.00119	0.49837
atdm15kr_7_3_4	4,200	500	na	na	3.99	6.0197	30,728.9	5,404.9	36,133.8	26.2562	0.0455	0.50053	0.00097	0.50248
atdm15kr_7_3_3	4,200	500	na	na	3.99	6.0197	20,485.9	3,603.3	24,089.2	22.9829	0.0495	0.50936	0.00114	0.51163
atdm15kr_7_3_2	4,200	500	na	na	3.99	6.0197	10,243.0	1,801.6	12,044.6	18.3502	0.0557	0.52826	0.00099	0.53024
atdm15kr_7_3_1	4,200	500	na	na	3.99	6.0197	0.0	0.0	0.0	6.0198	0.0735	0.69521	0.00106	0.69734
7,000 g HEU 40% enrichment														
atdm15kr_7_2_6	2,800	500	na	na	5.99	6.0176	51,214.9	9,008.1	60,223.0	31.0800	0.0409	0.43125	0.00093	0.43312
atdm15kr_7_2_5	2,800	500	na	na	5.99	6.0176	40,971.8	7,206.6	48,178.4	28.8696	0.0430	0.43173	0.00091	0.43356
atdm15kr_7_2_4	2,800	500	na	na	5.99	6.0176	30,728.9	5,404.9	36,133.8	26.2561	0.0454	0.43686	0.00096	0.43879
atdm15kr_7_2_3	2,800	500	na	na	5.99	6.0176	20,485.9	3,603.3	24,089.2	22.9828	0.0498	0.44558	0.00085	0.44727
atdm15kr_7_2_2	2,800	500	na	na	5.99	6.0176	10,243.0	1,801.6	12,044.6	18.3500	0.0559	0.46589	0.00105	0.46800
atdm15kr_7_2_1	2,800	500	na	na	5.99	6.0176	0.0	0.0	0.0	6.0177	0.0738	0.63718	0.00107	0.63932
7,000 g HEU 19% enrichment														
atdm15kr_7_1_6	1,330	500	na	na	12.61	6.0155	51,214.9	9,008.1	60,223.0	31.0799	0.0410	0.34386	0.00104	0.34594
atdm15kr_7_1_5	1,330	500	na	na	12.61	6.0155	40,971.8	7,206.6	48,178.4	28.8695	0.0430	0.34663	0.00078	0.34819
atdm15kr_7_1_4	1,330	500	na	na	12.61	6.0155	30,728.9	5,404.9	36,133.8	26.2560	0.0458	0.35247	0.00090	0.35428
atdm15kr_7_1_3	1,330	500	na	na	12.61	6.0155	20,485.9	3,603.3	24,089.2	22.9826	0.0495	0.36066	0.00085	0.36236
atdm15kr_7_1_2	1,330	500	na	na	12.61	6.0155	10,243.0	1,801.6	12,044.6	18.3497	0.0559	0.38250	0.00092	0.38433
atdm15kr_7_1_1	1,330	500	na	na	12.61	6.0155	0.0	0.0	0.0	6.0156	0.0743	0.56556	0.00123	0.56802

Table 6.9.6-22a. Results for TRIGA ($UZrH_x$) fuel element content at 19.7 wt % ^{235}U for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
compromised package, 10,400 g $UZrH_x$ plus poly in spherical configuration, 20.0 cm water reflector														
atdzr	921	500	na	na	43.37	7.4677	na	na	na	na	0.0617	0.67633	0.00116	0.67906
compromised package, spherical core (10,400 g $UZrH_x$ plus poly), stainless steel shell, 20.0 cm water reflector														
atdzsr_11	921	500	na	na	43.37	7.4677	na	na	66,133.0	13.3978	0.0271	0.61692	0.00121	0.61933
atdzsr_10	921	500	na	na	43.37	7.4677	na	na	59,520.0	13.0179	0.0285	0.61377	0.00109	0.61595
atdzsr_9	921	500	na	na	43.37	7.4677	na	na	52,907.0	12.6144	0.0301	0.60931	0.00156	0.61243
atdzsr_8	921	500	na	na	43.37	7.4677	na	na	46,293.0	12.1833	0.0315	0.60602	0.00132	0.60867
atdzsr_7	921	500	na	na	43.37	7.4677	na	na	39,680.0	11.7193	0.0332	0.60256	0.00138	0.60533
atdzsr_6	921	500	na	na	43.37	7.4677	na	na	33,067.0	11.2153	0.0356	0.59752	0.00129	0.60010
atdzsr_5	921	500	na	na	43.37	7.4677	na	na	26,453.0	10.6615	0.0379	0.59162	0.00109	0.59381
atdzsr_4	921	500	na	na	43.37	7.4677	na	na	19,840.0	10.0432	0.0407	0.59012	0.00116	0.59243
atdzsr_3	921	500	na	na	43.37	7.4677	na	na	13,227.0	9.3377	0.0458	0.58978	0.00116	0.59210
atdzsr_2	921	500	na	na	43.37	7.4677	na	na	6,613.0	8.5055	0.0515	0.60131	0.00135	0.60401
atdzsr_1	921	500	na	na	43.37	7.4677	na	na	0.0	7.4677	0.0614	0.67521	0.00128	0.67777
compromised package, spherical core (10,400 g $UZrH_x$ plus poly), wet (bound plus 15 lb free water) Kaolite shell, 20.0 cm water reflector														
atdz15kr_6	921	500	na	na	43.37	7.4677	51214.9	9008.1	60,223.0	31.1484	0.0352	0.46526	0.00113	0.46752
atdz15kr_5	921	500	na	na	43.37	7.4677	40971.9	7206.5	48,178.4	28.9488	0.0369	0.47017	0.00113	0.47243
atdz15kr_4	921	500	na	na	43.37	7.4677	30728.9	5404.9	36,133.8	26.3518	0.0393	0.47656	0.00109	0.47875
atdz15kr_3	921	500	na	na	43.37	7.4677	20486.0	3603.2	24,089.2	23.1074	0.0424	0.48601	0.00119	0.48839
atdz15kr_2	921	500	na	na	43.37	7.4677	10243.0	1801.6	12,044.6	18.5444	0.0476	0.50839	0.00112	0.51063
atdz15kr_1	921	500	na	na	43.37	7.4677	0.0	0.0	0.0	7.4678	0.0610	0.67612	0.00136	0.67885
compromised package, homogenous core (10,400 g $UZrH_x$, poly, and wet Kaolite) in spherical configuration, 20.0 cm water reflector														
athzp15kr_5	921	500	9,008.5	51,214.9	298.60	31.1484	na	na	na	na	0.0583	0.35614	0.00079	0.35772
athzp15kr_4	921	500	7,307.6	51,214.9	250.40	31.1484	na	na	na	na	0.0600	0.34337	0.00084	0.34504
athzp15kr_3	921	500	5,606.6	51,214.9	202.20	31.1484	na	na	na	na	0.0619	0.33243	0.00085	0.33414

Table 6.9.6-22a. Results for TRIGA ($UZrH_x$) fuel element content at 19.7 wt % ^{235}U for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
athzp15kr_2	921	500	3,905.7	51,214.9	154.00	31.1484	na	na	na	na	0.0646	0.31864	0.00079	0.32022
athzp15kr_1	921	500	2,204.7	51,214.9	105.80	31.1484	na	na	na	na	0.0666	0.30842	0.00079	0.31000
compromised package, homogenous core ($UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector														
9 fuel segments (10,400 g $UZrH_x$)														
athzpw15kr_5	921	500	6,803.8	na	236.10	12.6903	2,204.7	51,214.9	53,419.6	31.6977	0.0308	0.80474	0.00154	0.80781
athzpw15kr_4	921	500	5,102.9	na	187.90	11.7852	3,905.7	51,214.9	55,120.5	31.5622	0.0316	0.76177	0.00142	0.76460
athzpw15kr_3	921	500	3,401.9	na	139.70	10.7146	5,606.6	51,214.9	56,821.5	31.4254	0.0325	0.70349	0.00145	0.70638
athzpw15kr_2	921	500	1,701.0	na	91.57	9.3723	7,307.6	51,214.9	58,522.4	31.2875	0.0334	0.61344	0.00132	0.61608
athzpw15kr_1	921	500	0.0	na	43.37	7.4677	9,008.5	51,214.9	60,223.4	31.1484	0.0351	0.46733	0.00103	0.46938

Table 6.9.6-22b. Results for TRIGA ($UZrH_x$) fuel element content at 70.1 wt % ^{235}U for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
compromised package, 6847 g $UZrH_x$ plus poly in spherical configuration, 20.0 cm water reflector														
atdzr_70	408	500	na	na	103.30	7.4677	na	na	na	na	0.0624	0.67908	0.00139	0.68187
compromised package, spherical core (6,847 g $UZrH_x$ plus poly), stainless steel shell, 20.0 cm water reflector														
atdzsr_70_11	408	500	na	na	103.30	7.4677	na	na	66,133.1	13.3978	0.0280	0.62618	0.00125	0.62868
atdzsr_70_10	408	500	na	na	103.30	7.4677	na	na	59,519.8	13.0179	0.0296	0.62153	0.00132	0.62417
atdzsr_70_9	408	500	na	na	103.30	7.4677	na	na	52,906.5	12.6144	0.0306	0.61874	0.00131	0.62135
atdzsr_70_8	408	500	na	na	103.30	7.4677	na	na	46,293.2	12.1833	0.0323	0.61302	0.00159	0.61619
atdzsr_70_7	408	500	na	na	103.30	7.4677	na	na	39,679.9	11.7193	0.0343	0.60579	0.00123	0.60825

Table 6.9.6-22b. Results for TRIGA ($UZrH_x$) fuel element content at 70.1 wt % ^{235}U for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
atdzsr_70_6	408	500	na	na	103.30	7.4677	na	na	33,066.6	11.2153	0.0368	0.60315	0.00128	0.60571
atdzsr_70_5	408	500	na	na	103.30	7.4677	na	na	26,453.3	10.6615	0.0392	0.59802	0.00120	0.60043
atdzsr_70_4	408	500	na	na	103.30	7.4677	na	na	19,839.9	10.0432	0.0427	0.58654	0.00123	0.58900
atdzsr_70_3	408	500	na	na	103.30	7.4677	na	na	13,226.6	9.3377	0.0470	0.58790	0.00125	0.59040
atdzsr_70_2	408	500	na	na	103.30	7.4677	na	na	6,613.3	8.5055	0.0529	0.59739	0.00132	0.60003
atdzsr_70_1	408	500	na	na	103.30	7.4677	na	na	0.0	7.4677	0.0627	0.67646	0.00125	0.67896
compromised package, spherical core (6,847 g $UZrH_x$ plus poly), wet (bound plus 15 lb free water) Kaolite shell, 20.0 cm water reflector														
atdz15kr70_6	408	500	na	na	103.30	7.4677	na	na	60,223.0	31.1484	0.0362	0.45220	0.00122	0.45465
atdz15kr70_5	408	500	na	na	103.30	7.4677	na	na	48,178.4	28.9488	0.0381	0.45455	0.00142	0.45740
atdz15kr70_4	408	500	na	na	103.30	7.4677	na	na	36,133.8	26.3518	0.0404	0.46170	0.00131	0.46431
atdz15kr70_3	408	500	na	na	103.30	7.4677	na	na	24,089.2	23.1074	0.0437	0.47236	0.00111	0.47459
atdz15kr70_2	408	500	na	na	103.30	7.4677	na	na	12,044.6	18.5444	0.0490	0.49052	0.00132	0.49316
atdz15kr70_1	408	500	na	na	103.30	7.4677	na	na	0.0	7.4678	0.0626	0.67525	0.00131	0.67787
compromised package, homogenous core (6,847 g $UZrH_x$, poly, and wet Kaolite) in spherical configuration, 20.0 cm water reflector														
athzp15kr70_5	408	500	9,008.5	51,214.9	679.60	31.1484	na	na	na	na	0.0581	0.24018	0.00055	0.24128
athzp15kr70_4	408	500	7,307.6	51,214.9	570.80	31.1484	na	na	na	na	0.0598	0.23208	0.00050	0.23308
athzp15kr70_3	408	500	5,606.6	51,214.9	461.90	31.1484	na	na	na	na	0.0623	0.22392	0.00052	0.22495
athzp15kr70_2	408	500	3,905.7	51,214.9	353.10	31.1484	na	na	na	na	0.0650	0.21594	0.00064	0.21722
athzp15kr70_1	408	500	2,204.7	51,214.9	244.30	31.1484	na	na	na	na	0.0672	0.20933	0.00057	0.21047
compromised package, homogenous core (6,847 g $UZrH_x$, poly, and water from wet Kaolite), wet Kaolite shell, 20.0 cm water reflector														
9 fuel segments (6,847 g $UZrH_x$)														
athzpw15kr70_5	408	500	6,803.8	na	538.50	12.6903	2,204.7	51,214.9	53,419.6	31.6977	0.0310	0.71851	0.00148	0.72147
athzpw15kr70_4	408	500	5,102.9	na	429.70	11.7852	3,905.7	51,214.9	55,120.5	31.5622	0.0317	0.69647	0.00123	0.69894
athzpw15kr70_3	408	500	3,401.9	na	320.90	10.7146	5,606.6	51,214.9	56,821.5	31.4254	0.0326	0.66072	0.00122	0.66315

Table 6.9.6-22b. Results for TRIGA ($UZrH_x$) fuel element content at 70.1 wt % ^{235}U for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
athzpw15kr70_2	408	500	1,701.0	na	212.10	9.3723	7,307.6	51,214.9	58,522.4	31.2875	0.0341	0.59094	0.00118	0.59330
athzpw15kr70_1	408	500	0.0	na	103.30	7.4677	9,008.5	51,214.9	60,223.4	31.1484	0.0354	0.45119	0.00118	0.45355

Table 6.9.6-22c. Results for research reactor fuel (U_3O_8-Al) content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
compromised package, homogenous core ($UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector														
TRIGA content, 10,400 g $UZrH_x$ at 19.7 wt % ^{235}U (Reference Table 6.9.6-22a)														
athzpw15kr_5	921	500	6,803.8	na	236.10	12.6903	2,204.7	51,214.9	53,419.6	31.6977	0.0308	0.80474	0.00154	0.80781
athzpw15kr_4	921	500	5,102.9	na	187.90	11.7852	3,905.7	51,214.9	55,120.5	31.5622	0.0316	0.76177	0.00142	0.76460
athzpw15kr_3	921	500	3,401.9	na	139.70	10.7146	5,606.6	51,214.9	56,821.5	31.4254	0.0325	0.70349	0.00145	0.70638
athzpw15kr_2	921	500	1,701.0	na	91.57	9.3723	7,307.6	51,214.9	58,522.4	31.2875	0.0334	0.61344	0.00132	0.61608
athzpw15kr_1	921	500	0.0	na	43.37	7.4677	9,008.5	51,214.9	60,223.4	31.1484	0.0351	0.46733	0.00103	0.46938
compromised package, homogenous core ($UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector														
TRIGA content, 6,847 g $UZrH_x$ at 70.1 wt % ^{235}U (Reference Table 6.9.6-22b)														
athzpw15kr70_5	408	500	6,803.8	na	538.50	12.6903	2,204.7	51,214.9	53,419.6	31.6977	0.0310	0.71851	0.00148	0.72147
athzpw15kr70_4	408	500	5,102.9	na	429.70	11.7852	3,905.7	51,214.9	55,120.5	31.5622	0.0317	0.69647	0.00123	0.69894
athzpw15kr70_3	408	500	3,401.9	na	320.90	10.7146	5,606.6	51,214.9	56,821.5	31.4254	0.0326	0.66072	0.00122	0.66315
athzpw15kr70_2	408	500	1,701.0	na	212.10	9.3723	7,307.6	51,214.9	58,522.4	31.2875	0.0341	0.59094	0.00118	0.59330
athzpw15kr70_1	408	500	0.0	na	103.30	7.4677	9,008.5	51,214.9	60,223.4	31.1484	0.0354	0.45119	0.00118	0.45355

Table 6.9.6-22c. Results for research reactor fuel (U_3O_8-Al) content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
compromised package, homogenous core (U_3O_8-Al, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector														
THAR content, 15,763 g U_3O_8-Al at 20 wt % ^{235}U														
athopw15kr20_5	921	500	6,803.8	na	211.00	14.1381	2,204.7	51,214.9	53,419.6	31.9552	0.0370	0.62212	0.00133	0.62478
athopw15kr20_4	921	500	5,102.9	na	162.80	13.4243	3,905.7	51,214.9	55,120.5	31.8218	0.0386	0.54443	0.00136	0.54715
athopw15kr20_3	921	500	3,401.9	na	114.60	12.6252	5,606.6	51,214.9	56,821.5	31.6873	0.0412	0.43966	0.00106	0.44178
athopw15kr20_2	921	500	1,701.0	na	66.42	11.7097	7,307.6	51,214.9	58,522.4	31.5517	0.0453	0.29892	0.00105	0.30102
athopw15kr20_1	921	500	0.0	na	18.21	10.6230	9,008.5	51,214.9	60,223.4	31.4149	0.0515	0.16214	0.00052	0.16317
THAR content, 1,996 g U_3O_8-Al at 70 wt % ^{235}U														
athopw15kr70_5	408	500	6,803.8	na	476.30	12.3688	2,204.7	51,214.9	53,419.6	31.6474	0.0340	0.67791	0.00146	0.68084
athopw15kr70_4	408	500	5,102.9	na	367.50	11.4101	3,905.7	51,214.9	55,120.5	31.5114	0.0348	0.64009	0.00130	0.64269
athopw15kr70_3	408	500	3,401.9	na	258.70	10.2557	5,606.6	51,214.9	56,821.5	31.3743	0.0369	0.57400	0.00118	0.57635
athopw15kr70_2	408	500	1,701.0	na	149.90	8.7585	7,307.6	51,214.9	58,522.4	31.2359	0.0400	0.44909	0.00120	0.45150
athopw15kr70_1	408	500	0.0	na	41.10	6.4237	9,008.5	51,214.9	60,223.4	31.0963	0.0479	0.18508	0.00083	0.18674
THAR content, 1,505 g U_3O_8-Al at 93 wt % ^{235}U														
athopw15kr93_5	408	500	6,803.8	na	476.30	12.2959	2,204.7	51,214.9	53,419.6	31.6363	0.0338	0.69183	0.00144	0.69471
athopw15kr93_4	408	500	5,102.9	na	367.50	11.3242	3,905.7	51,214.9	55,120.5	31.5002	0.0348	0.65724	0.00123	0.65970
athopw15kr93_3	408	500	3,401.9	na	258.70	10.1491	5,606.6	51,214.9	56,821.5	31.3630	0.0365	0.59543	0.00147	0.59838
athopw15kr93_2	408	500	1,701.0	na	149.90	8.6114	7,307.6	51,214.9	58,522.4	31.2245	0.0395	0.47503	0.00134	0.47771
athopw15kr93_1	408	500	0.0	na	41.10	6.1427	9,008.5	51,214.9	60,223.4	31.0848	0.0471	0.20615	0.00083	0.20780

Table 6.9.6-22d. Results for research reactor fuel (UO_2-Mg) content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
compromised package, homogenous core ($UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector														
TRIGA content, 10,400 g $UZrH_x$ at 19.7 wt % ^{235}U (Reference Table 6.9.6-22a)														
athzpw15kr_5	921	500	6,803.8	na	236.10	12.6903	2,204.7	51,214.9	53,419.6	31.6977	0.0308	0.80474	0.00154	0.80781
compromised package, homogenous core (6,847 g $UZrH_x$, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector														
TRIGA content, 6,847 g $UZrH_x$ at 70.1 wt % ^{235}U (Reference Table 6.9.6-22b)														
athzpw15kr70_5	408	500	6,803.8	na	538.50	12.6903	2,204.7	51,214.9	53,419.6	31.6977	0.0310	0.71851	0.00148	0.72147
compromised package, homogenous core (UO_2-Mg Al clad, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector														
EK10 content, 19,592 g UO_2-Mg Al clad at 9.89 wt % ^{235}U														
athupw15kr09_5	921	500	6,803.8	na	210.70	14.3227	2,204.7	51,214.9	53,419.6	31.9917	0.0370	0.59466	0.00133	0.59731
athupw15kr09_4	921	500	5,102.9	na	162.60	13.6286	3,905.7	51,214.9	55,120.5	31.8587	0.0382	0.51941	0.00125	0.52191
athupw15kr09_3	921	500	3,401.9	na	114.40	12.8555	5,606.6	51,214.9	56,821.5	31.7245	0.0413	0.41977	0.00109	0.42195
athupw15kr09_2	921	500	1,701.0	na	66.34	11.9762	7,307.6	51,214.9	58,522.4	31.5892	0.0452	0.29437	0.00087	0.29611
athupw15kr09_1	921	500	0.0	na	18.19	10.9444	9,008.5	51,214.9	60,223.4	31.4527	0.0512	0.17226	0.00061	0.17348
EK10 content, 9,678 g UO_2-Mg Al clad at 20 wt % ^{235}U														
athupw15kr20_5	921	500	6,803.8	na	211.00	13.2769	2,204.7	51,214.9	53,419.6	31.7958	0.0356	0.68552	0.00138	0.68828
athupw15kr20_4	921	500	5,102.9	na	162.80	12.4581	3,905.7	51,214.9	55,120.5	31.6611	0.0371	0.61477	0.00137	0.61752
athupw15kr20_3	921	500	3,401.9	na	114.60	11.5148	5,606.6	51,214.9	56,821.5	31.5253	0.0394	0.51363	0.00128	0.51620
athupw15kr20_2	921	500	1,701.0	na	66.41	10.3849	7,307.6	51,214.9	58,522.4	31.3882	0.0435	0.36126	0.00110	0.36346
athupw15kr20_1	921	500	0.0	na	18.21	8.9343	9,008.5	51,214.9	60,223.4	31.2500	0.0514	0.16764	0.00069	0.16901
EK10 content, 921 g UO_2-Mg Al clad at 93.2 wt % ^{235}U														
athupw15kr93_5	408	500	6,803.8	na	476.30	12.2567	2,204.7	51,214.9	53,419.6	31.6304	0.0338	0.69466	0.00138	0.69741
athupw15kr93_4	408	500	5,102.9	na	367.50	11.2780	3,905.7	51,214.9	55,120.5	31.4943	0.0348	0.65939	0.00125	0.66189
athupw15kr93_3	408	500	3,401.9	na	258.70	10.0914	5,606.6	51,214.9	56,821.5	31.3570	0.0365	0.59641	0.00153	0.59947

Table 6.9.6-22d. Results for research reactor fuel (UO_2-Mg) content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
athupw15kr93_2	408	500	1,701.0	na	149.90	8.5310	7,307.6	51,214.9	58,522.4	31.2185	0.0395	0.47695	0.00113	0.47921
athupw15kr93_1	408	500	0.0	na	41.10	5.9820	9,008.5	51,214.9	60,223.4	31.0787	0.0471	0.21220	0.00082	0.21384
497 g UO_2 at 93.2 wt % ^{235}U														
athbpw15kr93_5	408	500	6,803.8	na	476.30	12.1057	2,204.7	51,214.9	53,419.6	31.6080	0.0329	0.70973	0.00139	0.71252
athbpw15kr93_4	408	500	5,102.9	na	367.50	11.0990	3,905.7	51,214.9	55,120.5	31.4717	0.0341	0.67992	0.00137	0.68266
athbpw15kr93_3	408	500	3,401.9	na	258.70	9.8664	5,606.6	51,214.9	56,821.5	31.3342	0.0360	0.62656	0.00139	0.62935
athbpw15kr93_2	408	500	1,701.0	na	149.90	8.2112	7,307.6	51,214.9	58,522.4	31.1954	0.0384	0.52289	0.00131	0.52550
athbpw15kr93_1	408	500	0.0	na	41.10	5.2756	9,008.5	51,214.9	60,223.4	31.0555	0.0437	0.30087	0.00123	0.30334

Table 6.9.6-23. Results for HEU broken metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
compromised package, HEU in spherical configuration, 20.0 cm water reflector (See Table 6.9.6-21)														
compromised package, HEU in spherical configuration, stainless steel, 20.0 cm water reflector (See Table 6.9.6-21)														
compromised package, HEU in spherical configuration, Kaolite shell, 20.0 cm water reflector (See Table 6.9.6-21)														
compromised package, homogenous core (HEU broken metal, poly, and wet Kaolite) in spherical configuration, 20.0 cm water reflector														
7,000 g HEU 100% enrichment														
athmp15kr_12_8_5	7,000	500	9008.5	51,214.9	35.99	31.0803	na	na	na	na	0.0579	0.58855	0.00115	0.59085
athmp15kr_12_8_4	7,000	500	7307.6	51,214.9	29.64	31.0803	na	na	na	na	0.0600	0.56644	0.00118	0.56880
athmp15kr_12_8_3	7,000	500	5606.6	51,214.9	23.30	31.0803	na	na	na	na	0.0617	0.54431	0.00107	0.54644

Table 6.9.6-23. Results for HEU broken metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
athmp15kr_12_8_2	7,000	500	3905.7	51,214.9	16.96	31.0803	na	na	na	na	0.0640	0.51987	0.00112	0.52211
athmp15kr_12_8_1	7,000	500	2204.7	51,214.9	10.62	31.0803	na	na	na	na	0.0658	0.50016	0.00111	0.50238
35,000 g HEU 20% enrichment														
athmp15kr_12_1_5	7,000	500	9008.5	51,214.9	7.20	31.2009	na	na	na	na	0.0558	0.56801	0.00109	0.57020
athmp15kr_12_1_4	7,000	500	7307.6	51,214.9	5.93	31.2009	na	na	na	na	0.0579	0.54764	0.00104	0.54972
athmp15kr_12_1_3	7,000	500	5606.6	51,214.9	4.66	31.2009	na	na	na	na	0.0603	0.52686	0.00109	0.52904
athmp15kr_12_1_2	7,000	500	3905.7	51,214.9	3.39	31.2009	na	na	na	na	0.0621	0.50549	0.00104	0.50757
athmp15kr_12_1_1	7,000	500	2204.7	51,214.9	2.12	31.2009	na	na	na	na	0.0645	0.48986	0.00121	0.49227
compromised package, homogenous core (HEU broken metal, poly, and water from wet Kaolite shell), wet Kaolite shell, 20.0 cm water reflector														
free water limited to 15 lb														
athmpw15kr_12_8_5	7,000	500	6803.8	na	27.77	12.2667	2,204.7	51,214.9	53,419.6	31.6319	0.0344	0.95651	0.00153	0.95956
athmpw15kr_12_8_4	7,000	500	5102.9	na	21.42	11.2898	3,905.7	51,214.9	55,120.5	31.4958	0.0345	0.89106	0.00148	0.89402
athmpw15kr_12_8_3	7,000	500	3401.9	na	15.08	10.1062	5,606.6	51,214.9	56,821.5	31.3585	0.0358	0.81175	0.00129	0.81433
athmpw15kr_12_8_2	7,000	500	1701.0	na	8.74	8.5517	7,307.6	51,214.9	58,522.4	31.2200	0.0377	0.70771	0.00118	0.71008
athmpw15kr_12_8_1	7,000	500	0.0	na	2.40	6.0238	9,008.5	51,214.9	60,223.4	31.0802	0.0401	0.60135	0.00123	0.60381
free water limited to 13 lb														
athmpw13kr_12_8_5	7,000	500	5896.7	na	24.38	11.7659	2,204.7	51,214.9	53,419.6	31.5595	0.0353	0.92418	0.00152	0.92721
athmpw13kr_12_8_4	7,000	500	4422.5	na	18.89	10.8471	3,678.9	51,214.9	54,893.7	31.4410	0.0359	0.85851	0.00141	0.86133
athmpw13kr_12_8_3	7,000	500	2948.3	na	13.39	9.7390	5,153.0	51,214.9	56,367.9	31.3217	0.0371	0.78403	0.00138	0.78680
athmpw13kr_12_8_2	7,000	500	1474.2	na	7.89	8.2969	6,627.2	51,214.9	57,842.0	31.2014	0.0388	0.69268	0.00133	0.69535
athmpw13kr_12_8_1	7,000	500	0.0	na	2.40	6.0238	8,101.3	51,214.9	59,316.2	31.0802	0.0413	0.59728	0.00111	0.59950
free water limited to 12 lb														
athmpw12kr_12_8_5	7,000	500	5443.1	na	22.69	11.4987	2,204.7	51,214.9	53,419.6	31.5231	0.0358	0.90261	0.00179	0.90618
athmpw12kr_12_8_4	7,000	500	4082.3	na	17.62	10.6116	3,565.5	51,214.9	54,780.3	31.4136	0.0363	0.84275	0.00146	0.84568
athmpw12kr_12_8_3	7,000	500	2721.5	na	12.54	9.5445	4,926.2	51,214.9	56,141.1	31.3033	0.0377	0.77003	0.00157	0.77317

Table 6.9.6-23. Results for HEU broken metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
athmpw12kr_12_8_2	7,000	500	1360.8	na	7.47	8.1635	6,287.0	51,214.9	57,501.8	31.1921	0.0397	0.68336	0.00123	0.68583
athmpw12kr_12_8_1	7,000	500	0.0	na	2.40	6.0238	7,647.8	51,214.9	58,862.6	31.0802	0.0420	0.59769	0.00093	0.59955
5,000 g HEU 100% enrichment														
compromised package, homogenous core (HEU broken metal, poly, and wet Kaolite), HEU shell, 20.0 cm water reflector														
7,000 g HEU total at 100% enrichment														
athmp15kmr_														
13_1_8_5	6,500	500	9,008.5	51,214.9	38.75	31.0781	na	na	500	31.0804	0.0574	0.60317	0.00119	0.60556
13_1_8_4	6,500	500	7,307.6	51,214.9	31.92	31.0781	na	na	500	31.0804	0.0591	0.57747	0.00116	0.57980
13_1_8_3	6,500	500	5,606.6	51,214.9	25.09	31.0781	na	na	500	31.0804	0.0599	0.55460	0.00118	0.55695
13_1_8_2	6,500	500	3,905.7	51,214.9	18.26	31.0781	na	na	500	31.0804	0.0628	0.52945	0.00111	0.53166
13_1_8_1	6,500	500	2,204.7	51,214.9	11.43	31.0781	na	na	500	31.0804	0.0653	0.50475	0.00103	0.50680
athmp15kmr_														
12_2_8_5	6,000	500	9,008.5	51,214.9	41.98	31.0759	na	na	1,000	31.0804	0.0570	0.61042	0.00108	0.61259
12_2_8_4	6,000	500	7,307.6	51,214.9	34.58	31.0759	na	na	1,000	31.0804	0.0584	0.58402	0.00116	0.58635
12_2_8_3	6,000	500	5,606.6	51,214.9	27.18	31.0759	na	na	1,000	31.0804	0.0597	0.56023	0.00112	0.56247
12_2_8_2	6,000	500	3,905.7	51,214.9	19.79	31.0759	na	na	1,000	31.0804	0.0622	0.53546	0.00120	0.53785
12_2_8_1	6,000	500	2,204.7	51,214.9	12.39	31.0759	na	na	1,000	31.0804	0.0641	0.51198	0.00121	0.51440
athmp15kmr_														
11_3_8_5	5,500	500	9,008.5	51,214.9	45.80	31.0737	na	na	1,500	31.0804	0.0562	0.61411	0.00105	0.61622
11_3_8_4	5,500	500	7,307.6	51,214.9	37.73	31.0737	na	na	1,500	31.0804	0.0580	0.58816	0.00119	0.59055
11_3_8_3	5,500	500	5,606.6	51,214.9	29.66	31.0737	na	na	1,500	31.0804	0.0596	0.56400	0.00110	0.56619
11_3_8_2	5,500	500	3,905.7	51,214.9	21.58	31.0737	na	na	1,500	31.0804	0.0620	0.53899	0.00140	0.54180
11_3_8_1	5,500	500	2,204.7	51,214.9	13.51	31.0737	na	na	1,500	31.0804	0.0643	0.51766	0.00116	0.51999

Table 6.9.6-23. Results for HEU broken metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
athmp15kmr_														
10_4_8_5	5,000	500	9,008.5	51,214.9	50.38	31.0715	na	na	2,000	31.0804	0.0561	0.61900	0.00118	0.62136
10_4_8_4	5,000	500	7,307.6	51,214.9	41.50	31.0715	na	na	2,000	31.0804	0.0575	0.59390	0.00121	0.59633
10_4_8_3	5,000	500	5,606.6	51,214.9	32.62	31.0715	na	na	2,000	31.0804	0.0594	0.57154	0.00119	0.57393
10_4_8_2	5,000	500	3,905.7	51,214.9	23.74	31.0715	na	na	2,000	31.0804	0.0609	0.54282	0.00127	0.54536
10_4_8_1	5,000	500	2,204.7	51,214.9	14.86	31.0715	na	na	2,000	31.0804	0.0634	0.52061	0.00121	0.52302
athmp15kmr_														
9_5_8_5	4,500	500	9,008.5	51,214.9	55.98	31.0693	na	na	2,500	31.0804	0.0554	0.62058	0.00116	0.62290
9_5_8_4	4,500	500	7,307.6	51,214.9	46.11	31.0693	na	na	2,500	31.0804	0.0575	0.59711	0.00124	0.59959
9_5_8_3	4,500	500	5,606.6	51,214.9	36.25	31.0693	na	na	2,500	31.0804	0.0590	0.57410	0.00120	0.57651
9_5_8_2	4,500	500	3,905.7	51,214.9	26.38	31.0693	na	na	2,500	31.0804	0.0602	0.54863	0.00137	0.55137
9_5_8_1	4,500	500	2,204.7	51,214.9	16.51	31.0693	na	na	2,500	31.0804	0.0626	0.52393	0.00109	0.52612
athmp15kmr_														
8_6_8_5	4,000	500	9,008.5	51,214.9	62.98	31.0671	na	na	3,000	31.0804	0.0550	0.62552	0.00127	0.62807
8_6_8_4	4,000	500	7,307.6	51,214.9	51.88	31.0671	na	na	3,000	31.0804	0.0567	0.59946	0.00102	0.60150
8_6_8_3	4,000	500	5,606.6	51,214.9	40.78	31.0671	na	na	3,000	31.0804	0.0586	0.57673	0.00115	0.57902
8_6_8_2	4,000	500	3,905.7	51,214.9	29.68	31.0671	na	na	3,000	31.0804	0.0600	0.54941	0.00110	0.55162
8_6_8_1	4,000	500	2,204.7	51,214.9	18.58	31.0671	na	na	3,000	31.0804	0.0618	0.52536	0.00112	0.52759
athmp15kmr_														
7_7_8_5	3,500	500	9,008.5	51,214.9	71.97	31.0649	na	na	3,500	31.0804	0.0549	0.62911	0.00118	0.63147
7_7_8_4	3,500	500	7,307.6	51,214.9	59.29	31.0649	na	na	3,500	31.0804	0.0559	0.60301	0.00111	0.60524
7_7_8_3	3,500	500	5,606.6	51,214.9	46.60	31.0649	na	na	3,500	31.0804	0.0585	0.58073	0.00114	0.58300
7_7_8_2	3,500	500	3,905.7	51,214.9	33.92	31.0649	na	na	3,500	31.0804	0.0595	0.55359	0.00105	0.55569
7_7_8_1	3,500	500	2,204.7	51,214.9	21.23	31.0649	na	na	3,500	31.0804	0.0616	0.52699	0.00109	0.52917

Table 6.9.6-23. Results for HEU broken metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
athmp15kmr_														
6_8_8_5	3,000	500	9,008.5	51,214.9	83.97	31.0627	na	na	4,000	31.0804	0.0546	0.62838	0.00151	0.63139
6_8_8_4	3,000	500	7,307.6	51,214.9	69.17	31.0627	na	na	4,000	31.0804	0.0555	0.60625	0.00125	0.60875
6_8_8_3	3,000	500	5,606.6	51,214.9	54.37	31.0627	na	na	4,000	31.0804	0.0578	0.58134	0.00125	0.58383
6_8_8_2	3,000	500	3,905.7	51,214.9	39.57	31.0627	na	na	4,000	31.0804	0.0594	0.55515	0.00127	0.55768
6_8_8_1	3,000	500	2,204.7	51,214.9	24.77	31.0627	na	na	4,000	31.0804	0.0610	0.53102	0.00108	0.53319
athmp15kmr_														
5_9_8_5	2,500	500	9,008.5	51,214.9	100.76	31.0605	na	na	4,500	31.0804	0.0538	0.63099	0.00114	0.63327
5_9_8_4	2,500	500	7,307.6	51,214.9	83.00	31.0605	na	na	4,500	31.0804	0.0558	0.60575	0.00136	0.60847
5_9_8_3	2,500	500	5,606.6	51,214.9	65.24	31.0605	na	na	4,500	31.0804	0.0567	0.58348	0.00109	0.58565
5_9_8_2	2,500	500	3,905.7	51,214.9	47.48	31.0605	na	na	4,500	31.0804	0.0589	0.55833	0.00117	0.56068
5_9_8_1	2,500	500	2,204.7	51,214.9	29.73	31.0605	na	na	4,500	31.0804	0.0603	0.53262	0.00106	0.53475
athmp15kmr_														
4_10_8_5	2,000	500	9,008.5	51,214.9	125.95	31.0583	na	na	5,000	31.0804	0.0543	0.62891	0.00114	0.63120
4_10_8_4	2,000	500	7,307.6	51,214.9	103.75	31.0583	na	na	5,000	31.0804	0.0550	0.60731	0.00134	0.60999
4_10_8_3	2,000	500	5,606.6	51,214.9	81.55	31.0583	na	na	5,000	31.0804	0.0571	0.58296	0.00114	0.58524
4_10_8_2	2,000	500	3,905.7	51,214.9	59.36	31.0583	na	na	5,000	31.0804	0.0585	0.55876	0.00107	0.56090
4_10_8_1	2,000	500	2,204.7	51,214.9	37.16	31.0583	na	na	5,000	31.0804	0.0595	0.53467	0.00107	0.53680
athmp15kmr_														
3_11_8_5	1,500	500	9,008.5	51,214.9	167.93	31.0562	na	na	5,500	31.0804	0.0537	0.62987	0.00112	0.63211
3_11_8_4	1,500	500	7,307.6	51,214.9	138.34	31.0562	na	na	5,500	31.0804	0.0548	0.60668	0.00123	0.60914
3_11_8_3	1,500	500	5,606.6	51,214.9	108.74	31.0562	na	na	5,500	31.0804	0.0562	0.58487	0.00114	0.58715
3_11_8_2	1,500	500	3,905.7	51,214.9	79.14	31.0562	na	na	5,500	31.0804	0.0576	0.56087	0.00115	0.56318
3_11_8_1	1,500	500	2,204.7	51,214.9	49.54	31.0562	na	na	5,500	31.0804	0.0591	0.53887	0.00135	0.54156

Table 6.9.6-23. Results for HEU broken metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Kaolite (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	core						shell							
athmp15kmr_														
2_12_8_5	1,000	500	9,008.5	51,214.9	251.90	31.0540	na	na	6,000	31.0804	0.0533	0.62727	0.00121	0.62970
2_12_8_4	1,000	500	7,307.6	51,214.9	207.50	31.0540	na	na	6,000	31.0804	0.0544	0.60687	0.00128	0.60942
2_12_8_3	1,000	500	5,606.6	51,214.9	163.11	31.0540	na	na	6,000	31.0804	0.0559	0.58520	0.00134	0.58788
2_12_8_2	1,000	500	3,905.7	51,214.9	118.71	31.0540	na	na	6,000	31.0804	0.0571	0.56092	0.00109	0.56310
2_12_8_1	1,000	500	2,204.7	51,214.9	74.32	31.0540	na	na	6,000	31.0804	0.0587	0.54206	0.00105	0.54415
athmp15kmr_														
1_13_8_5	500	500	9,008.5	51,214.9	503.80	31.0518	na	na	6,500	31.0804	0.0526	0.62145	0.00093	0.62332
1_13_8_4	500	500	7,307.6	51,214.9	415.01	31.0518	na	na	6,500	31.0804	0.0534	0.60274	0.00132	0.60537
1_13_8_3	500	500	5,606.6	51,214.9	326.22	31.0518	na	na	6,500	31.0804	0.0552	0.58252	0.00115	0.58482
1_13_8_2	500	500	3,905.7	51,214.9	237.42	31.0518	na	na	6,500	31.0804	0.0567	0.56327	0.00121	0.56570
1_13_8_1	500	500	2,204.7	51,214.9	148.63	31.0518	na	na	6,500	31.0804	0.0579	0.54039	0.00112	0.54263

Appendix 6.9.7

Input Listings of ES-3100 Calculation Models for Select Cases

This appendix contains selected input listing for calculations identified Tables 6.1a-f and Sects. 6.4, 6.5, and 6.6 of this document, and Sect. 6.7 on air transport.

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ES-3100 Input file - Results table crosswalk

Section	Case	Description	Results table
6.9.7.1	cvcrcyt11_21_1	3 cyl, 0.0 in. np, 21000 g U (21000 g ^{235}U, 9082.6 g H_2O, h/x=11.29)	6.9.6-1
6.9.7.2	cvcrcyt11_36_2	3 cyl, 1.4 in. np, 36000 g U (36000 g ^{235}U, 7673.1 g H_2O, h/x=5.56)	6.9.6-1
6.9.7.3	cvcrsqt11_36_1	3 bar, 0.0 in. np, 36000 g U (36000 g ^{235}U, 8286.7 g H_2O, h/x=6.01)	6.9.6-4
6.9.7.4	cvcrcyct11_17_1	3 cyl, 0.0 in. np, 17000 gU (17000 g ^{235}U, 9294.9 g H_2O, h/x=14.27)	6.9.6-6
6.9.7.5	cvcrcyct11_32_2	3 cyl, 1.4 in. np, 32000 g U (32000 g ^{235}U, 7885.3 g H_2O, h/x= 6.43)	6.9.6-6
6.9.7.6	cvcr5est11_1_1	0.0 in. np, 18286.5 g U (18286.5 g ^{235}U, 9226.6 g H_2O, h/x=13.75)	6.9.6-8
6.9.7.7	cvcr6e4st11_1	1.4 in. np, 36573.0 g U (36573.0 g ^{235}U, 7642.7 g H_2O, h/x= 5.45)	6.9.6-8
6.9.7.8	cvcr70st11_2	1.4 in. np, 25588.2 g U (25588.2 g ^{235}U, 8225.3 g H_2O, h/x= 8.39)	6.9.6-8
6.9.7.9	cvr3sqa_26_1_8_15	0.0 in. np, 25893.7 g U (25893.7 g ^{235}U, 8822.9 g H_2O, h/x= 8.89)	N/A[a]
6.9.7.10	cvr3lha_26_1_8_15	0.0 in. np, 25893.7 g U (25893.7 g ^{235}U, 8822.9 g H_2O, h/x= 8.89)	6.9.6-10
6.9.7.11	cvr3cha_26_1_8_15	0.0 in. np, 25893.7 g U (25893.7 g ^{235}U, 8822.9 g H_2O, h/x= 8.89)	N/A[a]
6.9.7.12	cvcrpdoxt11_1_5_24_15	0.0 in. np, disp. 24,000 g UO_2 (21,124.9 g ^{235}U, 1,477.3 g Sat.H_2O), 4 g H_2O CV, h/x= 10.02)	6.9.6-12
6.9.7.13	cvcrsk3cc_9_15_17	0.0 in. np, 21300 g SOC (19865.3 g UOx, 15672.8 g ^{235}U, 921.0 g C, h/x=12.82)	6.9.6-17
6.9.7.14	cvcrunhct11_9_1	0.0 in. np, disp. 9000 g UNHc (4238.7 g ^{235}U, 6980.8 g H_2O, h/x=54.99)	6.9.6-14
6.9.7.15	cvcrtriga_1_15	0.0 in. np, 10400.0 g UZrHx (921.0 g ^{235}U, 8998.2 g H_2O, h/x=255.01)	6.9.6-19a
6.9.7.16	ncsrcyt11_21_1_15	3 cyl, 0.0 in. np, 21000 g U (21000 g ^{235}U, 9082.6 g H_2O, h/x=11.29)	6.9.6-2
6.9.7.17	nciacyct11_25_2_3	3 cyl, 1.4 in. np, 25000 g U (25000 g ^{235}U, 8256.8 g H_2O, h/x= 8.62)	6.9.6-7
6.9.7.18	hciacyct12_25_2_3	3 cyl, 1.4 in. np, 25000 g U (25000 g ^{235}U, 8256.8 g H_2O, h/x= 8.62)	6.9.6-7
6.9.7.19	ncia70st11_2_8_3	1.4 in. np, 25588.2 g U (25588.2 g ^{235}U, 8224.9 g H_2O, h/x= 8.39)	6.9.6-9
6.9.7.20	ncia5est11_2_2_5_3	1.4 in. np, 36647 g U (29318 g ^{235}U, 7642.7 g H_2O, h/x= 6.80)	6.9.6-9
6.9.7.21	nciabmt11_4_1_5_3	0.0 in. np, 3708.5 g U (2966.8 g ^{235}U, 10000.7 g H_2O, h/x=87.98)	6.9.6-11
6.9.7.22	hctf5bmt12_25_2_8_3	1.4 in. np, 24968.9 g U (24968.9 g ^{235}U, 8258.4 g H_2O, h/x= 8.63)	6.9.6-11
6.9.7.23	nciaoxt11_1_24_1_3	0.0 in. np, disp. 24000 g UO_2 (21124.9 g ^{235}U, 6533.9 g H_2O, h/x= 9.90)	N/A[a]
6.9.7.24	nciask_9_15	0.0 in. np, 21300 g SOC (19865.3 g UOx, 15672.8 g ^{235}U, 921.0 g C, h/x=12.82)	6.9.6-18a
6.9.7.25	ncsrunhct11_9_1_15	0.0 in. np, disp. 9000 g UNHc (4238.7 g ^{235}U, 6980.8 g H_2O, h/x=54.99)	6.9.6-15
6.9.7.26	icsrunhct12_15_1_15	0.0 in. np, disp. 15,000.0 g UNHc (7064.4 g ^{235}U, 6870.7 g H_2O, h/x=52.91)	6.9.6-16

ES-3100 Input file - Results table crosswalk

Section	Case	Description	Results table
6.9.7.27	ncsrtriga_1_15_15	0.0 in. np, 10400.0 g UZrHx (921.0 g ^{235}U, 8998.2 g H_2O, h/x=255.01)	6.9.6-20a
6.9.7.28	nciatriga_1_15_3	0.0 in. np, 10400.0 g UZrHx (921.0 g ^{235}U, 8998.2 g H_2O, h/x=255.01)	6.9.6-20a
6.9.7.29	atdmr_7_8	7000 g U, 7000 g ^{235}U, 500.0 g CH_2, h/x=2.40, Rc=6.02382 cm	6.9.6-21
6.9.7.30	atdmsr_7_8_11	7000 g U, 7000 g ^{235}U, 500.0 g CH_2, h/x=2.40, Rc=6.02382 cm, 66133.1 g SS, Rs=13.0198 cm	6.9.6-21
6.9.7.31	atdmdkr_7_8_6	7000 g U, 7000 g ^{235}U, 500.0 g CH_2, h/x=2.40, Rc=6.02382 cm, 53419.1 g Kao, Rk=31.0802 cm	6.9.6-21
6.9.7.32	atdzr	10400.0 g $UZrH_x$ (921.0 g ^{235}U, 500.0 g CH_2, h/x=43.37), Rc=7.4677 cm	6.9.6-22a
6.9.7.33	athzp15kr_5	10400.0 g $UZrH_x$ (921.0 g ^{235}U, 500.0 g CH_2, 9008.5 g H_2O, h/x=298.6), Rc=31.14838 cm	6.9.6-22a
6.9.7.34	athzpw15kr_5	10400 g $UZrH_x$, 921.0 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, h/x=236.1, Rc=12.69027 cm, Rs=31.69769 cm	6.9.6-22a
6.9.7.35	athmp15kr_12_8_5	7000 g U, 7000 g ^{235}U, 500.0 g CH_2, 9008.3 g H_2O, h/x=35.99, Rc=31.08025 cm	6.9.6-23
6.9.7.36	athmpw15kr_12_8_5	7000 g U, 7000 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, h/x=27.77, Rc=12.26673 cm, 53419.6 g Kao, Rs=31.63191 cm	6.9.6-23
6.9.7.37	athmpw13kr_12_8_5	7000 g U, 7000 g ^{235}U, 500.0 g CH_2, 5896.6 g H_2O, h/x=24.38, Rc=11.76592 cm, 53419.6 g Kao, Rs=31.55946 cm	6.9.6-23
6.9.7.38	athmp15kmr_7_7_8_5	7000 g U,(3500 g ^{235}U, 500 g CH_2, 9008.5 g H_2O, h/x=71.97, Rc=31.06492 cm, 3500 g ^{235}U, Rs=31.08035 cm	6.9.6-23
6.9.7.39	cvcrtriga_1_1	0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g ^{235}U, 0.0 g H_2O, hx = 0.00)	6.9.6-19a
6.9.7.40	cvcrtriga_1_15	0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g ^{235}U, 8998.2 g H_2O, hx = 255.01)	6.9.6-19a
6.9.7.41	cvcrtriga_2_15	1.4 in. np, 10400.0 g $UZrH_x$ (921.0 g ^{235}U, 8384.6 g H_2O, h/x = 237.62)	6.9.6-19a
6.9.7.42	cvcrtriga_70_1_1	0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g ^{235}U, 0.0 g H_2O, h/x = 0.0)	6.9.6-19a
6.9.7.43	cvcrtriga_70_1_15	0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g ^{235}U, 8998.2 g H_2O, h/x = 575.64)	6.9.6-19a
6.9.7.44	cvcrtriga_70_2_15	1.4 in. np, 6847.1 g $UZrH_x$ (408.0 g ^{235}U, 8384.6 g H_2O, h/x = 536.39)	6.9.6-19a
6.9.7.45	ncsrtriga_1_15_15	0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g ^{235}U, 8998.2 g H_2O, h/x = 255.01)	6.9.6-20a
6.9.7.46	ncsrtriga70_1_15_15	0.0 in. np, 6847.1 g UZrHx (408.0 g ^{235}U, 8998.2 g H_2O, h/x = 575.64)	6.9.6-20b
6.9.7.47	ncsrt55d2_1_15_15	0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g ^{235}U, 8998.2 g H_2O, h/x = 255.01)	6.9.6-20d
6.9.7.48	hcsrtriga_1_15_15	0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g ^{235}U, 8998.2 g H_2O, h/x = 255.01)	6.9.6-20a
6.9.7.49	hcsrtriga70_1_15_15	0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g ^{235}U, 8998.2 g H_2O, h/x = 575.64)	6.9.6-20b
6.9.7.50	nciatriga_1_15_3	0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g ^{235}U, 8998.2 g H_2O, h/x = 255.01)	6.9.6-20a
6.9.7.51	nciatriga70_1_15_3	0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g ^{235}U, 8998.2 g H_2O, h/x = 575.64)	6.9.6-20b
6.9.7.52	hciatriga_1_15_3	0.0 in. np, 10400.0 g $UZrH_x$ (921.0 g ^{235}U, 8998.2 g H_2O, h/x = 255.01)	6.9.6-20a

ES-3100 Input file - Results table crosswalk

Section	Case	Description	Results table
6.9.7.53	hciatriga70_1_15_3	0.0 in. np, 6847.1 g $UZrH_x$ (408.0 g ^{235}U, 8998.2 g H_2O, h/x = 575.64)	6.9.6-20b
6.9.7.54	ncsrT70_131_1_15_15	0.0in. np, 5666.6 g $UZrH_x$ (337.7 g ^{235}U, 9204.9 g H_2O, hx = 711.53), fr=1.0E+00	6.9.6-20c
6.9.7.55	nciaT70_131_1_15_3	0.0in. np, 5666.6 g $UZrH_x$ (337.7 g ^{235}U, 9204.9 g H_2O, hx = 711.53), fr=1.0E-04	6.9.6-20c
6.9.7.56	athopw15kr20_5	15763.0 g U_3O_8-Al (921.0 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, h/x = 211.0, Rc=14.13813 cm, 53419.6 g Kao, Rs=31.95515 cm	6.9.6-22c
6.9.7.57	athopw15kr70_5	1995.7 g U_3O_8-Al (408.0 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, h/x = 476.3, Rc=12.36884 cm, 53419.6 g Kao, Rs=31.64738 cm	6.9.6-22c
6.9.7.58	athopw15kr93_5	1505.0 g U_3O_8-Al (408.0 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, h/x=476.3, Rc=12.29589 cm, 53419.6 g Kao, Rs=31.63630 cm	6.9.6-22c
6.9.7.59	athupw15kr93_5	920.5 g UO_2 Mg-Al (408.0 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, g htox=476.3, Rc=12.25670 cm, 53419.6 g Kao, Rs=31.63040 cm	6.9.6-22d
6.9.7.60	athupw15kr20_5	9677.7 g UO Mg-Al (921.0 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, g htox=211.0, Rc=13.27685 cm, 53419.6 g Kao, Rs=31.79582 cm	6.9.6-22d
6.9.7.61	athupw15kr09_5	19592.0 g UO_2 Mg-Al (921.0 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, g htox=210.7, Rc=14.32268 cm, 53419.6 g Kao, Rs=31.99170 cm	6.9.6-22d
6.9.7.62	athbpw15kr93_5	497.30 g UO_2 (408.0 g ^{235}U, 500.0 g CH_2, 6803.8 g H_2O, htox=476.3, Rc=12.10567 cm, 53419.6 g Kao, Rs=31.60798 cm	6.9.6-22d
6.9.7.63	cvcrcyat11_2_2	3 cyl, 1.4 in. np, 30,000 g U (30,000 g ^{235}U, 7,991.5 g H_2O, hx=6.95), sep=0.254	6.9.6-3b
6.9.7.64	cvcrcyat11_11_2	3 cyl, 1.4 in. np, 30,000 g U (30,000 g ^{235}U, 7,991.5 g H_2O, hx=6.95), sep=4.826	6.9.6-3b
6.9.7.65	cvcrpunhct11_10_15	10,000.2 g UNHc (4,709.7 g ^{235}U, 2,165.3 g H_2O) 6,081 g H_2O CV, hx=49.26	6.9.6-14
6.9.7.66	cvcrbpunhct11_24_15	24,000.0 g UNHc (11,303.1 g ^{235}U, 5,196.7 g H_2O) 1,077.9 g H_2O CV, hx=15.97	6.9.6-14
6.9.7.67	nciapbmflt11_1_6_4_5	0.0 in. np, 4,000.2 g U (3,200.2 g ^{235}U), 9,442.7 g H_2O CV, hx=82.26, fr=0.0001	6.9.6-11b
6.9.7.68	nciapbmfdt11_1_6_4_5	0.0 in. np, 4,000.2 g U (3,200.2 g ^{235}U), 9,442.7 g H_2O CV, hx=82.26, fr=0.0001	6.9.6-11b
6.9.7.69	ncsrpunhct11_8_15	8,000.1 g UNHc (3,767.7 g ^{235}U, 1,732.2 g H_2O) 6,795.6 g H_2O CV, hx= 63.53	6.9.6-15
6.9.7.70	icsrpunhct12_15_15	15,000.0 g UNHc (7,064.4 g ^{235}U, 3,247.9 g H_2O) 6,397.6 g H_2O CV, hx=53.28	6.9.6-16

[a] N/A = not applicable. Input files included in appendix for comparison with bounding model but not recorded in results tables.

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6.9.7.1 Case cvcrcyt11_21_1

```
=csas25    parm=size=3000000
cvcrcyt11 3cyl,0.0in thk np,21000.0gU(21000.0g235, 9082.6gH2O hx= 11.29),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1116.36286, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.80, CV void volume 9098.99908'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrcyt11 3cyl,0.0in thk np,21000.0gU(21000.0g235, 9082.6gH2O,hx= 11.29),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 7.675 in.]'
 cylinder  1  1    4.114800     6.99579   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    6.99629  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    6.99629  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    6.99629  -0.0005  com='drum chine outer radius'
```

```
unit 1007
'np277_4 spacer [Elev= 7.675 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'20.99097             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   56.09803   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   56.09803   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   56.09803   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
```

```
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.2 Case cvcrcyt11_36_2

```
=csas25    parm=size=3000000
cvcrcyt11 3cyl,1.4in thk np,36000.0gU(36000.0g235, 7673.1gH2O hx=  5.56),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1913.76490, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.47, CV void volume 7686.91692'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrcyt11 3cyl,1.4in thk np,36000.0gU(36000.0g235, 7673.1gH2O,hx=  5.56),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
```

```
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 9.642 in.]'
 cylinder  1  1    4.114800    11.99278   0.0     com='cylindrical content'
 cylinder  3  1    6.426200   11.99328  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   11.99328  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   11.99328  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.042 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'43.09395             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   33.99505   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   33.99505   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   33.99505   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
```

```
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.3 Case cvcrsqt11_36_1

```
=csas25    parm=size=3000000
cvcrsqt11 3bar,0.0in thk np,36000.0gU(36000.0g235, 8286.7gH2O hx=  6.01),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1913.76490, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.47, CV void volume 8301.59704'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
```

```
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrsqt11 3bar,0.0in thk np,36000.0gU(36000.0g235, 8286.7gH2O,hx=  6.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev=12.337 in.]'
 cuboid    1  1  4p2.909600    18.83826   0.0     com='block content'
 cylinder  3  1    6.426200   18.83876  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   18.83876  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   18.83876  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=12.337 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'56.51838             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   20.57062   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   20.57062   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   20.57062   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
```

```
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.4 Case cvcrcyct11_17_1

```
=csas25    parm=size=3000000
cvcrcyct11 3cyl,0.0in thk np,17000.1gU(17000.1g235, 9294.9gH2O hx= 14.27),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume = 903.72763, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.99, CV void volume 9311.63431'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
```

```
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                                 8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                 8016   88.8087   21  1.0     293  end
end comp
cvcrcyct11 3cyl,0.0in thk np,17000.1gU(17000.1g235, 9294.9gH2O,hx= 14.27),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                           end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 6.216 in.]'
 cylinder  1  1    5.397500     3.29140   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    3.29190  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    3.29190  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.29190  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 6.216 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
' 9.87781             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   67.21119   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   67.21119   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   67.21119   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
```

```
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.5 Case cvcrcyct11_32_2

```
=csas25    parm=size=3000000
cvcrcyct11 3cyl,1.4in thk np,32000.1gU(32000.1g235, 7885.3gH2O hx=  6.43),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1701.12968, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.52, CV void volume 7899.55215'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
```

```
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                  5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                  7014    0.0141
                                  8016   43.4251
                                 11023    0.1174
                                 12000    0.3378
                                 13027   39.0479
                                 14000    2.4672
                                 16000    0.3083
                                 20000   11.8336
                                 26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                  8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrcyct11 3cyl,1.4in thk np,32000.1gU(32000.1g235, 7885.3gH2O,hx=  6.43),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 7.360 in.]'
 cylinder  1  1    5.397500     6.19557   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    6.19607  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    6.19607  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    6.19607  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 8.760 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'25.70230             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   51.38670   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   51.38670   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   51.38670   0.0     com='drum chine outer radius'
unit 1010
```

```
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.6 Case cvcr5est11_1_1

```
=csas25    parm=size=3000000
cvcr5est11,0.0in np,18277.3gU(18277.3g235, 9226.9gH2O hx= 13.18),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume = 971.62217, SPACER volume    0.01729'
'HEU wrapped dry content can hx=0.92, CV void volume 9243.50194'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                              8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
```

```
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcr5est11,0.0in np,18277.3gU(18277.3g235, 9226.9gH2O,hx= 13.18),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                          end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 6.983 in.]'
'Reference CRC 29 Ed. pg 105'
'side of pentagon denoted spent'
'radius of inscribed circle in pentagon denoted icrpent'
'radius of circumscribed circle outside pentagon denoted ccrpent'
'ccrpent equals 0.85065 times spent'
'icrpent equals 0.68819 times spent'
'side of pentagon equals diameter of a cylinder fit into cc'
'radius of cc equals ccrpent plus radius of cylinder fit into cc'
'radius of ccrpent equal diamater of slug'
' 3.96875 radius of circumscribed circle'
' 2.33277 half of side of pentagon'
' 3.21078 radius of inscribed circle'
' 3.77452 x axis location of 2nd cyl in cc'
' 1.22642 y axis location of 2nd cyl in cc'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1020    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1020    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1020    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1020   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1020   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 6.983 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev= 9.046 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1021    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1021    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1021    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1021   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1021   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
```

```
unit 1007
'np277_4 spacer [Elev= 9.046 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev= 9.046 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1022    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1022    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1022    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1022   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1022   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'15.72155             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   61.36745   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   61.36745   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   61.36745   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
```

```
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
global
unit 1023
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.7 Case cvcr6e4st11_1

```
=csas25    parm=size=3000000
cvcr6e4st11,0.0in np,36554.5gU(36554.5g235, 8257.0gH2O hx=  5.90),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1943.24434, SPACER volume    0.01729'
'HEU wrapped dry content can hx=0.46, CV void volume 8271.87977'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
```

```
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
```

```
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcr6e4st11,0.0in np,36554.5gU(36554.5g235, 8257.0gH2O,hx=  5.90),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 9.045 in.]'
'Reference CRC 29 Ed. pg 105'
'side of pentagon denoted spent'
'radius of inscribed circle in pentagon denoted icrpent'
'radius of circumscribed circle outside pentagon denoted ccrpent'
```

```
'ccrpent equals 0.85065 times spent'
'icrpent equals 0.68819 times spent'
'side of pentagon equals diameter of a cylinder fit into cc'
'radius of cc equals ccrpent plus radius of cylinder fit into cc'
'radius of ccrpent equal diamater of slug'
' 3.96925 radius of circumscribed circle'
' 2.33307 half of side of pentagon'
' 3.21119 radius of inscribed circle'
' 3.77499 x axis location of 2nd cyl in cc'
' 1.22658 y axis location of 2nd cyl in cc'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1020    0.0       3.96925 0.0        com='cy1 (0,ccrpent)'
 hole  1020    3.77499   1.22658 0.0        com='cy2 (xtwo,ytwo)'
 hole  1020    2.33307  -3.21119 0.0        com='cy3 (hspent,-icrpent)'
 hole  1020   -2.33307  -3.21119 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1020   -3.77499   1.22658 0.0        com='cy5 (-xtwo,ytwo)'
 hole  1020    0.0       0.0    0.0        com='cy6 (0,0)'
 hole  1020    2.80704   0.0 5.23875      com='cy7'
 hole  1020   -2.80704   0.0 5.23875      com='cy8'
 hole  1020    0.0     2.80704 5.23875      com='cy9'
 hole  1020    0.0    -2.80704 5.23875      com='cy10'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   10.47800  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 9.046 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev=13.171 in.]'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1021    0.0       3.96925 0.0        com='cy1 (0,ccrpent)'
 hole  1021    3.77499   1.22658 0.0        com='cy2 (xtwo,ytwo)'
 hole  1021    2.33307  -3.21119 0.0        com='cy3 (hspent,-icrpent)'
 hole  1021   -2.33307  -3.21119 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1021   -3.77499   1.22658 0.0        com='cy5 (-xtwo,ytwo)'
 hole  1021    0.0       0.0    0.0        com='cy6 (0,0)'
 hole  1021    2.80704   0.0 5.23875      com='cy7'
 hole  1021   -2.80704   0.0 5.23875      com='cy8'
 hole  1021    0.0     2.80704 5.23875      com='cy9'
 hole  1021    0.0    -2.80704 5.23875      com='cy10'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   10.47800  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=13.171 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev=13.171 in.]'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1022    0.0       3.96925 0.0        com='cy1 (0,ccrpent)'
 hole  1022    3.77499   1.22658 0.0        com='cy2 (xtwo,ytwo)'
 hole  1022    2.33307  -3.21119 0.0        com='cy3 (hspent,-icrpent)'
 hole  1022   -2.33307  -3.21119 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1022   -3.77499   1.22658 0.0        com='cy5 (-xtwo,ytwo)'
 hole  1022    0.0       0.0    0.0        com='cy6 (0,0)'
 hole  1022    2.80704   0.0 5.23875      com='cy7'
 hole  1022   -2.80704   0.0 5.23875      com='cy8'
```

```
 hole  1022    0.0     2.80704 5.23875      com='cy9'
 hole  1022    0.0    -2.80704 5.23875      com='cy10'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   10.47800  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'31.43780             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   45.65120   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   45.65120   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   45.65120   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
global
unit 1023
```

```
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.8 Case cvcr70st11_2

```
=csas25    parm=size=3000000
cvcr70st11,1.4in np,25588.2gU(25588.2g235, 8225.3gH2O hx=  8.39),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1360.27104, SPACER volume  614.69740'
'HEU wrapped dry content can hx=0.66, CV void volume 8240.17295'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
```

```
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
```

```
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcr70st11,1.4in np,25588.2gU(25588.2g235, 8225.3gH2O,hx=  8.39),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 6.983 in.]'
'3.437212   plus-y location cylinders'
'-3.437212  minus-y location cylinders'
'1.984375   plus-x location cylinders'
'-1.984375  minus-x location cylinders'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1020   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1020   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1020    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1020    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1020    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1020   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1020    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 8.383 in.]'
```

```
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev=10.446 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1021   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1021   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1021    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1021    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1021    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1021   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1021    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.846 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev=10.446 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1022   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1022   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1022    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1022    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1022    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1022   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1022    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200    5.23925  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'22.83355             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   54.25545   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   54.25545   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   54.25545   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
```

```
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
global
unit 1023
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.9 Case cvr3sqa_26_1_8_15

```
=csas25    parm=size=3000000
cvr 3x3sqa,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O hx=  8.89),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1376.51338, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.65, CV void volume 8838.84856'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
```

```
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07072e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4264
                                11023    0.1174
                                12000    0.3378
                                13027   39.0470
                                14000    2.4671
                                16000    0.3083
                                20000   11.8333
                                26000    0.5297    2  1.0000  293  end
arbmnph2o 3.84144e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'void space internal to containmment vessel -- including content cans'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvr 3x3sqa,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O,hx=  8.89),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  308.25850             HEU mass one cube'
'   28                   number of HEU cubes per can'
' 8631.23808             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    4    VARIABLE       number of HEU layers in z-axis'
'    1    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    8    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill'
```

```
'    0.48924     0.19261 gap dimension                        CALCULATED
'    3.02924     1.19261 unit cell dimension                  CALCULATED
'    1.51462     0.59631 unit cell half-dimension             CALCULATED
'   27.79719     1.69629 volume of unit cell                  CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell     CALCULATED
 cuboid    1  1  6p1.26990                       com='content cube'
 cuboid    3  1  6p1.51452                       com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    3  1  6p1.51452                       com='unit cell'
unit 1006
'content (collapsed) [Elev= 9.691 in.]'
' 4.54386     1.78892 half width-depth lattice            CALCULATED'
'12.11696             height lattice                      CALCULATED'
 array 1         2r-4.54386      0.0
 cuboid    3  1  4p4.54386     12.1169   0.0     com='content-array'
 cylinder  3  1    6.426200   12.11746  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   12.11746  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.11746  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.691 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'36.35448             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   40.73452   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   40.73452   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   40.73452   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
```

```
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
 array 3   2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.10 Case cvr3lha_26_1_8_15

```
=csas25    parm=size=3000000
cvr 3x3lha,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O hx=  8.89),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1376.51338, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.65, CV void volume 8838.84856'
uranium  1 den=18.81109 0.45852 293      92235  100.00
                                      92238   0.000               end
arbmh20i   0.54051  2 0 0 0    1001   11.1913
                               8016   88.8087    1  1       293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07072e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4264
                                11023    0.1174
                                12000    0.3378
                                13027   39.0470
                                14000    2.4671
                                16000    0.3083
                                20000   11.8333
                                26000    0.5297    2  1.0000  293  end
arbmnph2o 3.84144e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
```

```
'void space internal to containmment vessel -- including content cans'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvr 3x3lha,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O,hx=  8.89),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                           end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  308.25850             HEU mass one cube'
'   28                   number of HEU cubes per can'
' 8631.23808             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    4    VARIABLE       number of HEU layers in z-axis'
'    1    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    8    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill'
'    0.48924     0.19261 gap dimension                        CALCULATED
'    3.02924     1.19261 unit cell dimension                  CALCULATED
'    1.51462     0.59631 unit cell half-dimension             CALCULATED
'   27.79719     1.69629 volume of unit cell                  CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell     CALCULATED
' 1000.69893             lattice volume in cc                 CALCULATED
'  541.86113             moderator volume in lattice in cc    CALCULATED
'  458.83779             HEU volume in lattice in cc          CALCULATED
'    0.45852             volume fraction of HEU in lattice'   CALCULATED
'    0.54051             bulk dens of water in lattice in cc  CALCULATED
 cuboid    1  1  6p1.51452                       com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    1  1  6p1.51452                       com='unit cell'
unit 1006
'content (collapsed) [Elev= 9.691 in.]'
' 4.54386     1.78892 half width-depth lattice             CALCULATED'
'12.11696             height lattice                       CALCULATED'
```

```
'array 1         2r-4.54386      0.0'
 cuboid    1  1  4p4.54386     12.1169   0.0     com='homog. content-array'
 cylinder  3  1    6.426200   12.11746  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   12.11746  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.11746  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.691 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'36.35448             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   40.73452   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   40.73452   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   40.73452   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
 array 3   2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
```

```
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.11 Case cvr3cha_26_1_8_15

```
=csas25    parm=size=3000000
cvr 3x3cha,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O hx=  8.89),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1376.51338, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.65, CV void volume 8838.84856'
uranium  1 den=18.81109 0.13475 293      92235  100.00
                                       92238   0.000               end
arbmh20i   0.86369  2 0 0 0    1001   11.1913
                              8016   88.8087    1  1       293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                               5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07072e+0 10 0 0 0    6012    1.9188
                               7014    0.0141
                               8016   43.4264
                              11023    0.1174
                              12000    0.3378
                              13027   39.0470
                              14000    2.4671
                              16000    0.3083
                              20000   11.8333
                              26000    0.5297    2  1.0000  293  end
arbmnph2o 3.84144e-1  2 0 0 0    1001   11.1913
                               8016   88.8087    2  1.0000  293  end
'void space internal to containmment vessel -- including content cans'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvr 3x3cha,0.0in thk np,25893.7gU(25893.7g235, 8822.9gH2O,hx=  8.89),fr=1.0e+00
```

```
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                          end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  308.25850             HEU mass one cube'
'   28                   number of HEU cubes per can'
' 8631.23808             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    4    VARIABLE       number of HEU layers in z-axis'
'    1    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    8    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill'
'    0.48924     0.19261 gap dimension                        CALCULATED
'    3.02924     1.19261 unit cell dimension                  CALCULATED
'    1.51462     0.59631 unit cell half-dimension             CALCULATED
'   27.79719     1.69629 volume of unit cell                  CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell     CALCULATED
' 1000.69893             lattice volume in cc                 CALCULATED
'  541.86113             moderator volume in lattice in cc    CALCULATED
'  458.83779             HEU volume in lattice in cc          CALCULATED
'    0.13475             volume fraction of HEU in CV         CALCULATED
'    0.86369             bulk dens of water in CV             CALCULATED
 cuboid    1  1  6p1.51452                       com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    1  1  6p1.51452                       com='unit cell'
unit 1006
'content (collapsed) [Elev= 9.691 in.]'
' 4.54386     1.78892 half width-depth lattice            CALCULATED'
'12.11696             height lattice                      CALCULATED'
'array 1         2r-4.54386      0.0'
 cuboid    1  1  4p4.54386     12.1169   0.0     com='homog. content-array'
 cylinder  1  1    6.426200   12.11746  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   12.11746  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.11746  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.691 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'36.35448             stack height (content spacers)       CALCULATED
```

```
 cylinder  1  1    6.426200   40.73452   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   40.73452   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   40.73452   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
 array 3   2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=4   fill 28r1004  8r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
```

```
end start
end data
end
```

6.9.7.12 Case cvcrpdoxt11_1_5_24_15

```
(This case name is actually cvcrpdoxt11_1_5_24_15.)
=csas25    parm=size=3000000
cvcrpoxt11,24000.0gUO2 (21124.9g235)1477.3gSH2O 5991.4gH2Ocv hx= 10.02 fr=1
238groupndf5 infhommedium
'HEU volume =3669.72477 HEU oxide, bulk density of oxide in cans=  6.54000 g/cm3'
'oxide= 24000.0 g, sat.h2o in HEU oxide=1477.3 g, oxide h/x= 1.83'
'poly (packed or wrapped) dry content h/x=0.79, CV void volume 6002.15891'
arbmuox    5.69638   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  3.5063e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  1.1867e-01  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
```

```
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
```

```
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrpoxt11,24000.0gUO2 (21124.9g235)1477.3gSH2O 5991.4gH2Ocv,hx= 10.02 fr=1
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  33.11036 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
```

```
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.13 Case cvcrsk3cc_9_15_17

```
csas25    parm=size=3000000
cvcrsk3cc,0.0,21300.0g soc(19865.3uox,15672.8u235,  921.0c),hx= 12.82,fr=1.0e+00
238groupndf5 infhommedium
'  cm3: Skull oxide content 6974.5, SPACER    0.0, CV void 3240.9; CV htox=12.82'
'g/cm3: Skull oxide content  3.05400'
'U3O8   (19865.33gUOX,16816.3gU,15672.8g235U, 3801.4g.sat.H2O, HX=  7.43)'
'Carbon (  921.00gC,   58764.1mgC/g235U)'
'Poly   (  513.00gCH2)'
'Other  (    0.67gUnident (assumed H2O)'
''
'Increm (  921.0gC,15672.8g235U,   58764.1mgC/g235U)'
'GREP1:21300.00 19865.33 3.8014e+03    7.43 16816.35 15672.84   921.00  58764.1
'GREP2: 3235.07   513.00      12.82    0.67  1.0e+00
''
arbmuox    2.84830    3 0 0 0  92235   78.8954
                               92238    5.7563
                                8016   15.3483    1  1.0000  293  end
arbmc     1.3205e-01  1 0 0 0   6012  100.0000    1  1.0000  293  end
arbmastm  5.4505e-01  2 0 0 0   1001   11.1913
                                8016   88.8087    1  1.0000  293  end
arbmpoly   0.07355    2 0 0 0   1001   14.3798
                                6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
```

```
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrsk3cc,0.0,21300.0g soc(19865.3uox,15672.8u235,  921.0c),hx= 12.82 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  54.39413 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
```

```
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.14 Case cvcrunhct11_9_1

```
=csas25    parm=size=3000000
cvcrunhct11 0.0innp,disp. 9000.0gUNHc( 4238.7g235, 6980.8gH2O hx= 54.99),fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], gU/L= 414.9296'
'UNH crystals in cans  2.79329 g/cm3. wrapped dry content can hx=3.96'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.31541 293  end
```

```
arbmh2oc  6.8336e-01  2 0 0 0  1001   11.1913
                               8016   88.8087    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  6.8336e-01  2 0 0 0   1001   11.1913
                                8016   88.8087     3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                            8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                            9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                           10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrunhct11 0.0innp,disp. 9000.0gUNHc( 4238.7g235, 6980.8gH2O,hx= 54.99),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                          end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
```

```
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.15 Case cvcrtriga_1_15

```
=csas25    parm=size=3000000
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
```

```
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
```

```
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
```

```
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.16 Case ncsrcyt11_21_1_15

```
=csas25    parm=size=3000000
ncsrcyt11 3cyl,0.0in thk np,21000.0gU(21000.0g235, 9082.6gH2O hx= 11.29),fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1116.36286, SPACER volume    0.00000'
'HEU wrapped dry content can hx=0.80, CV void volume 9098.99908'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
```

```
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
```

```
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrcyt11 3cyl,0.0in thk np,21000.0gU(21000.0g235, 9082.6gH2O,hx= 11.29),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 7.675 in.]'
 cylinder  1  1    4.114800     6.99579   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    6.99629  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    6.99629  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    6.99629  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    6.99629  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    6.99629  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    6.99629  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500    6.99629  -0.0005  com='kaolite'
 cylinder  19 1   23.329900    6.99629  -0.0005  com='drum'
 cuboid    21 1 4p24.587200    6.99629  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 7.675 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
```

```
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'20.99097             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   56.09803   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   56.09803   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   56.09803   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   56.09803   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   56.09803   0.0     com='np277_4'
 cylinder  16 1   11.074400   56.09803   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   56.09803   0.0     com='kaolite'
 cylinder  19 1   23.329900   56.09803   0.0     com='drum'
 cuboid    21 1 4p24.587200   56.09803   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
```

```
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
```

```
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.17 Case nciacyct11_25_2_3

```
=csas25    parm=size=3000000
nciacyct11 3cyl,1.4in thk np,25000.2gU(25000.2g235, 8256.8gH2O hx=  8.62),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume =1329.01404, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.67, CV void volume 8271.66778'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
```

```
                              14000    2.4672
                              16000    0.3083
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
```

```
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciacyct11 3cyl,1.4in thk np,25000.2gU(25000.2g235, 8256.8gH2O,hx=  8.62),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 6.832 in.]'
 cylinder  1  1    5.397500     4.84031   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    4.84081  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    4.84081  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    4.84081  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    4.84081  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    4.84081  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    4.84081  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    4.84081  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    4.84081  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    4.84081  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 8.232 in.]'
```

```
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    3.55620  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.55620  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    3.55620  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    3.55620  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    3.55620  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    3.55620  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'21.63653             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   55.45247   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   55.45247   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   55.45247   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   55.45247   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   55.45247   0.0     com='np277_4'
 cylinder  16 1   11.074400   55.45247   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   55.45247   0.0     com='kaolite'
 cylinder  19 1   21.722275   55.45247   0.0     com='drum'
 cuboid    20 1 4p22.866096   55.45247   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
```

```
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
```

```
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.18 Case hciacyct12_25_2_3

```
=csas25    parm=size=3000000
hciacyct12 3cyl,1.4in thk np,25000.2gU(25000.2g235, 8256.8gH2O hx=  8.62),fr=1.0e-04
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.67, CV void volume 8271.66778'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
```

```
                              13027   39.0477
                              14000    2.4671
                              16000    0.3083
                              20000   11.8335
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
```

```
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
hciacyct12 3cyl,1.4in thk np,25000.2gU(25000.2g235, 8256.8gH2O,hx=  8.62),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1006
'content (collapsed) [Elev= 6.826 in.]'
 cylinder  1  1    5.397500     4.84031   0.0     com='cylindrical content'
 cylinder  3  1    6.426200    4.84081  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    4.84081  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    4.84081  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    4.84081  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    4.84081  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    4.84081  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692    4.84081  -0.0005  com='kaolite'
 cylinder  19 1   21.838092    4.84081  -0.0005  com='drum'
 cuboid    20 1 4p21.838092    4.84081  -0.0005  com='drum(chine)outer radius'
unit 1007
'np277_4 spacer [Elev= 8.226 in.]'
```

```
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    3.55620  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.55620  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    3.55620  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    3.55620  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    3.55620  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    3.55620  -0.0001  com='drum'
 cuboid    20 1 4p21.838092    3.55620  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'21.63653             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   55.45247   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   55.45247   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   55.45247   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   55.45247   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   55.45247   0.0     com='np277_4'
 cylinder  16 1   11.074400   55.45247   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   55.45247   0.0     com='kaolite'
 cylinder  19 1   21.838092   55.45247   0.0     com='drum'
 cuboid    20 1 4p21.838092   55.45247   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    20 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
```

```
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    20 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    20 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  20 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  20 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
'cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
```

```
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.19 Case ncia70st11_2_8_3

```
=csas25    parm=size=3000000
ncia70st11,1.4in np,25588.2gU(25588.2g235, 8225.3gH2O hx=  8.39),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume =1360.27104, SPACER volume  614.69740'
'HEU wrapped dry content can hx=0.66, CV void volume 8240.17295'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
```

```
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                                8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
```

```
ss304                                              17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                              18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                              18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                              19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                              19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
ncia70st11,1.4in np,25588.2gU(25588.2g235, 8225.3gH2O,hx=  8.39),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 6.989 in.]'
'3.437212   plus-y location cylinders'
'-3.437212  minus-y location cylinders'
'1.984375   plus-x location cylinders'
'-1.984375  minus-x location cylinders'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1020   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1020   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1020    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1020    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1020    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1020   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
```

```
 hole  1020    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    5.23925  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    5.23925  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    5.23925  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    5.23925  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    5.23925  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    5.23925  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    5.23925  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 8.389 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    3.55620  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.55620  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    3.55620  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    3.55620  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    3.55620  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    3.55620  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    3.55620  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev=10.452 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1021   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1021   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1021    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1021    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1021    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1021   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1021    0.0        0.0       0.0     com='cy7 (0,0)'
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    5.23925  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    5.23925  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    5.23925  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    5.23925  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    5.23925  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    5.23925  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    5.23925  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.852 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    3.55620  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.55620  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    3.55620  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    3.55620  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    3.55620  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    3.55620  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev=10.452 in.]'
 cylinder  3  1    6.426200    5.23925  -0.0005  com='cv well cavity'
 hole  1022   -3.968750   0.0       0.0     com='cy1 (2cymx,0)'
 hole  1022   -1.984375   3.437212  0.0     com='cy2 (cymx,cypy)'
 hole  1022    1.984375   3.437212  0.0     com='cy3 (cypx,cypy)'
 hole  1022    3.968750   0.0       0.0     com='cy4 (2cypx,0)'
 hole  1022    1.984375  -3.437212  0.0     com='cy5 (cypx,cymx)'
 hole  1022   -1.984375  -3.437212  0.0     com='cy6 (cymx,cymy)'
 hole  1022    0.0        0.0       0.0     com='cy7 (0,0)'
```

```
 cylinder  8  1    6.680200    5.23925  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    5.23925  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    5.23925  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    5.23925  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    5.23925  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    5.23925  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    5.23925  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    5.23925  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'22.83355             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   54.25545   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   54.25545   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   54.25545   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   54.25545   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   54.25545   0.0     com='np277_4'
 cylinder  16 1   11.074400   54.25545   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   54.25545   0.0     com='kaolite'
 cylinder  19 1   21.722275   54.25545   0.0     com='drum'
 cuboid    20 1 4p22.866096   54.25545   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
```

```
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by  5.23875cm height'
'  64.77481cm3 single slug volume'
 cylinder  1  1    1.983875  5.23875   0.0       com='cyl'
global
```

```
unit 1023
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.20 Case ncia5est11_2_2_5_3

*(This case name is actually **ncia5est11_2_2_5_3**.)*

```
=csas25    parm=size=3000000
ncia5est11,0.0in np,73294.2gU(58635.4g235, 6317.2gH2O hx=  2.81),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume =3886.48867, SPACER volume    0.01729'
'HEU wrapped dry content can hx=0.57, CV void volume 6328.63543'
uranium  1 den=18.85873 1.0 293      92235  80.000
                                     92238  20.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
```

```
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
```

```
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
ncia5est11,0.0in np,73294.2gU(58635.4g235, 6317.2gH2O,hx=  2.81),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'1st content can (collapsed) [Elev= 9.051 in.]'
```

```
'Reference CRC 29 Ed. pg 105'
'side of pentagon denoted spent'
'radius of inscribed circle in pentagon denoted icrpent'
'radius of circumscribed circle outside pentagon denoted ccrpent'
'ccrpent equals 0.85065 times spent'
'icrpent equals 0.68819 times spent'
'side of pentagon equals diameter of a cylinder fit into cc'
'radius of cc equals ccrpent plus radius of cylinder fit into cc'
'radius of ccrpent equal diamater of slug'
' 3.96875 radius of circumscribed circle'
' 2.33277 half of side of pentagon'
' 3.21078 radius of inscribed circle'
' 3.77452 x axis location of 2nd cyl in cc'
' 1.22642 y axis location of 2nd cyl in cc'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1020    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1020    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1020    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1020   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1020   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   10.47800  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   10.47800  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   10.47800  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   10.47800  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   10.47800  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   10.47800  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   10.47800  -0.0005  com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 9.051 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'2nd content can (collapsed) [Elev=13.177 in.]'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1021    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1021    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1021    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1021   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1021   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   10.47800  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   10.47800  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   10.47800  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   10.47800  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   10.47800  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   10.47800  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   10.47800  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=13.177 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
```

```
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'3rd content can (collapsed) [Elev=13.177 in.]'
 cylinder  3  1    6.426200   10.47800  -0.0005  com='cv well cavity'
 hole  1022    0.0       3.96875 0.0        com='cy1 (0,ccrpent)'
 hole  1022    3.77452   1.22642 0.0        com='cy2 (xtwo,ytwo)'
 hole  1022    2.33277  -3.21078 0.0        com='cy3 (hspent,-icrpent)'
 hole  1022   -2.33277  -3.21078 0.0        com='cy4 (-hspent,-icrpent)'
 hole  1022   -3.77452   1.22642 0.0        com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200   10.47800  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   10.47800  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   10.47800  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   10.47800  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   10.47800  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   10.47800  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   10.47800  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   10.47800  -0.0005  com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'31.43780             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   45.65120   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   45.65120   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   45.65120   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   45.65120   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   45.65120   0.0     com='np277_4'
 cylinder  16 1   11.074400   45.65120   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   45.65120   0.0     com='kaolite'
 cylinder  19 1   21.722275   45.65120   0.0     com='drum'
 cuboid    20 1 4p22.866096   45.65120   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
```

```
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
```

```
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
unit 1020
'HEU cylinder content, 3.96875cm diameter by 10.47750cm height'
' 129.54962cm3 single slug volume'
 cylinder  1  1    1.983875  10.4775   0.0       com='cyl'
unit 1021
'HEU cylinder content, 3.96875cm diameter by 10.47750cm height'
' 129.54962cm3 single slug volume'
 cylinder  1  1    1.983875  10.4775   0.0       com='cyl'
unit 1022
'HEU cylinder content, 3.96875cm diameter by 10.47750cm height'
' 129.54962cm3 single slug volume'
 cylinder  1  1    1.983875  10.4775   0.0       com='cyl'
global
unit 1023
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1025
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1023               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.21 Case nciabmt11_4_1_5_3

```
=csas25    parm=size=3000000
nciabmt11,0.0in thk np, 3708.5gU( 2966.8g235,10000.7gH2O hx= 87.98),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume = 196.64477, SPACER volume    0.00000'
'HEU wrapped dry content can hx=5.65, CV void volume 10018.7171'
uranium  1 den=18.85873 0.01925 293      92235  80.000
                                      92238  20.000               end
arbmh20i   0.97898  2 0 0 0    1001   11.1913
                               8016   88.8087    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
```

```
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
```

```
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciabmt11,0.0in thk np, 3708.5gU( 2966.8g235,10000.7gH2O,hx= 87.98),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
```

```
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  309.03922             HEU mass one cube'
'   4                    number of HEU cubes per can'
' 1236.15687             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    1    VARIABLE       number of HEU layers in z-axis'
'    4    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    5    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=1   fill  4r1004  5r1005      end fill'
'    0.48924     0.19261 gap dimension                       CALCULATED
'    3.02924     1.19261 unit cell dimension                 CALCULATED
'    1.51462     0.59631 unit cell half-dimension            CALCULATED
'   27.79719     1.69629 volume of unit cell                 CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell    CALCULATED
'  250.17473             lattice volume in cc                CALCULATED
'  184.62648             moderator volume in lattice in cc   CALCULATED
'   65.54826             HEU volume in lattice in cc         CALCULATED
'    0.01925             volume fraction of HEU in CV        CALCULATED
'    0.97898             bulk dens of water in CV            CALCULATED
 cuboid    1  1  6p1.51452                      com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    1  1  6p1.51452                      com='unit cell'
unit 1006
'content (collapsed) [Elev= 6.119 in.]'
' 4.54386     1.78892 half width-depth lattice            CALCULATED'
' 3.02924             height lattice                      CALCULATED'
'array 1         2r-4.54386      0.0'
 cuboid    1  1  4p4.54386     3.02924   0.0     com='homog. content-array'
 cylinder  1  1    6.426200    3.02974  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200    3.02974  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800    3.02974  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200    3.02974  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000    3.02974  -0.0005  com='np277_4'
 cylinder  16 1   11.074400    3.02974  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075    3.02974  -0.0005  com='kaolite'
 cylinder  19 1   21.722275    3.02974  -0.0005  com='drum'
 cuboid    20 1 4p22.866096    3.02974  -0.0005  com='drum chine outer radius'
unit 1007
```

```
'np277_4 spacer [Elev= 6.119 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
' 9.09132             stack height (content spacers)       CALCULATED
 cylinder  1  1    6.426200   67.99768   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   67.99768   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   67.99768   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   67.99768   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   67.99768   0.0     com='np277_4'
 cylinder  16 1   11.074400   67.99768   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   67.99768   0.0     com='kaolite'
 cylinder  19 1   21.722275   67.99768   0.0     com='drum'
 cuboid    20 1 4p22.866096   67.99768   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
```

```
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=1   fill  4r1004  5r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.22 Case hctf5bmt12_25_2_8_3

```
=csas25    parm=size=4000000
hctf5bmt12,1.4in thk np,24968.9gU(24968.9g235, 8258.4gH2O hx=  8.63),fr=1.0e-04
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.67, CV void volume 8273.32964'
uranium  1 den=18.81109 0.13826 293      92235  100.00
                                      92238   0.000               end
arbmh20i   0.86019  2 0 0 0    1001   11.1913
                               8016   88.8087    1  1.0000  293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
```

```
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                 8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                 8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                 8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                 8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                 8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                 8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                 8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                 8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                 8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                 8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                 8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                 8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                 8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                 8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                 8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                 8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                 1001    8.1573
                                 8016   21.5782
```

```
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516 for HAC'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645 for HAC'
ss304                                          19  1.08401 293  end
'void space external to drum'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
more data dab=400 end
hctf5bmt12,1.4in thk np,24968.9gU(24968.9g235, 8258.4gH2O,hx=  8.63),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 nb8=400 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'zhemicyl-y  19 1   21.838092    0.26620   0.00050 com='extend radius not used'
 zhemicyl-y  19 1   21.838092    0.26620   0.00050 com='drum bottom flat cover'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 zhemicyl-y  15 1    3.175000   11.59460  11.16330 com='void in pad-1'
 zhemicyl-y  14 1    7.924800   11.59460  11.16330 com='pad-1'
 zhemicyl-y  16 1    8.077200   11.59460  11.16330 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000   11.59460  11.16330 com='np277_4'
 zhemicyl-y  16 1   11.074400   11.59460  10.85850 com='kaolite liner bottom'
 zhemicyl-y  12 1   21.685692   11.59460   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092   11.59460   0.00050 com='drum'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 zhemicyl-y  8  1    6.680200    0.63450   0.00050 com='cv bottom'
 zhemicyl-y  15 1    7.924800    0.63450   0.00050 com='void btw cv-np liner'
 zhemicyl-y  16 1    8.077200    0.63450   0.00050 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000    0.63450   0.00050 com='np277_4'
 zhemicyl-y  16 1   11.074400    0.63450   0.00050 com='kaolite liner'
 zhemicyl-y  12 1   21.685692    0.63450   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    0.63450   0.00050 com='drum'
unit 1004
'cubical content, stacked per cc'
'    9.08802     3.57796 lattice width-depth'
'    2.54000     1.00000 cube dimension'
'    1.27000     0.50000 cube half-dimension'
'   16.38706     1.00000 volume of HEU cube in unit cell'
'  308.25850             HEU mass one cube'
'   27                   number of HEU cubes per can'
' 8322.97957             HEU mass of cubes in cc'
'    3           3       number of cubes in -x direction'
'    3           3       number of cubes in -y direction'
'    9           9       number of HEU cubes in a layer'
'    4    VARIABLE       number of HEU layers in z-axis'
```

```
'    0    VARIABLE       number of HEU cubes in top layer modulus(Z%N)'
'    9    VARIABLE       number of HEU voids in top layer'
'    ara=1 nux=3 nuy=3 nuz=4   fill 27r1004  9r1005      end fill'
'    0.48924     0.19261 gap dimension                        CALCULATED
'    3.02924     1.19261 unit cell dimension                  CALCULATED
'    1.51462     0.59631 unit cell half-dimension             CALCULATED
'   27.79719     1.69629 volume of unit cell                  CALCULATED
'   11.41013     0.69629 volume of water gap in unit cell     CALCULATED
' 1000.69893             lattice volume in cc                 CALCULATED
'  558.24820             moderator volume in lattice in cc    CALCULATED
'  442.45073             HEU volume in lattice in cc          CALCULATED
'    0.13826             volume fraction of HEU in CV         CALCULATED
'    0.86019             bulk dens of water in CV             CALCULATED
 cuboid    1  1  6p1.51452                      com='unit cell'
unit 1005
'cubical void, filler for layers'
 cuboid    1  1  6p1.51452                      com='unit cell'
unit 1006
'content (collapsed) [Elev= 9.691 in.]'
' 4.54386     1.78892 half width-depth lattice             CALCULATED'
'12.11696             height lattice                       CALCULATED'
'array 1         2r-4.54386      0.0'
 cuboid  1  1  2p4.54386 0.0 -4.54386 12.1169 0.0005 com='homog. content-array'
 zhemicyl-y  1  1    6.426200   12.11696   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200   12.11696   0.00050 com='cv below 1st step'
 zhemicyl-y  15 1    7.924800   12.11696   0.00050 com='void btw cv-np liner'
 zhemicyl-y  16 1    8.077200   12.11696   0.00050 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000   12.11696   0.00050 com='np277_4'
 zhemicyl-y  16 1   11.074400   12.11696   0.00050 com='kaolite liner'
 zhemicyl-y  12 1   21.685692   12.11696   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092   12.11696   0.00050 com='drum'
unit 1007
'np277_4 spacer [Elev=11.091 in.]'
 zhemicyl-y  2  1    5.24510     3.55660   0.00050 com='np spacer'
 zhemicyl-y  1  1    6.426200    3.55660   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200    3.55660   0.00050 com='cv below 1st step'
 zhemicyl-y  15 1    7.924800    3.55660   0.00050 com='void btw cv-np liner'
 zhemicyl-y  16 1    8.077200    3.55660   0.00050 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000    3.55660   0.00050 com='np277_4'
 zhemicyl-y  16 1   11.074400    3.55660   0.00050 com='kaolite liner'
 zhemicyl-y  12 1   21.685692    3.55660   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    3.55660   0.00050 com='drum'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'43.46828             stack height (content spacers)       CALCULATED
 zhemicyl-y  1  1    6.426200   33.62022   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200   33.62022   0.00050 com='cv below 1st step'
 zhemicyl-y  15 1    7.924800   33.62022   0.00050 com='void btw cv-np liner'
 zhemicyl-y  16 1    8.077200   33.62022   0.00050 com='np277_4 liner'
 zhemicyl-y  11 1   10.922000   33.62022   0.00050 com='np277_4'
 zhemicyl-y  16 1   11.074400   33.62022   0.00050 com='kaolite liner'
 zhemicyl-y  12 1   21.685692   33.62022   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092   33.62022   0.00050 com='drum'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 zhemicyl-y  1  1    6.426200    0.15190   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200    0.15190   0.00050 com='cv at 1st step'
 zhemicyl-y  15 1    7.924800    0.15190   0.00050 com='void btw cv and liner'
 zhemicyl-y  16 1   11.074400    0.15190   0.00050 com='liner 1st step'
 zhemicyl-y  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    0.15190   0.00050 com='drum'
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unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 zhemicyl-y  1  1    6.426200    0.22810   0.00050 com='cv well cavity'
 zhemicyl-y  8  1    6.680200    0.22810   0.00050 com='cv gap btw step-flng'
 zhemicyl-y  15 1   10.922000    0.22810   0.00050 com='void btw cv and liner'
 zhemicyl-y  16 1   11.074400    0.22810   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    0.22810   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    0.22810   0.00050 com='drum'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 zhemicyl-y  1  1    6.426200    1.26950   0.00050 com='cavity'
 zhemicyl-y  9  1    9.525000    1.26950   0.00050 com='flange to top of well'
 zhemicyl-y  15 1    9.525000    1.26950   0.00050 com='void btw cv and pad-2'
 zhemicyl-y  14 1   10.033000    1.26950   0.00050 com='pad-2'
 zhemicyl-y  15 1   10.922000    1.26950   0.00050 com='void btw cv and liner'
 zhemicyl-y  16 1   11.074400    1.26950   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    1.26950   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    1.26950   0.00050 com='drum'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 zhemicyl-y  10 1    9.525000    2.92050   0.00050 com='flange above cv well'
 zhemicyl-y  15 1    9.525000    2.92050   0.00050 com='void btw cv and pad-2'
 zhemicyl-y  14 1   10.033000    2.92050   0.00050 com='pad-2'
 zhemicyl-y  15 1   10.922000    2.92050   0.00050 com='void btw pad2-liner'
 zhemicyl-y  16 1   11.074400    2.92050   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    2.92050   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    2.92050   0.00050 com='drum'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 zhemicyl-y  14 1   10.033000    0.76150   0.00050 com='pad-2'
 zhemicyl-y  15 1   10.922000    1.01550   0.00050 com='void btw pad2-liner'
 zhemicyl-y  16 1   11.074400    1.01550   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    1.01550   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    1.01550   0.00050 com='drum'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 zhemicyl-y  15 1   10.922000    0.15190   0.00050 com='void abv pad2'
 zhemicyl-y  16 1   18.757900    0.15190   0.00050 com='liner 2nd step'
 zhemicyl-y  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    0.15190   0.00050 com='drum'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 zhemicyl-y  13 1   18.097500    8.17830   0.49276 com='plug kaolite'
 zhemicyl-y  17 1   18.249900    8.17830   0.34036 com='sides of plug case'
 zhemicyl-y  15 1   18.605500    8.17830   0.00050 com='void: plug to liner'
 zhemicyl-y  16 1   18.757900    8.17830   0.00050 com='liner wall'
 zhemicyl-y  12 1   21.685692    8.17830   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    8.17830   0.00050 com='drum'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 zhemicyl-y  13 1   18.097500    4.44450   0.00050 com='plug kaolite'
 zhemicyl-y  17 1   18.249900    4.44450   0.00050 com='sides of plug case'
 zhemicyl-y  15 1   18.605500    4.44450   0.00050 com='void: plug to liner'
 zhemicyl-y  16 1   18.757900    4.44450   0.00050 com='liner wall'
 zhemicyl-y  18 1   19.392900    4.44450   0.00050 com='lower angle iron'
 zhemicyl-y  12 1   21.685692    4.44450   0.00050 com='kaolite'
 zhemicyl-y  19 1   21.838092    4.44450   0.00050 com='drum'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 zhemicyl-y  13 1   18.097500    0.11126   0.00050 com='plug kaolite'
 zhemicyl-y  17 1   18.249900    0.26366   0.00050 com='sides of plug case'
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 zhemicyl-y  15 1   18.605500    0.63450   0.00050 com='void: plug to liner'
 zhemicyl-y  16 1   18.757900    0.63450   0.00050 com='liner wall'
 zhemicyl-y  18 1   21.685692    0.63450   0.00050 com='bend section of ai'
 zhemicyl-y  19 1   21.838092    0.63450   0.00050 com='drum'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 zhemicyl-y  20 1   21.469792    1.90450   0.15240 com='void above lid'
 zhemicyl-y  19 1   21.622192    1.90450   0.00050 com='drum lid'
 zhemicyl-y  20 1   21.685692    1.90450   0.00050 com='void btw lid-drumwall'
 zhemicyl-y  19 1   21.838092    1.90450   0.00050 com='drum'
unit 2001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'zhemicyl+y  19 1   21.838092    0.26620   0.00050 com='extended radius not used'
 zhemicyl+y  19 1   21.838092    0.26620   0.00050 com='drum bottom flat cover'
unit 2002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 zhemicyl+y  15 1    3.175000   11.59460  11.16330 com='void in pad-1'
 zhemicyl+y  14 1    7.924800   11.59460  11.16330 com='pad-1'
 zhemicyl+y  16 1    8.077200   11.59460  11.16330 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000   11.59460  11.16330 com='np277_4'
 zhemicyl+y  16 1   11.074400   11.59460  10.85850 com='kaolite liner bottom'
 zhemicyl+y  12 1   21.685692   11.59460   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092   11.59460   0.00050 com='drum'
unit 2003
'cv bottom [Elev= 4.920 in.]'
 zhemicyl+y  8  1    6.680200    0.63450   0.00050 com='cv bottom'
 zhemicyl+y  15 1    7.924800    0.63450   0.00050 com='void btw cv-np liner'
 zhemicyl+y  16 1    8.077200    0.63450   0.00050 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000    0.63450   0.00050 com='np277_4'
 zhemicyl+y  16 1   11.074400    0.63450   0.00050 com='kaolite liner'
 zhemicyl+y  12 1   21.685692    0.63450   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    0.63450   0.00050 com='drum'
unit 2006
'content (collapsed) [Elev= 9.691 in.]'
 zhemicyl+y  1  1    6.426200   12.11696   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200   12.11696   0.00050 com='cv below 1st step'
 zhemicyl+y  15 1    7.924800   12.11696   0.00050 com='void btw cv-np liner'
 zhemicyl+y  16 1    8.077200   12.11696   0.00050 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000   12.11696   0.00050 com='np277_4'
 zhemicyl+y  16 1   11.074400   12.11696   0.00050 com='kaolite liner'
 zhemicyl+y  12 1   21.685692   12.11696   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092   12.11696   0.00050 com='drum'
unit 2007
'np277_4 spacer [Elev=11.091 in.]'
 zhemicyl+y  2  1    5.24510     3.55660   0.00050 com='np spacer'
 zhemicyl+y  1  1    6.426200    3.55660   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200    3.55660   0.00050 com='cv below 1st step'
 zhemicyl+y  15 1    7.924800    3.55660   0.00050 com='void btw cv-np liner'
 zhemicyl+y  16 1    8.077200    3.55660   0.00050 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000    3.55660   0.00050 com='np277_4'
 zhemicyl+y  16 1   11.074400    3.55660   0.00050 com='kaolite liner'
 zhemicyl+y  12 1   21.685692    3.55660   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    3.55660   0.00050 com='drum'
unit 2008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
 zhemicyl+y  1  1    6.426200   33.62022   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200   33.62022   0.00050 com='cv below 1st step'
 zhemicyl+y  15 1    7.924800   33.62022   0.00050 com='void btw cv-np liner'
 zhemicyl+y  16 1    8.077200   33.62022   0.00050 com='np277_4 liner'
 zhemicyl+y  11 1   10.922000   33.62022   0.00050 com='np277_4'
 zhemicyl+y  16 1   11.074400   33.62022   0.00050 com='kaolite liner'
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 zhemicyl+y  12 1   21.685692   33.62022   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092   33.62022   0.00050 com='drum'
unit 2010
'cv at 1st step in liner [Elev=35.330 in.]'
 zhemicyl+y  1  1    6.426200    0.15190   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200    0.15190   0.00050 com='cv at 1st step'
 zhemicyl+y  15 1    7.924800    0.15190   0.00050 com='void btw cv and liner'
 zhemicyl+y  16 1   11.074400    0.15190   0.00050 com='liner 1st step'
 zhemicyl+y  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    0.15190   0.00050 com='drum'
unit 2011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 zhemicyl+y  1  1    6.426200    0.22810   0.00050 com='cv well cavity'
 zhemicyl+y  8  1    6.680200    0.22810   0.00050 com='cv gap btw step-flng'
 zhemicyl+y  15 1   10.922000    0.22810   0.00050 com='void btw cv and liner'
 zhemicyl+y  16 1   11.074400    0.22810   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    0.22810   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    0.22810   0.00050 com='drum'
unit 2012
'cv flange to top of cv well [Elev=35.920 in.]'
 zhemicyl+y  1  1    6.426200    1.26950   0.00050 com='cavity'
 zhemicyl+y  9  1    9.525000    1.26950   0.00050 com='flange to top of well'
 zhemicyl+y  15 1    9.525000    1.26950   0.00050 com='void btw cv and pad-2'
 zhemicyl+y  14 1   10.033000    1.26950   0.00050 com='pad-2'
 zhemicyl+y  15 1   10.922000    1.26950   0.00050 com='void btw cv and liner'
 zhemicyl+y  16 1   11.074400    1.26950   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    1.26950   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    1.26950   0.00050 com='drum'
unit 2013
'cv flange above cv well [Elev=37.070 in.]'
 zhemicyl+y  10 1    9.525000    2.92050   0.00050 com='flange above cv well'
 zhemicyl+y  15 1    9.525000    2.92050   0.00050 com='void btw cv and pad-2'
 zhemicyl+y  14 1   10.033000    2.92050   0.00050 com='pad-2'
 zhemicyl+y  15 1   10.922000    2.92050   0.00050 com='void btw pad2-liner'
 zhemicyl+y  16 1   11.074400    2.92050   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    2.92050   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    2.92050   0.00050 com='drum'
unit 2014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 zhemicyl+y  14 1   10.033000    0.76150   0.00050 com='pad-2'
 zhemicyl+y  15 1   10.922000    1.01550   0.00050 com='void btw pad2-liner'
 zhemicyl+y  16 1   11.074400    1.01550   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    1.01550   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    1.01550   0.00050 com='drum'
unit 2015
'2nd step in liner [Elev=37.530 in.]'
 zhemicyl+y  15 1   10.922000    0.15190   0.00050 com='void abv pad2'
 zhemicyl+y  16 1   18.757900    0.15190   0.00050 com='liner 2nd step'
 zhemicyl+y  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    0.15190   0.00050 com='drum'
unit 2016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 zhemicyl+y  13 1   18.097500    8.17830   0.49276 com='plug kaolite'
 zhemicyl+y  17 1   18.249900    8.17830   0.34036 com='sides of plug case'
 zhemicyl+y  15 1   18.605500    8.17830   0.00050 com='void: plug to liner'
 zhemicyl+y  16 1   18.757900    8.17830   0.00050 com='liner wall'
 zhemicyl+y  12 1   21.685692    8.17830   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    8.17830   0.00050 com='drum'
unit 2017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 zhemicyl+y  13 1   18.097500    4.44450   0.00050 com='plug kaolite'
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 zhemicyl+y  17 1   18.249900    4.44450   0.00050 com='sides of plug case'
 zhemicyl+y  15 1   18.605500    4.44450   0.00050 com='void: plug to liner'
 zhemicyl+y  16 1   18.757900    4.44450   0.00050 com='liner wall'
 zhemicyl+y  18 1   19.392900    4.44450   0.00050 com='lower angle iron'
 zhemicyl+y  12 1   21.685692    4.44450   0.00050 com='kaolite'
 zhemicyl+y  19 1   21.838092    4.44450   0.00050 com='drum'
unit 2018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 zhemicyl+y  13 1   18.097500    0.11126   0.00050 com='plug kaolite'
 zhemicyl+y  17 1   18.249900    0.26366   0.00050 com='sides of plug case'
 zhemicyl+y  15 1   18.605500    0.63450   0.00050 com='void: plug to liner'
 zhemicyl+y  16 1   18.757900    0.63450   0.00050 com='liner wall'
 zhemicyl+y  18 1   21.685692    0.63450   0.00050 com='bend section of ai'
 zhemicyl+y  19 1   21.838092    0.63450   0.00050 com='drum'
unit 2019
'drum lid and lip [Elev=43.500 in.]'
 zhemicyl+y  20 1   21.469792    1.90450   0.15240 com='void above lid'
 zhemicyl+y  19 1   21.622192    1.90450   0.00050 com='drum lid'
 zhemicyl+y  20 1   21.685692    1.90450   0.00050 com='void btw lid-drumwall'
 zhemicyl+y  19 1   21.838092    1.90450   0.00050 com='drum'
unit 3001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'zhemicyl-x  19 1   21.838092    0.26620   0.00050 com='extended radius not used'
 zhemicyl-x  19 1   21.838092    0.26620   0.00050 com='drum bottom flat cover'
unit 3002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 zhemicyl-x  15 1    3.175000   11.59460  11.16330 com='void in pad-1'
 zhemicyl-x  14 1    7.924800   11.59460  11.16330 com='pad-1'
 zhemicyl-x  16 1    8.077200   11.59460  11.16330 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000   11.59460  11.16330 com='np277_4'
 zhemicyl-x  16 1   11.074400   11.59460  10.85850 com='kaolite liner bottom'
 zhemicyl-x  12 1   21.685692   11.59460   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092   11.59460   0.00050 com='drum'
unit 3003
'cv bottom [Elev= 4.920 in.]'
 zhemicyl-x  8  1    6.680200    0.63450   0.00050 com='cv bottom'
 zhemicyl-x  15 1    7.924800    0.63450   0.00050 com='void btw cv-np liner'
 zhemicyl-x  16 1    8.077200    0.63450   0.00050 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000    0.63450   0.00050 com='np277_4'
 zhemicyl-x  16 1   11.074400    0.63450   0.00050 com='kaolite liner'
 zhemicyl-x  12 1   21.685692    0.63450   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    0.63450   0.00050 com='drum'
unit 3006
'content (collapsed) [Elev= 9.691 in.]'
 zhemicyl-x  1  1    6.426200   12.11696   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200   12.11696   0.00050 com='cv below 1st step'
 zhemicyl-x  15 1    7.924800   12.11696   0.00050 com='void btw cv-np liner'
 zhemicyl-x  16 1    8.077200   12.11696   0.00050 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000   12.11696   0.00050 com='np277_4'
 zhemicyl-x  16 1   11.074400   12.11696   0.00050 com='kaolite liner'
 zhemicyl-x  12 1   21.685692   12.11696   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092   12.11696   0.00050 com='drum'
unit 3007
'np277_4 spacer [Elev=11.091 in.]'
 zhemicyl-x  2  1    5.24510     3.55660   0.00050 com='np spacer'
 zhemicyl-x  1  1    6.426200    3.55660   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200    3.55660   0.00050 com='cv below 1st step'
 zhemicyl-x  15 1    7.924800    3.55660   0.00050 com='void btw cv-np liner'
 zhemicyl-x  16 1    8.077200    3.55660   0.00050 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000    3.55660   0.00050 com='np277_4'
 zhemicyl-x  16 1   11.074400    3.55660   0.00050 com='kaolite liner'
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 zhemicyl-x  12 1   21.685692    3.55660   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    3.55660   0.00050 com='drum'
unit 3008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
 zhemicyl-x  1  1    6.426200   33.62022   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200   33.62022   0.00050 com='cv below 1st step'
 zhemicyl-x  15 1    7.924800   33.62022   0.00050 com='void btw cv-np liner'
 zhemicyl-x  16 1    8.077200   33.62022   0.00050 com='np277_4 liner'
 zhemicyl-x  11 1   10.922000   33.62022   0.00050 com='np277_4'
 zhemicyl-x  16 1   11.074400   33.62022   0.00050 com='kaolite liner'
 zhemicyl-x  12 1   21.685692   33.62022   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092   33.62022   0.00050 com='drum'
unit 3010
'cv at 1st step in liner [Elev=35.330 in.]'
 zhemicyl-x  1  1    6.426200    0.15190   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200    0.15190   0.00050 com='cv at 1st step'
 zhemicyl-x  15 1    7.924800    0.15190   0.00050 com='void btw cv and liner'
 zhemicyl-x  16 1   11.074400    0.15190   0.00050 com='liner 1st step'
 zhemicyl-x  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    0.15190   0.00050 com='drum'
unit 3011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 zhemicyl-x  1  1    6.426200    0.22810   0.00050 com='cv well cavity'
 zhemicyl-x  8  1    6.680200    0.22810   0.00050 com='cv gap btw step-flng'
 zhemicyl-x  15 1   10.922000    0.22810   0.00050 com='void btw cv and liner'
 zhemicyl-x  16 1   11.074400    0.22810   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    0.22810   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    0.22810   0.00050 com='drum'
unit 3012
'cv flange to top of cv well [Elev=35.920 in.]'
 zhemicyl-x  1  1    6.426200    1.26950   0.00050 com='cavity'
 zhemicyl-x  9  1    9.525000    1.26950   0.00050 com='flange to top of well'
 zhemicyl-x  15 1    9.525000    1.26950   0.00050 com='void btw cv and pad-2'
 zhemicyl-x  14 1   10.033000    1.26950   0.00050 com='pad-2'
 zhemicyl-x  15 1   10.922000    1.26950   0.00050 com='void btw cv and liner'
 zhemicyl-x  16 1   11.074400    1.26950   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    1.26950   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    1.26950   0.00050 com='drum'
unit 3013
'cv flange above cv well [Elev=37.070 in.]'
 zhemicyl-x  10 1    9.525000    2.92050   0.00050 com='flange above cv well'
 zhemicyl-x  15 1    9.525000    2.92050   0.00050 com='void btw cv and pad-2'
 zhemicyl-x  14 1   10.033000    2.92050   0.00050 com='pad-2'
 zhemicyl-x  15 1   10.922000    2.92050   0.00050 com='void btw pad2-liner'
 zhemicyl-x  16 1   11.074400    2.92050   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    2.92050   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    2.92050   0.00050 com='drum'
unit 3014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 zhemicyl-x  14 1   10.033000    0.76150   0.00050 com='pad-2'
 zhemicyl-x  15 1   10.922000    1.01550   0.00050 com='void btw pad2-liner'
 zhemicyl-x  16 1   11.074400    1.01550   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    1.01550   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    1.01550   0.00050 com='drum'
unit 3015
'2nd step in liner [Elev=37.530 in.]'
 zhemicyl-x  15 1   10.922000    0.15190   0.00050 com='void abv pad2'
 zhemicyl-x  16 1   18.757900    0.15190   0.00050 com='liner 2nd step'
 zhemicyl-x  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    0.15190   0.00050 com='drum'
unit 3016
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'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 zhemicyl-x  13 1   18.097500    8.17830   0.49276 com='plug kaolite'
 zhemicyl-x  17 1   18.249900    8.17830   0.34036 com='sides of plug case'
 zhemicyl-x  15 1   18.605500    8.17830   0.00050 com='void: plug to liner'
 zhemicyl-x  16 1   18.757900    8.17830   0.00050 com='liner wall'
 zhemicyl-x  12 1   21.685692    8.17830   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    8.17830   0.00050 com='drum'
unit 3017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 zhemicyl-x  13 1   18.097500    4.44450   0.00050 com='plug kaolite'
 zhemicyl-x  17 1   18.249900    4.44450   0.00050 com='sides of plug case'
 zhemicyl-x  15 1   18.605500    4.44450   0.00050 com='void: plug to liner'
 zhemicyl-x  16 1   18.757900    4.44450   0.00050 com='liner wall'
 zhemicyl-x  18 1   19.392900    4.44450   0.00050 com='lower angle iron'
 zhemicyl-x  12 1   21.685692    4.44450   0.00050 com='kaolite'
 zhemicyl-x  19 1   21.838092    4.44450   0.00050 com='drum'
unit 3018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 zhemicyl-x  13 1   18.097500    0.11126   0.00050 com='plug kaolite'
 zhemicyl-x  17 1   18.249900    0.26366   0.00050 com='sides of plug case'
 zhemicyl-x  15 1   18.605500    0.63450   0.00050 com='void: plug to liner'
 zhemicyl-x  16 1   18.757900    0.63450   0.00050 com='liner wall'
 zhemicyl-x  18 1   21.685692    0.63450   0.00050 com='bend section of ai'
 zhemicyl-x  19 1   21.838092    0.63450   0.00050 com='drum'
unit 3019
'drum lid and lip [Elev=43.500 in.]'
 zhemicyl-x  20 1   21.469792    1.90450   0.15240 com='void above lid'
 zhemicyl-x  19 1   21.622192    1.90450   0.00050 com='drum lid'
 zhemicyl-x  20 1   21.685692    1.90450   0.00050 com='void btw lid-drumwall'
 zhemicyl-x  19 1   21.838092    1.90450   0.00050 com='drum'
unit 4001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'zhemicyl+x  19 1   21.838092    0.26620   0.00050 com='extended radius not used'
 zhemicyl+x  19 1   21.838092    0.26620   0.00050 com='drum bottom flat cover'
unit 4002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 zhemicyl+x  15 1    3.175000   11.59460  11.16330 com='void in pad-1'
 zhemicyl+x  14 1    7.924800   11.59460  11.16330 com='pad-1'
 zhemicyl+x  16 1    8.077200   11.59460  11.16330 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000   11.59460  11.16330 com='np277_4'
 zhemicyl+x  16 1   11.074400   11.59460  10.85850 com='kaolite liner bottom'
 zhemicyl+x  12 1   21.685692   11.59460   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092   11.59460   0.00050 com='drum'
unit 4003
'cv bottom [Elev= 4.920 in.]'
 zhemicyl+x  8  1    6.680200    0.63450   0.00050 com='cv bottom'
 zhemicyl+x  15 1    7.924800    0.63450   0.00050 com='void btw cv-np liner'
 zhemicyl+x  16 1    8.077200    0.63450   0.00050 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000    0.63450   0.00050 com='np277_4'
 zhemicyl+x  16 1   11.074400    0.63450   0.00050 com='kaolite liner'
 zhemicyl+x  12 1   21.685692    0.63450   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    0.63450   0.00050 com='drum'
unit 4006
'content (collapsed) [Elev= 9.691 in.]'
 zhemicyl+x  1  1    6.426200   12.11696   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200   12.11696   0.00050 com='cv below 1st step'
 zhemicyl+x  15 1    7.924800   12.11696   0.00050 com='void btw cv-np liner'
 zhemicyl+x  16 1    8.077200   12.11696   0.00050 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000   12.11696   0.00050 com='np277_4'
 zhemicyl+x  16 1   11.074400   12.11696   0.00050 com='kaolite liner'
 zhemicyl+x  12 1   21.685692   12.11696   0.00050 com='kaolite'
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 zhemicyl+x  19 1   21.838092   12.11696   0.00050 com='drum'
unit 4007
'np277_4 spacer [Elev=11.091 in.]'
 zhemicyl+x  2  1    5.24510     3.55660   0.00050 com='np spacer'
 zhemicyl+x  1  1    6.426200    3.55660   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200    3.55660   0.00050 com='cv below 1st step'
 zhemicyl+x  15 1    7.924800    3.55660   0.00050 com='void btw cv-np liner'
 zhemicyl+x  16 1    8.077200    3.55660   0.00050 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000    3.55660   0.00050 com='np277_4'
 zhemicyl+x  16 1   11.074400    3.55660   0.00050 com='kaolite liner'
 zhemicyl+x  12 1   21.685692    3.55660   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    3.55660   0.00050 com='drum'
unit 4008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
 zhemicyl+x  1  1    6.426200   33.62022   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200   33.62022   0.00050 com='cv below 1st step'
 zhemicyl+x  15 1    7.924800   33.62022   0.00050 com='void btw cv-np liner'
 zhemicyl+x  16 1    8.077200   33.62022   0.00050 com='np277_4 liner'
 zhemicyl+x  11 1   10.922000   33.62022   0.00050 com='np277_4'
 zhemicyl+x  16 1   11.074400   33.62022   0.00050 com='kaolite liner'
 zhemicyl+x  12 1   21.685692   33.62022   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092   33.62022   0.00050 com='drum'
unit 4010
'cv at 1st step in liner [Elev=35.330 in.]'
 zhemicyl+x  1  1    6.426200    0.15190   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200    0.15190   0.00050 com='cv at 1st step'
 zhemicyl+x  15 1    7.924800    0.15190   0.00050 com='void btw cv and liner'
 zhemicyl+x  16 1   11.074400    0.15190   0.00050 com='liner 1st step'
 zhemicyl+x  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    0.15190   0.00050 com='drum'
unit 4011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 zhemicyl+x  1  1    6.426200    0.22810   0.00050 com='cv well cavity'
 zhemicyl+x  8  1    6.680200    0.22810   0.00050 com='cv gap btw step-flng'
 zhemicyl+x  15 1   10.922000    0.22810   0.00050 com='void btw cv and liner'
 zhemicyl+x  16 1   11.074400    0.22810   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    0.22810   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    0.22810   0.00050 com='drum'
unit 4012
'cv flange to top of cv well [Elev=35.920 in.]'
 zhemicyl+x  1  1    6.426200    1.26950   0.00050 com='cavity'
 zhemicyl+x  9  1    9.525000    1.26950   0.00050 com='flange to top of well'
 zhemicyl+x  15 1    9.525000    1.26950   0.00050 com='void btw cv and pad-2'
 zhemicyl+x  14 1   10.033000    1.26950   0.00050 com='pad-2'
 zhemicyl+x  15 1   10.922000    1.26950   0.00050 com='void btw cv and liner'
 zhemicyl+x  16 1   11.074400    1.26950   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    1.26950   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    1.26950   0.00050 com='drum'
unit 4013
'cv flange above cv well [Elev=37.070 in.]'
 zhemicyl+x  10 1    9.525000    2.92050   0.00050 com='flange above cv well'
 zhemicyl+x  15 1    9.525000    2.92050   0.00050 com='void btw cv and pad-2'
 zhemicyl+x  14 1   10.033000    2.92050   0.00050 com='pad-2'
 zhemicyl+x  15 1   10.922000    2.92050   0.00050 com='void btw pad2-liner'
 zhemicyl+x  16 1   11.074400    2.92050   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    2.92050   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    2.92050   0.00050 com='drum'
unit 4014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 zhemicyl+x  14 1   10.033000    0.76150   0.00050 com='pad-2'
 zhemicyl+x  15 1   10.922000    1.01550   0.00050 com='void btw pad2-liner'
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 zhemicyl+x  16 1   11.074400    1.01550   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    1.01550   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    1.01550   0.00050 com='drum'
unit 4015
'2nd step in liner [Elev=37.530 in.]'
 zhemicyl+x  15 1   10.922000    0.15190   0.00050 com='void abv pad2'
 zhemicyl+x  16 1   18.757900    0.15190   0.00050 com='liner 2nd step'
 zhemicyl+x  12 1   21.685692    0.15190   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    0.15190   0.00050 com='drum'
unit 4016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 zhemicyl+x  13 1   18.097500    8.17830   0.49276 com='plug kaolite'
 zhemicyl+x  17 1   18.249900    8.17830   0.34036 com='sides of plug case'
 zhemicyl+x  15 1   18.605500    8.17830   0.00050 com='void: plug to liner'
 zhemicyl+x  16 1   18.757900    8.17830   0.00050 com='liner wall'
 zhemicyl+x  12 1   21.685692    8.17830   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    8.17830   0.00050 com='drum'
unit 4017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 zhemicyl+x  13 1   18.097500    4.44450   0.00050 com='plug kaolite'
 zhemicyl+x  17 1   18.249900    4.44450   0.00050 com='sides of plug case'
 zhemicyl+x  15 1   18.605500    4.44450   0.00050 com='void: plug to liner'
 zhemicyl+x  16 1   18.757900    4.44450   0.00050 com='liner wall'
 zhemicyl+x  18 1   19.392900    4.44450   0.00050 com='lower angle iron'
 zhemicyl+x  12 1   21.685692    4.44450   0.00050 com='kaolite'
 zhemicyl+x  19 1   21.838092    4.44450   0.00050 com='drum'
unit 4018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 zhemicyl+x  13 1   18.097500    0.11126   0.00050 com='plug kaolite'
 zhemicyl+x  17 1   18.249900    0.26366   0.00050 com='sides of plug case'
 zhemicyl+x  15 1   18.605500    0.63450   0.00050 com='void: plug to liner'
 zhemicyl+x  16 1   18.757900    0.63450   0.00050 com='liner wall'
 zhemicyl+x  18 1   21.685692    0.63450   0.00050 com='bend section of ai'
 zhemicyl+x  19 1   21.838092    0.63450   0.00050 com='drum'
unit 4019
'drum lid and lip [Elev=43.500 in.]'
 zhemicyl+x  20 1   21.469792    1.90450   0.15240 com='void above lid'
 zhemicyl+x  19 1   21.622192    1.90450   0.00050 com='drum lid'
 zhemicyl+x  20 1   21.685692    1.90450   0.00050 com='void btw lid-drumwall'
 zhemicyl+x  19 1   21.838092    1.90450   0.00050 com='drum'
unit 5001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    20 1 2p21.839092  2p37.826417   0.26670   0.0
 hole 1001 0.0   37.826417   0.0
 hole 2001 0.0  -37.826417   0.0
 hole 3001  21.839092   0.0   0.0
 hole 4001 -21.839092   0.0   0.0
unit 5002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    20 1 2p21.839092  2p37.826417  11.59510   0.0
 hole 1002 0.0   37.826417   0.0
 hole 2002 0.0  -37.826417   0.0
 hole 3002  21.839092   0.0   0.0
 hole 4002 -21.839092   0.0   0.0
unit 5003
'cv bottom [Elev= 4.920 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.63500   0.0
 hole 1003 0.0   37.826417   0.0
 hole 2003 0.0  -37.826417   0.0
 hole 3003  21.839092   0.0   0.0
 hole 4003 -21.839092   0.0   0.0
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unit 5006
'content (collapsed) [Elev= 9.691 in.]'
 cuboid    20 1 2p21.839092  2p37.826417  12.11746   0.0
 hole 1006 0.0   37.826417   0.0
 hole 2006 0.0  -37.826417   0.0
 hole 3006  21.839092   0.0   0.0
 hole 4006 -21.839092   0.0   0.0
unit 5007
'np277_4 spacer [Elev=11.091 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   3.55710   0.0
 hole 1007 0.0   37.826417   0.0
 hole 2007 0.0  -37.826417   0.0
 hole 3007  21.839092   0.0   0.0
 hole 4007 -21.839092   0.0   0.0
unit 5008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
 cuboid    20 1 2p21.839092  2p37.826417  33.62072   0.0
 hole 1008 0.0   37.826417   0.0
 hole 2008 0.0  -37.826417   0.0
 hole 3008  21.839092   0.0   0.0
 hole 4008 -21.839092   0.0   0.0
unit 5010
'cv at 1st step in liner [Elev=35.330 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.15240   0.0
 hole 1010 0.0   37.826417   0.0
 hole 2010 0.0  -37.826417   0.0
 hole 3010  21.839092   0.0   0.0
 hole 4010 -21.839092   0.0   0.0
unit 5011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.22860   0.0
 hole 1011 0.0   37.826417   0.0
 hole 2011 0.0  -37.826417   0.0
 hole 3011  21.839092   0.0   0.0
 hole 4011 -21.839092   0.0   0.0
unit 5012
'cv flange to top of cv well [Elev=35.920 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   1.27000   0.0
 hole 1012 0.0   37.826417   0.0
 hole 2012 0.0  -37.826417   0.0
 hole 3012  21.839092   0.0   0.0
 hole 4012 -21.839092   0.0   0.0
unit 5013
'cv flange above cv well [Elev=37.070 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   2.92100   0.0
 hole 1013 0.0   37.826417   0.0
 hole 2013 0.0  -37.826417   0.0
 hole 3013  21.839092   0.0   0.0
 hole 4013 -21.839092   0.0   0.0
unit 5014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   1.01600   0.0
 hole 1014 0.0   37.826417   0.0
 hole 2014 0.0  -37.826417   0.0
 hole 3014  21.839092   0.0   0.0
 hole 4014 -21.839092   0.0   0.0
unit 5015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.15240   0.0
 hole 1015 0.0   37.826417   0.0
 hole 2015 0.0  -37.826417   0.0
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 hole 3015  21.839092   0.0   0.0
 hole 4015 -21.839092   0.0   0.0
unit 5016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   8.17880   0.0
 hole 1016 0.0   37.826417   0.0
 hole 2016 0.0  -37.826417   0.0
 hole 3016  21.839092   0.0   0.0
 hole 4016 -21.839092   0.0   0.0
unit 5017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   4.44500   0.0
 hole 1017 0.0   37.826417   0.0
 hole 2017 0.0  -37.826417   0.0
 hole 3017  21.839092   0.0   0.0
 hole 4017 -21.839092   0.0   0.0
unit 5018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   0.63500   0.0
 hole 1018 0.0   37.826417   0.0
 hole 2018 0.0  -37.826417   0.0
 hole 3018  21.839092   0.0   0.0
 hole 4018 -21.839092   0.0   0.0
unit 5019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    20 1 2p21.839092  2p37.826417   1.90500   0.0
 hole 1019 0.0   37.826417   0.0
 hole 2019 0.0  -37.826417   0.0
 hole 3019  21.839092   0.0   0.0
 hole 4019 -21.839092   0.0   0.0
unit 5020
'es3100 drum [Elev=43.500 in.]'
array 3         -21.839092   -37.826417    0.0
 cuboid    20  1 2p21.839592 2p37.826917 110.4905 0.0 com='interst. array space'
unit 6001
'drum bottom flat cover'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.26670 0.0
 hole 1001 0.0   0.0   0.0
unit 6002
'above drum bottom flat cover and below containment vessel'
 cuboid    20  1 2p21.839092 0.0 -21.839092 11.59510 0.0
 hole 1002 0.0   0.0   0.0
unit 6003
'cv bottom'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.63500 0.0
 hole 1003 0.0   0.0   0.0
unit 6006
'drum stand'
'content (collapsed)'
 cuboid    20  1 2p21.839092 0.0 -21.839092 12.11746 0.0
 hole 1006 0.0   0.0   0.0
unit 6007
'np277_4 spacer'
 cuboid    20  1 2p21.839092 0.0 -21.839092  3.55710 0.0
 hole 1007 0.0   0.0   0.0
unit 6008
'top of content stack to bottom of 1st step'
 cuboid    20  1 2p21.839092 0.0 -21.839092 33.62072 0.0
 hole 1008 0.0   0.0   0.0
unit 6010
'cv at 1st step in liner'
```

```
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.15240 0.0
 hole 1010 0.0   0.0   0.0
unit 6011
'vertical gap between 1st step in liner and cv flange'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.22860 0.0
 hole 1011 0.0   0.0   0.0
unit 6012
'cv flange to top of cv well'
 cuboid    20  1 2p21.839092 0.0 -21.839092  1.27000 0.0
 hole 1012 0.0   0.0   0.0
unit 6013
'cv flange above cv well'
 cuboid    20  1 2p21.839092 0.0 -21.839092  2.92100 0.0
 hole 1013 0.0   0.0   0.0
unit 6014
'plugpad2 below liner 2nd step'
 cuboid    20  1 2p21.839092 0.0 -21.839092  1.01600 0.0
 hole 1014 0.0   0.0   0.0
unit 6015
'2nd step in liner'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.15240 0.0
 hole 1015 0.0   0.0   0.0
unit 6016
'abv 2nd step in liner to bottom of angle iron'
 cuboid    20  1 2p21.839092 0.0 -21.839092  8.17880 0.0
 hole 1016 0.0   0.0   0.0
unit 6017
'bottom of angle iron to bend in angle iron'
 cuboid    20  1 2p21.839092 0.0 -21.839092  4.44500 0.0
 hole 1017 0.0   0.0   0.0
unit 6018
'bend in angle iron to top of angle iron'
 cuboid    20  1 2p21.839092 0.0 -21.839092  0.63500 0.0
 hole 1018 0.0   0.0   0.0
unit 6019
'drum lid and lip'
 cuboid    20  1 2p21.839092 0.0 -21.839092  1.90500 0.0
 hole 1019 0.0   0.0   0.0
unit 6020
'es3100 drum'
array 4         2r-21.839092     0.0
 cuboid    20  1 2p21.839592 0.0005 -21.839592 110.4905 0.0
unit 7001
 cuboid    20  1 2p21.839092 21.839092 0.0  0.26670 0.0
 hole 2001 0.0   0.0   0.0
unit 7002
 cuboid    20  1 2p21.839092 21.839092 0.0 11.59510 0.0
 hole 2002 0.0   0.0   0.0
unit 7003
 cuboid    20  1 2p21.839092 21.839092 0.0  0.63500 0.0
 hole 2003 0.0   0.0   0.0
unit 7006
 cuboid    20  1 2p21.839092 21.839092 0.0 12.11746 0.0
 hole 2006 0.0   0.0   0.0
unit 7007
 cuboid    20  1 2p21.839092 21.839092 0.0  3.55710 0.0
 hole 2007 0.0   0.0   0.0
unit 7008
 cuboid    20  1 2p21.839092 21.839092 0.0 33.62072 0.0
 hole 2008 0.0   0.0   0.0
unit 7010
```

```
 cuboid    20  1 2p21.839092 21.839092 0.0  0.15240 0.0
 hole 2010 0.0   0.0   0.0
unit 7011
 cuboid    20  1 2p21.839092 21.839092 0.0  0.22860 0.0
 hole 2011 0.0   0.0   0.0
unit 7012
 cuboid    20  1 2p21.839092 21.839092 0.0  1.27000 0.0
 hole 2012 0.0   0.0   0.0
unit 7013
 cuboid    20  1 2p21.839092 21.839092 0.0  2.92100 0.0
 hole 2013 0.0   0.0   0.0
unit 7014
 cuboid    20  1 2p21.839092 21.839092 0.0  1.01600 0.0
 hole 2014 0.0   0.0   0.0
unit 7015
 cuboid    20  1 2p21.839092 21.839092 0.0  0.15240 0.0
 hole 2015 0.0   0.0   0.0
unit 7016
 cuboid    20  1 2p21.839092 21.839092 0.0  8.17880 0.0
 hole 2016 0.0   0.0   0.0
unit 7017
 cuboid    20  1 2p21.839092 21.839092 0.0  4.44500 0.0
 hole 2017 0.0   0.0   0.0
unit 7018
 cuboid    20  1 2p21.839092 21.839092 0.0  0.63500 0.0
 hole 2018 0.0   0.0   0.0
unit 7019
 cuboid    20  1 2p21.839092 21.839092 0.0  1.90500 0.0
 hole 2019 0.0   0.0   0.0
unit 7020
'es3100 drum'
array 5         -21.839092     0.0     0.0
 cuboid    20  1 2p21.839592 21.839592 -0.0005 110.4905 0.0
unit 8001
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.26670 0.0
 hole 3001 0.0   0.0   0.0
unit 8002
 cuboid    20  1 0.0 -21.839092 2p37.826417 11.59510 0.0
 hole 3002 0.0   0.0   0.0
unit 8003
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.63500 0.0
 hole 3003 0.0   0.0   0.0
unit 8006
 cuboid    20  1 0.0 -21.839092 2p37.826417 12.11746 0.0
 hole 3006 0.0   0.0   0.0
unit 8007
 cuboid    20  1 0.0 -21.839092 2p37.826417  3.55710 0.0
 hole 3007 0.0   0.0   0.0
unit 8008
 cuboid    20  1 0.0 -21.839092 2p37.826417 33.62072 0.0
 hole 3008 0.0   0.0   0.0
unit 8010
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.15240 0.0
 hole 3010 0.0   0.0   0.0
unit 8011
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.22860 0.0
 hole 3011 0.0   0.0   0.0
unit 8012
 cuboid    20  1 0.0 -21.839092 2p37.826417  1.27000 0.0
 hole 3012 0.0   0.0   0.0
unit 8013
```

```
 cuboid    20  1 0.0 -21.839092 2p37.826417  2.92100 0.0
 hole 3013 0.0   0.0   0.0
unit 8014
 cuboid    20  1 0.0 -21.839092 2p37.826417  1.01600 0.0
 hole 3014 0.0   0.0   0.0
unit 8015
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.15240 0.0
 hole 3015 0.0   0.0   0.0
unit 8016
 cuboid    20  1 0.0 -21.839092 2p37.826417  8.17880 0.0
 hole 3016 0.0   0.0   0.0
unit 8017
 cuboid    20  1 0.0 -21.839092 2p37.826417  4.44500 0.0
 hole 3017 0.0   0.0   0.0
unit 8018
 cuboid    20  1 0.0 -21.839092 2p37.826417  0.63500 0.0
 hole 3018 0.0   0.0   0.0
unit 8019
 cuboid    20  1 0.0 -21.839092 2p37.826417  1.90500 0.0
 hole 3019 0.0   0.0   0.0
unit 8020
'es3100 drum'
array 6         -21.839092    -37.826417    0.0
 cuboid    20  1 0.0005 -21.839592 2p37.826917 110.4905 0.0
unit 9001
 cuboid    20  1 21.839092 0.0 2p37.826417  0.26670 0.0
 hole 4001 0.0   0.0   0.0
unit 9002
 cuboid    20  1 21.839092 0.0 2p37.826417 11.59510 0.0
 hole 4002 0.0   0.0   0.0
unit 9003
 cuboid    20  1 21.839092 0.0 2p37.826417  0.63500 0.0
 hole 4003 0.0   0.0   0.0
unit 9006
 cuboid    20  1 21.839092 0.0 2p37.826417 12.11746 0.0
 hole 4006 0.0   0.0   0.0
unit 9007
 cuboid    20  1 21.839092 0.0 2p37.826417  3.55710 0.0
 hole 4007 0.0   0.0   0.0
unit 9008
 cuboid    20  1 21.839092 0.0 2p37.826417 33.62072 0.0
 hole 4008 0.0   0.0   0.0
unit 9010
 cuboid    20  1 21.839092 0.0 2p37.826417  0.15240 0.0
 hole 4010 0.0   0.0   0.0
unit 9011
 cuboid    20  1 21.839092 0.0 2p37.826417  0.22860 0.0
 hole 4011 0.0   0.0   0.0
unit 9012
 cuboid    20  1 21.839092 0.0 2p37.826417  1.27000 0.0
 hole 4012 0.0   0.0   0.0
unit 9013
 cuboid    20  1 21.839092 0.0 2p37.826417  2.92100 0.0
 hole 4013 0.0   0.0   0.0
unit 9014
 cuboid    20  1 21.839092 0.0 2p37.826417  1.01600 0.0
 hole 4014 0.0   0.0   0.0
unit 9015
 cuboid    20  1 21.839092 0.0 2p37.826417  0.15240 0.0
 hole 4015 0.0   0.0   0.0
unit 9016
```

```
 cuboid    20  1 21.839092 0.0 2p37.826417  8.17880 0.0
 hole 4016 0.0   0.0   0.0
unit 9017
 cuboid    20  1 21.839092 0.0 2p37.826417  4.44500 0.0
 hole 4017 0.0   0.0   0.0
unit 9018
 cuboid    20  1 21.839092 0.0 2p37.826417  0.63500 0.0
 hole 4018 0.0   0.0   0.0
unit 9019
 cuboid    20  1 21.839092 0.0 2p37.826417  1.90500 0.0
 hole 4019 0.0   0.0   0.0
unit 9020
'es3100 drum'
array 7         0.0    -37.826417    0.0
 cuboid    20  1 21.839592 -0.0005 2p37.826917 110.4905 0.0
unit 9021
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.26670 0.0
unit 9022
 cuboid    20  1 21.839092 0.0 21.839092 0.0 11.59510 0.0
unit 9023
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.63500 0.0
unit 9026
 cuboid    20  1 21.839092 0.0 21.839092 0.0 12.11746 0.0
unit 9027
 cuboid    20  1 21.839092 0.0 21.839092 0.0  3.55710 0.0
unit 9028
 cuboid    20  1 21.839092 0.0 21.839092 0.0 33.62072 0.0
unit 9030
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.15240 0.0
unit 9031
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.22860 0.0
unit 9032
 cuboid    20  1 21.839092 0.0 21.839092 0.0  1.27000 0.0
unit 9033
 cuboid    20  1 21.839092 0.0 21.839092 0.0  2.92100 0.0
unit 9034
 cuboid    20  1 21.839092 0.0 21.839092 0.0  1.01600 0.0
unit 9035
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.15240 0.0
unit 9036
 cuboid    20  1 21.839092 0.0 21.839092 0.0  8.17880 0.0
unit 9037
 cuboid    20  1 21.839092 0.0 21.839092 0.0  4.44500 0.0
unit 9038
 cuboid    20  1 21.839092 0.0 21.839092 0.0  0.63500 0.0
unit 9039
 cuboid    20  1 21.839092 0.0 21.839092 0.0  1.90500 0.0
unit 9040
'array end space'
array 8         0.0    0.0    0.0
 cuboid    20  1 21.839592 -0.0005 21.839592 -0.0005 110.4905 0.0
global
unit 9050
array 9    3r0.0
reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=3 nuy=3 nuz=4   fill 27r1004  9r1005      end fill
ara=3 nux=1 nuy=1 nuz=19 fill
5001 5002 5003 5006 5007 5006 5007 5006 5008 5010
5011 5012 5013 5014 5015 5016 5017 5018 5019       end fill
```

```
ara=4 nux=1 nuy=1 nuz=19                                fill
6001 6002 6003 6006 6007 6006 6007 6006 6008 6010
6011 6012 6013 6014 6015 6016 6017 6018 6019       end fill
ara=5 nux=1 nuy=1 nuz=19                                fill
7001 7002 7003 7006 7007 7006 7007 7006 7008 7010
7011 7012 7013 7014 7015 7016 7017 7018 7019       end fill
ara=6 nux=1 nuy=1 nuz=19                                fill
8001 8002 8003 8006 8007 8006 8007 8006 8008 8010
8011 8012 8013 8014 8015 8016 8017 8018 8019       end fill
ara=7 nux=1 nuy=1 nuz=19                                fill
9001 9002 9003 9006 9007 9006 9007 9006 9008 9010
9011 9012 9013 9014 9015 9016 9017 9018 9019       end fill
ara=8 nux=1 nuy=1 nuz=19                                fill
9021 9022 9023 9026 9027 9026 9027 9026 9028 9030
9031 9032 9033 9034 9035 9036 9037 9038 9039       end fill
ara=9 nux=7 nuy=3 nuz=3                                 fill
9040 5r6020 9040 8020 5r5020 9020 9040 5r7020 9040 2q21 end fill
end array
read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.23 Case nciaoxt11_1_24_1_3

```
=csas25    parm=size=3000000
nciaoxt11,0.0in np,disp.24000.0gUO2 (21124.9g235, 6533.9gH2O hx=  9.90),fr=1.0e-04
238groupndf5 infhommedium
'HEU volume =3669.72477, SPACER volume    0.00000'
'HEU oxide, bulk density of oxide in cans=  6.54000 g/cm3'
'wrapped dry content can hx=0.79, CV void volume 6545.63717'
'oxide= 24000.0 g, sat. moisture in HEU oxide=1477.3 g, oxide htox= 1.83'
arbmuox    6.54000   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  4.0256e-01  2 0 0 0   1001   11.1913
                              8016   88.8087    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
```

```
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
```

```
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                                8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciaoxt11,0.0in np,disp.24000.0gUO2 (21124.9g235, 6533.9gH2O,hx=  9.90),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  28.92123 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
```

```
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.24 Case nciask_9_15

```
=csas25    parm=size=3000000
nciask,0.0 21300.0g soc(19865.3uox,15672.8u235,  921.0c),hx= 12.82,fr=1.0e+00
238groupndf5 infhommedium
'  cm3: Skull oxide content 6974.5, SPACER    0.0, CV void 3240.9; CV htox=12.82'
'g/cm3: Skull oxide content  3.05400'
'U3O8   (19865.33gUOX,16816.3gU,15672.8g235U, 3801.4g.sat.H2O, HX=  7.43)'
'Carbon (  921.00gC,   58764.1mgC/g235U)'
'Poly   (  513.00gCH2)'
'Other  (    0.67gUnident (assumed H2O)'
''
'Increm (  921.0gC,15672.8g235U,   58764.1mgC/g235U)'
'GREP1:21300.00 19865.33 3.8014e+03    7.43 16816.35 15672.84   921.00  58764.1
'GREP2: 3235.07   513.00      12.82    0.67  1.0e+00
''
arbmuox    2.84830    3 0 0 0  92235   78.8954
                               92238    5.7563
                                8016   15.3483    1  1.0000  293  end
arbmc     1.3205e-01  1 0 0 0   6012  100.0000    1  1.0000  293  end
arbmastm  5.4505e-01  2 0 0 0   1001   11.1913
                                8016   88.8087    1  1.0000  293  end
arbmpoly   0.07355    2 0 0 0   1001   14.3798
                                6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
```

```
                                8016   43.4251
                               11023    0.1174
                               12000    0.3378
                               13027   39.0479
                               14000    2.4672
                               16000    0.3083
                               20000   11.8336
                               26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
```

```
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  1       293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciask,0.0,21300.0g soc(19865.3uox,15672.8u235,  921.0c),hx= 12.82 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  54.39413 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
```

```
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
```

```
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.25 Case ncsrunhct11_9_1_15

```
=csas25    parm=size=3000000
ncsrunhct11 0.0innp,disp. 9000.0gUNHc( 4238.7g235, 6980.8gH2O hx= 54.99),fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], gU/L= 414.9296'
'UNH crystals in cans  2.79329 g/cm3. wrapped dry content can hx=3.96'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.31541 293  end
arbmh2oc  6.8336e-01  2 0 0 0  1001   11.1913
                               8016   88.8087    1  1.0000  293  end
```

```
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  6.8336e-01  2 0 0 0   1001   11.1913
                                8016   88.8087     3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                              8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
```

```
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrunhct11 0.0innp,disp. 9000.0gUNHc( 4238.7g235, 6980.8gH2O,hx= 54.99),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
```

```
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   77.72400   0.0     com='kaolite'
 cylinder  19 1   23.329900   77.72400   0.0     com='drum'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
```

```
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
```

```
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.26 Case icsrunhct12_15_1_15

```
=csas25    parm=size=3000000
icsrunhct12 0.0innp,disp.15000.0gUNHc( 7064.4g235, 6870.7gH2O hx= 52.91),fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], gU/L= 429.1329 dispersed'
'UNH crystals in cans  2.79329 g/cm3. wrapped dry content can hx=2.37'
'UNHc in cv   9308.07449 g.'
'water in cv  6870.67680 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.32620 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                               8016   88.8087    1  0.67380 293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0    1001   11.1913
                                 8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
```

```
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.516887 = (den.mult)(np277-4 min.den.) = 0.9935052*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.80508e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
```

```
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
'UNHc in cv well   5691.92551 g.'
'water in cv well  4201.44688 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                             92238    0.0000
                              1001    2.4232
                              7014    5.6116
                              8016   44.8690   15  0.32620 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                              8016   88.8087   15  0.67380 293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
icsrunhct12 0.0innp,disp.15000.0gUNHc( 7064.4g235, 6870.7gH2O,hx= 52.91),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
'v1002=1.36748e+01  '
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
'v1003=4.43850e+03  '
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
```

```
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.838092   77.72400   0.0     com='drum'
 cuboid    21 1 4p21.838092   77.72400   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
'v1010=8.70294e+00  '
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
'v1011=5.36220e+01  '
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
'v1012=7.43264e+01  '
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
'v1013=1.70951e+02  '
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
'v1014=1.39785e+02  '
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
```

```
'2nd step in liner [Elev=37.530 in.]'
'v1015=5.71136e+01  '
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
'v1016=6.92877e+02  '
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
'v1017=1.83014e+02  '
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
'v1018=4.14168e+02  '
'Volume cv well=6.24674e+03  '
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
```

```
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.27 Case ncsrtriga_1_15_15

```
=csas25    parm=size=3000000
ncsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
```

```
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
```

```
ss304                                              18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                              18  1.25705 293  end
'steel: drum steel for single units'
ss304                                              19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                              19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                            end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
```

```
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
```

```
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
```

```
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.28 Case nciatriga_1_15_3

```
=csas25    parm=size=3000000
nciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
```

```
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
```

```
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
```

```
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.926 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.926 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.722275   38.98540   0.0     com='drum'
 cuboid    20 1 4p22.866096   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
```

```
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
```

```
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.29 Case atdmr_7_8

```
=csas25    parm=size=300000
atdmr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40,Rc= 6.02382cm
238groupndf5 multiregion
'U= 7000.0g, poly=500.0g, content hx=2.40'
'core htox= 2.40'
uranium  1 den=18.81109 0.4064 293  92235  100.00
                                    92238   0.000                end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.5936  293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv    0.9982   2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.0     293  end
'steel: cv, drum liner, plug liner, angle iron, drum'
ss304                                          3  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    4  0.0287  293  end
```

```
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    4  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
arbmh2ok   0.61533  2 0 0 0    1001   11.1913
                               8016   88.8087    6  1.0e+00  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
```

```
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
spherical end
1   6.02382
7  26.02382
end zone
atdmr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40 Rc= 6.02382cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Mass of fm in core region   = 7000.00000 g'
'Mass of poly in core region =  500.00000 g'
'Mass of core region         = 7500.00000 g'
'Vol of fm                   =  372.12095 cm3'
'Vol of poly                 =  543.47826 cm3'
'Volume of core region       =  915.59921 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =   2.3957'
read geometry
global
unit 1001
'uranium metal/poly dry core with 20.0 cm water reflection'
sphere  1  1   6.02382  com='uranium metal/poly core'
sphere  7  1  26.02382  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.30 Case atdmsr_7_8_11

```
=csas25    parm=size=300000
atdmsr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40,Rc= 6.02382cm, 33066.6gSS,Rs=10.6643cm
238groupndf5 multiregion
'U= 7000.0g, poly=500.0g, content hx=2.40'
'core htox= 2.40'
uranium  1 den=18.81109 0.4064 293  92235  100.00
                               92238   0.000                end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                              6012   85.6202    1  0.5936  293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv    0.9982   2 0 0 0   1001   11.1913
                              8016   88.8087    2  1.0     293  end
'steel: cv, drum liner, plug liner, angle iron, drum'
ss304                                         3  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    4  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    4  0.067   293  end
```

```
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
arbmh2ok   0.61533  2 0 0 0    1001   11.1913
                              8016   88.8087    6  1.0e+00  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
spherical end
1   6.02382
```

```
3  10.66433
7  30.66433
end zone
atdmsr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40 Rc= 6.02382cm, 33066.6gSS,Rs=10.6643cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Mass of fm in core region   = 7000.00000 g'
'Mass of poly in core region =  500.00000 g'
'Mass of core region         = 7500.00000 g'
'Vol of fm                   =  372.12095 cm3'
'Vol of poly                 =  543.47826 cm3'
'Volume of core region       =  915.59921 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =   2.3957'
' '
'Mass of steel is derived from the mass of the steel in the CV,'
'steel liner, plug liner, angle iron and drum.  The mass of each'
'was taken directly from Case hciabmt12_36_1_8_1_in.output'
'Model volume taken as stainless steel mass divided by ss density'
'total mass of ss304=  66133.15000'
'total volume of ss304= 8329.1'
'maximum ss304 radius = 13.01972'
read geometry
global
unit 1001
'uranium metal/poly dry core, ss304 shell, 20.0 cm h2o reflector'
'increase ss304 shell by equal volume increments'
'8.32911e+02  cm3  volume of increment'
'5080.155 cm3               accumulative volume of core and ss304'
'10.66433 cm                accumulative radius of ss304 shell'
'3.30666e+04  g             accumulative mass of ss304 shell'
sphere  1  1   6.02382  com='uranium metal/poly core'
sphere  3  1  10.66433  com='ss304 shell around core'
sphere  7  1  30.66433  com='20cm h2o reflector around ss304 shell'
end geometry
end data
end
```

6.9.7.31 Case atdmdkr_7_8_6

```
=csas25    parm=size=300000
atdmdkr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40,Rc= 6.02382cm, 53419.1gKao,Rk=31.0802cm
238groupndf5 multiregion
'U= 7000.0g, poly=500.0g, content hx=2.40'
'core htox= 2.40'
uranium  1 den=18.81109 0.4064 293  92235  100.00
                                    92238   0.000                end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.5936  293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv    0.9982   2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.0     293  end
'steel: cv, drum liner, plug liner, angle iron, drum'
ss304                                          3  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
```

```
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    4  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    4  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    6 0.244736 293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
```

```
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
spherical end
1   6.02382
6  31.08024
7  51.08024
end zone
atdmdkr,[ 7000.0U, 7000.0U235,500.0CH2]g htox= 2.40 Rc= 6.02382cm, 53419.1gKao,Rk=31.0802cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Mass of fm in core region   = 7000.00000 g'
'Mass of poly in core region =  500.00000 g'
'Mass of core region         = 7500.00000 g'
'Vol of fm                   =  372.12095 cm3'
'Vol of poly                 =  543.47826 cm3'
'Volume of core region       =  915.59921 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =   2.3957'
read geometry
global
unit 1001
'uranium metal/poly dry core, 15lb free h2o-kaolite shell, 20.0 cm water reflection'
'maximum kaolite radius =  31.08014 cm'
'increase kaolite shell by equal volume increments'
'2.49686e+04  cm3 volume of increment'
'125758.5 cm3 accumulative volume of core and kaolite'
'31.08024 cm accumulative radius of kaolite shell'
'5.34191e+04  g accumulative mass of kaolite shell'
sphere  1  1   6.02382  com='uranium metal/poly core'
sphere  6  1  31.08024  com='dry-kaolite shell around core'
sphere  7  1  51.08024  com='20cm h2o reflector around kaolite shell'
end geometry
end data
end
```

6.9.7.32 Case atdzr

```
=csas25    parm=size=300000
atdzr,[10400.UZrHx, 921.0U235,500.0CH2]g htox=43.37,Rc= 7.46774cm
238groupndf5 multiregion
'UZrHx=10400.0g, poly=500.0g, content hx=18.2'
'core htox=43.37'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  0.6885 293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.3115  293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
```

```
spherical end
1   7.46774
7  27.46774
end zone
atdzr,[10400.UZrHx, 921.0U235,500.0CH2]g htox=43.37 Rc= 7.46774cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Mass of fm in core region   = 10400.0010 g'
'Mass of poly in core region =  500.00000 g'
'Mass of core region         = 10900.0010 g'
'Vol of fm                   = 1200.95996 cm3'
'Vol of poly                 =  543.47826 cm3'
'Volume of core region       = 1744.43822 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =  43.3700'
read geometry
global
unit 1001
'fissile material dry core with 20.0 cm water reflection'
sphere  1  1   7.46774  com='HEU core'
sphere  7  1  27.46774  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.33 Case athzp15kr_5

```
=csas25    parm=size=300000
athzp15kr,[10400.UZrHx, 921.0U235,500.0CH2,9008.5H2O]g htox=298.6,Rc=31.14838cm
238groupndf5 multiregion
'UZrHx=10400.0g poly=500.0g cont.hx=18.2, H2O in Kaolite=  9008.5g, homgcore hx=298.6'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  0.0095 293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0043  293  end
arbmh2ok   0.07216   2 0 0 0    1001   11.1913
                               8016   88.8087    1  9.8620e-01    293  end
arbmal2o3  0.40458   2 0 0 0   13027   52.9390
                               8016   47.0610    1  0.096   293  end
arbmsio2   0.40458   2 0 0 0   14000   46.7570
                               8016   53.2430    1  0.367   293  end
arbmfe2o3  0.40458   2 0 0 0   26000   69.9540
                               8016   30.0460    1  0.067   293  end
arbmtio2   0.40458   2 0 0 0   22000   59.9535
                               8016   40.0465    1  0.012   293  end
arbmcao    0.40458   2 0 0 0   20000   71.4815
                               8016   28.5185    1  0.307   293  end
arbmmgo    0.40458   2 0 0 0   12000   60.3169
                               8016   39.6831    1  0.131   293  end
arbmna2o   0.40458   2 0 0 0   11023   74.1961
                               8016   25.8039    1  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    2  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          3  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
```

```
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    4  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    4  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    6  1.0e+00  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
```

```
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.0000  293  end
end comp
spherical end
1  31.14838
7  51.14838
end zone
athzp15kr,[10400.UZrHx, 921.0U235,500.0CH2,9008.5H2O]g htox=298.6 Rc=31.14838cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 10400.0010 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 9008.54567 g'
'Mass of kao in homogenized region  = 51214.8849 g'
'Mass of homogenized region         = 71123.4316 g'
'Vol of homogenized fm              = 1200.95996 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 124841.264 cm3'
'Vol of kao                         = 124844.318 cm3'
'Volume of homogenized region       = 126588.757 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 298.6696'
read geometry
global
unit 1001
'homogenized UZrHx/poly/15lb free h2o-Kaolite, 20.0 cm refl'
sphere  1  1  31.14838  com='HEU core/water mixture'
sphere  7  1  51.14838  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.34 Case athzpw15kr_5

```
=csas25    parm=size=300000
athzpw15kr,[10400.UZrHx, 921.0U235,500.0CH2,6803.8H2O]g
htox=236.1,Rc=12.69027cm,53419.6,Rs=31.69769cm
238groupndf5 multiregion
'UZrHx=10400.0g poly=500.0g cont.hx=18.2, H2O in Kaolite=  6803.8g, homgcore hx=236.1'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
```

```
                              92235    8.8558
                              92238   36.1442    1  0.1403 293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                              6012   85.6202    1  0.0635  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                              8016   88.8087    1  7.9622e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                              8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                              8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                              8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                              8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                              8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                              8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                              8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
```

```
                                8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                                8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                                8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                                8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                                8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                                8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                                8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                                8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                                8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.69027
2  31.69769
8  51.69769
end zone
athzpw15kr,[10400.UZrHx, 921.0U235,500.0CH2,6803.8H2O]g htox=236.1
Rc=12.69027cm,53419.6,Rs=31.69769cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
```

```
'                            CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 10400.0010 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 17703.8312 g'
'Vol of homogenized fm              = 1200.95996 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 8560.53744 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 236.1886'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.69027  com='HEU core/water mixture'
sphere  2  1  31.69769  com='radius of kaolite shell'
sphere  8  1  51.69769  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.35 Case athmp15kr_12_8_5

```
=csas25    parm=size=300000
athmp15kr,[ 7000.0U, 7000.0U235,500.0CH2,9008.5H2O]g htox=35.99,Rc=31.08025cm
238groupndf5 multiregion
'U= 7000.0g poly=500.0g cont.hx=2.40, H2O in Kaolite=  9008.5g, core hx=35.99'
uranium  1 den=18.81109 2.9590e-03   293   92235  100.00
                                           92238    0.000               end
arbmpoly   0.92000   2 0 0 0    1001   14.3798
                                6012   85.6202    1  4.3216e-03    293  end
arbmh2ok   0.07216   2 0 0 0    1001   11.1913
                                8016   88.8087    1  9.9270e-01    293  end
arbmal2o3  0.40724   2 0 0 0   13027   52.9390
                                8016   47.0610    1  0.096   293  end
arbmsio2   0.40724   2 0 0 0   14000   46.7570
                                8016   53.2430    1  0.367   293  end
arbmfe2o3  0.40724   2 0 0 0   26000   69.9540
                                8016   30.0460    1  0.067   293  end
arbmtio2   0.40724   2 0 0 0   22000   59.9535
                                8016   40.0465    1  0.012   293  end
arbmcao    0.40724   2 0 0 0   20000   71.4815
                                8016   28.5185    1  0.307   293  end
arbmmgo    0.40724   2 0 0 0   12000   60.3169
                                8016   39.6831    1  0.131   293  end
arbmna2o   0.40724   2 0 0 0   11023   74.1961
                                8016   25.8039    1  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    2  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          3  1.0     293  end
'kaolite 1600 body'
```

```
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    4  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    4  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    4  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    4  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    4  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    4  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    4  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    4  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
```

```
                                8016   88.8087    6  1.0e+00  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                                8016   47.0610    6  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                                8016   53.2430    6  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                                8016   30.0460    6  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                                8016   40.0465    6  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                                8016   28.5185    6  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                                8016   39.6831    6  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                                8016   25.8039    6  0.020   293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087    7  1.0000  293  end
end comp
spherical end
1  31.08025
7  51.08025
end zone
athmp15kr,[ 7000.0U, 7000.0U235,500.0CH2,9008.5H2O]g htox=35.99 Rc=31.08025cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                           CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                           CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                           CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 7000.00000 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 9008.54567 g'
'Mass of kao in homogenized region  = 51214.8849 g'
'Mass of homogenized region         = 67723.4306 g'
'Vol of homogenized fm              =  372.12095 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 124841.264 cm3'
'Vol of kao                         = 124844.318 cm3'
'Volume of homogenized region       = 125759.918 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =  35.9859'
read geometry
global
unit 1001
'homogenized uranium/poly/15lb free h2o-Kaolite, 20.0 cm refl'
sphere  1  1  31.08025  com='HEU core/water mixture'
sphere  7  1  51.08025  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.36 Case athmpw15kr_12_8_5

```
=csas25    parm=size=300000
athmpw15kr,[ 7000.0U, 7000.0U235,500.0CH2,6803.8H2O]g
htox=27.77,Rc=12.26673cm,53419.6,Rs=31.63191cm
238groupndf5 multiregion
```

```
'U= 7000.0g poly=500.0g cont.hx=2.40, H2O in Kaolite=  6803.8g, core hx=27.77'
uranium  1 den=18.81109 4.8129e-02   293   92235  100.00
                                           92238    0.000              end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  7.0292e-02    293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.8158e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    6  0.0287  293  end
```

```
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.26673
2  31.63191
8  51.63191
end zone
athmpw15kr,[ 7000.0U, 7000.0U235,500.0CH2,6803.8H2O]g htox=27.77
Rc=12.26673cm,53419.6,Rs=31.63191cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
```

```
'Mass of kao from Kaolite = 51214.88 g'
'                           CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 7000.00000 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 14303.8302 g'
'Vol of homogenized fm              =  372.12095 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7731.69843 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =  27.7652'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized uranium/poly/excess water, 15lb free h2o-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.26673  com='HEU core/water mixture'
sphere  2  1  31.63191  com='radius of kaolite shell'
sphere  8  1  51.63191  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.37 Case athmpw13kr_12_8_5

```
=csas25    parm=size=300000
athmpw13kr,[ 7000.0U, 7000.0U235,500.0CH2,5896.6H2O]g
htox=24.38,Rc=11.76592cm,53419.6,Rs=31.55946cm
238groupndf5 multiregion
'U= 7000.0g poly=500.0g cont.hx=2.40, H2O in Kaolite=  5896.6g, core hx=24.38'
uranium  1 den=18.81109 5.4540e-02   293   92235  100.00
                                           92238    0.000              end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  7.9656e-02    293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.6580e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
```

```
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                             4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 13lb free h2o-Kaolite = 8101.3937 = 5896.67 + 2204.7237 g'
```

```
'density of water in 13lb free h2o-Kaolite = 0.06489 g/cm3 = 8101.3937/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.272142 = 2204.7237/8101.3937'
arbmh2ok   0.06489  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  11.76592
2  31.55946
8  51.55946
end zone
athmpw13kr,[ 7000.0U, 7000.0U235,500.0CH2,5896.6H2O]g htox=24.38
Rc=11.76592cm,53419.6,Rs=31.55946cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 8101.342 g'
'                             CHECK=> 8101.062 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.639 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fm             = 7000.00000 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 5896.62664 g'
'Mass of homogenized region         = 13396.6266 g'
'Vol of homogenized fm              =  372.12095 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 5907.25971 cm3'
'Volume of homogenized region       = 6822.85892 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  =  24.3825'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized uranium/poly/excess water, 13lb free h2o-Kaolite shell, 20.0 cm refl'
sphere  1  1  11.76592  com='HEU core/water mixture'
sphere  2  1  31.55946  com='radius of kaolite shell'
```

```
sphere  8  1  51.55946  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.38 Case athmp15kmr_7_7_8_5

```
=csas25    parm=size=300000
athmp15kmr, 7.0kgU,[3500.0U235,500.0CH2, 9008.5H2O]g htox=
71.97,Rc=31.06492cm,3500.0U235,Rs=31.08035cm
238groupndf5 multiregion
'dry CV hx=2.40 for  7.0 kilograms HEU metal wrapped content'
'Core  3500.0g235U,500.0g Poly,  9008.5gH2O in Kaolite.  htox=71.97'
uranium  1 den=18.81109 1.4817e-03   293   92235  100.00
                                           92238    0.00                end
arbmpoly   0.92000   2 0 0 0    1001   14.3798
                                6012   85.6202    1  4.3280e-03    293  end
arbmh2ok   0.07216   2 0 0 0    1001   11.1913
                                8016   88.8087    1  9.9417e-01    293  end
arbmal2o3  0.40785   2 0 0 0   13027   52.9390
                                8016   47.0610    1  0.096   293  end
arbmsio2   0.40785   2 0 0 0   14000   46.7570
                                8016   53.2430    1  0.367   293  end
arbmfe2o3  0.40785   2 0 0 0   26000   69.9540
                                8016   30.0460    1  0.067   293  end
arbmtio2   0.40785   2 0 0 0   22000   59.9535
                                8016   40.0465    1  0.012   293  end
arbmcao    0.40785   2 0 0 0   20000   71.4815
                                8016   28.5185    1  0.307   293  end
arbmmgo    0.40785   2 0 0 0   12000   60.3169
                                8016   39.6831    1  0.131   293  end
arbmna2o   0.40785   2 0 0 0   11023   74.1961
                                8016   25.8039    1  0.020   293  end
uranium  2 den=18.81109  1.0   293   92235  100.00
                                      92238    0.00              end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
```

```
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in 15lb free h2o-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in 15lb free h2o-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                              8016   88.8087    7  0.0287  293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                              8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
```

```
1  31.06492
2  31.08035
8  51.08035
end zone
athmp15kmr, 7.0kgU,[3500.0U235,500.0CH2, 9008.5H2O]g htox= 71.97
Rc=31.06492cm,3500.0U235,Rs=31.08035cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                           CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                           CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                           CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of homogenized fissile U     = 3500.00000 g'
'Mass of poly in homogenized region=  500.00000 g'
'Mass of h2o in homogenized region = 9008.54567 g'
'Mass of kao in homogenized region = 51214.8849 g'
'Mass of homogenized core region   = 64223.4306 g'
'Vol of homogenized fissile U      =  186.06048 cm3'
'Vol of poly                       =  543.47826 cm3'
'Vol of h2o                        = 124841.264 cm3'
'Vol of kao                        = 124844.318 cm3'
'Volume of homogenized core region = 125573.857 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'Core hydrogen to fissile U ratio  =  71.9718'
' '
read geometry
global
unit 1001
'fissile material, homog, remaining fm as shell around mixture, 20.0 cm refl'
'Radius of homogenized core         =   31.06492 cm'
'Mass of fm shell                   = 3500.00000 g'
'Vol of fm shell                    =  186.06048 cm3'
'Radius of fm shell                 =   31.08035 cm'
sphere  1  1  31.06492  com='HEU core/water mixture'
sphere  2  1  31.08035  com='radius of fissile material shell'
sphere  8  1  51.08035  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.39 Case cvcrtriga_1_1

```
=csas25    parm=size=3000000
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235,    0.0gH2O hx=  0.00),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                               40000   54.0446
                               92235    8.8558
                               92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
```

```
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087    3  1e-20   293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
```

```
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235,    0.0gH2O,hx=  0.00),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
```

```
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
```

```
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.40 Case cvcrtriga_1_15

```
=csas25    parm=size=3000000
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
```

```
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
```

```
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   21  1.0     293  end
end comp
cvcrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
```

```
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
```

```
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.41 Case cvcrtriga_2_15

```
=csas25    parm=size=3000000
cvcrtriga 1.4in thk np,10400.0gUZrHx(  921.0g235, 8384.6gH2O hx=237.62),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume  614.68012'
'TRIGA wrapped dry content can hx=18.2, CV void volume 8399.72186'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                         10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
```

```
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
```

```
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrtriga 1.4in thk np,10400.0gUZrHx(  921.0g235, 8384.6gH2O,hx=237.62),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.321 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
```

```
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'45.21560             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   31.87340   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   31.87340   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   31.87340   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
```

```
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.42 Case cvcrtriga_70_1_1

```
=csas25    parm=size=3000000
cvcrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235,    0.0gH2O hx=  0.00),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1e-20   293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
```

```
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
```

```
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   21  1.0     293  end
end comp
cvcrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235,    0.0gH2O,hx=  0.00),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
```

```
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.43 Case cvcrtriga_70_1_15

```
=csas25    parm=size=3000000
cvcrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e+00
238groupndf5 infhommedium
```

```
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
```

```
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
```

```
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
```

```
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.44 Case cvcrtriga_70_2_15

```
=csas25    parm=size=3000000
cvcrtriga_70 1.4in thk np, 6847.1gUZrHx(  408.0g235, 8384.6gH2O hx=536.39),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume  614.68012'
'TRIGA wrapped dry content can hx=41.1, CV void volume 8399.72186'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
```

```
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
```

```
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
cvcrtriga_70 1.4in thk np, 6847.1gUZrHx(  408.0g235, 8384.6gH2O,hx=536.39),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
```

```
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=11.321 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'45.21560             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   31.87340   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   31.87340   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   31.87340   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
```

```
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.45 Case ncsrtriga_1_15_15

```
=csas25    parm=size=3000000
ncsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
```

```
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
```

```
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
```

```
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
```

```
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
```

```
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.46 Case ncsrtriga70_1_15_15

```
=csas25    parm=size=3000000
ncsrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
```

```
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
```

```
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrtriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
```

```
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
```

```
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
```

```
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.47 Case ncsrt55d2_1_15_15

```
=csas25    parm=size=3000000
ncsrt55d2 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
```

```
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1   0.11756  293  end
arbmwicv 9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    1   0.88244  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
```

```
                                8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
```

```
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrt55d2 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
 cylinder  1  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  1  1    6.426200   38.98540   0.0     com='cv well cavity'
```

```
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
```

```
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.48 Case hcsrtriga_1_15_15

```
=csas25    parm=size=3000000
hcsrtriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
```

```
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
```

```
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
hcsrtriga 0.0in thk np,10400.0gU(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.838092   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p21.838092   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
```

```
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p21.838092    0.00020  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.838092   38.98540   0.0     com='drum'
 cuboid    21 1 4p21.838092   38.98540   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
```

```
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
```

```
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.49 Case hcsrtriga70_1_15_15

```
=csas25    parm=size=3000000
hcsrtriag_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
```

```
                                8016   43.4254
                               11023    0.1174
                               12000    0.3378
                               13027   39.0477
                               14000    2.4671
                               16000    0.3083
                               20000   11.8335
                               26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
```

```
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
hcsrtriag_70 0.0in thk np, 6847.1gU(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
```

```
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.838092   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p21.838092   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p21.838092    0.00020  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.838092   38.98540   0.0     com='drum'
 cuboid    21 1 4p21.838092   38.98540   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
```

```
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
```

```
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.50 Case nciatriga_1_15_3

```
=csas25    parm=size=3000000
nciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
```

```
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
```

```
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                            16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                            17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                            18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                            18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                            19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                            19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                     end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.926 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.926 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.722275   38.98540   0.0     com='drum'
 cuboid    20 1 4p22.866096   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
```

```
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
```

```
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.51 Case nciatriga70_1_15_3

```
=csas25    parm=size=3000000
nciatriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
```

```
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                              8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
nciatriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
```

```
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.926 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.926 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.722275   38.98540   0.0     com='drum'
 cuboid    20 1 4p22.866096   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
```

```
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
```

```
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.52 Case hciatriga_1_15_3

```
=csas25    parm=size=3000000
hciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O hx=255.01),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=18.2, CV void volume 9014.40198'
arbmtriga  8.65974  4 0 0 0    1001    0.9554
                              40000   54.0446
                              92235    8.8558
                              92238   36.1442    1  1.0     293  end
```

```
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
```

```
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                         18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                         19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
hciatriga 0.0in thk np,10400.0gUZrHx(  921.0g235, 8998.2gH2O,hx=255.01),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
```

```
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.838092   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p21.838092   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p21.838092    0.00020  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
```

```
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.838092   38.98540   0.0     com='drum'
 cuboid    20 1 4p21.838092   38.98540   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    20 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
```

```
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    20 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    20 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  20 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  20 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
'cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.53 Case hciatriga70_1_15_3

```
=csas25    parm=size=3000000
hciatriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O hx=575.64),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume =1200.95996, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=41.1, CV void volume 9014.40198'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
```

```
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                         18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                         19  1.08401 293  end
```

```
'void space external to drum'
'array density is assumed not reduced by hac'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
hciatriga_70 0.0in thk np, 6847.1gUZrHx(  408.0g235, 8998.2gH2O,hx=575.64),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.685692    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.828800   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.685692   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.838092   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p21.838092   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
```

```
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.685692    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.838092    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p21.838092    0.00020  -0.0001  com='drum(chine)outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.838092   38.98540   0.0     com='drum'
 cuboid    20 1 4p21.838092   38.98540   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    20 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
```

```
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    20 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    20 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  20 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  20 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
'cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
```

```
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.54 Case ncsrT70_131_1_15_15

```
=csas25    parm=size=3000000
ncsrT70131 0.0in thk np, 5666.6gUZrHx(  337.7g235, 9204.9gH2O hx=711.53),fr=1.0e+00
238groupndf5 infhommedium
'TRIGA volume = 993.90789, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=49.6, CV void volume 9221.45406'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
```

```
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
```

```
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrT70131 0.0in thk np, 5666.6gUZrHx(  337.7g235, 9204.9gH2O,hx=711.53),fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   23.177500    0.63500   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.663700   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.920 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
```

```
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   23.177500   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   23.329900   12.70050  -0.0005  com='drum'
 cuboid    21 1 4p24.587200   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.921 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   23.177500    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   23.329900    0.00020  -0.0001  com='drum'
 cuboid    21 1 4p24.587200    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   38.98540   0.0     com='kaolite'
 cylinder  19 1   23.329900   38.98540   0.0     com='drum'
 cuboid    21 1 4p24.587200   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
```

```
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
```

```
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.55 Case nciaT70_131_1_15_3

```
=csas25    parm=size=3000000
nciaT70131 0.0in thk np, 5666.6gUZrHx(  337.7g235, 9204.9gH2O hx=711.53),fr=1.0e-04
238groupndf5 infhommedium
'TRIGA volume = 993.90789, SPACER volume    0.00000'
'TRIGA wrapped dry content can hx=49.6, CV void volume 9221.45406'
arbmtriga  5.70132  4 0 0 0    1001    1.5894
                              40000   89.9107
                              92235    5.9587
                              92238    2.5412    1  1.0     293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
```

```
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
```

```
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciaT70131 0.0in thk np, 5666.6gUZrHx(  337.7g235, 9204.9gH2O,hx=711.53),fr=1.0e-04
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'UZrHx fuel element'
 cylinder  1  1    1.663700   12.70000   0.0     com='cylindrical content'
unit 1006
'content (collapsed) [Elev= 9.926 in.]'
'1.437900   plus-y location upper cylinders'
'-2.875700  minus-y location lower cylinder'
'2.490443   plus-x location upper cylinder'
'-2.490443  minus-x location upper cylinder'
 cylinder  3  1    6.426200   12.70050  -0.0005  com='cv well cavity'
 hole  1004   -2.490443  1.437900  0.0     com='cyl1'
 hole  1004    2.490443  1.437900  0.0     com='cyl2'
 hole  1004    0.0      -2.875700  0.0     com='cyl3'
 cylinder  8  1    6.680200   12.70050  -0.0005  com='cv below 1st step'
 cylinder  15 1    7.924800   12.70050  -0.0005  com='void btw cv-np liner'
 cylinder  16 1    8.077200   12.70050  -0.0005  com='np277_4 liner'
 cylinder  11 1   10.922000   12.70050  -0.0005  com='np277_4'
 cylinder  16 1   11.074400   12.70050  -0.0005  com='kaolite liner'
 cylinder  12 1   21.555075   12.70050  -0.0005  com='kaolite'
 cylinder  19 1   21.722275   12.70050  -0.0005  com='drum'
 cuboid    20 1 4p22.866096   12.70050  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 9.926 in.]'
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
'38.10360             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   38.98540   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   38.98540   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   38.98540   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   38.98540   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   38.98540   0.0     com='np277_4'
 cylinder  16 1   11.074400   38.98540   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   38.98540   0.0     com='kaolite'
 cylinder  19 1   21.722275   38.98540   0.0     com='drum'
 cuboid    20 1 4p22.866096   38.98540   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
```

```
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
```

```
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    110.4900  0.0    com='bare package'
'cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.56 Case athopw15kr20_5

```
=csas25    parm=size=300000
athopw15kr20,[15763.u3o8al, 921.0U235,500.0CH2,6803.8H2O]g
htox=211.0,Rc=14.13813cm,53419.6,Rs=31.95515cm
238groupndf5 multiregion
'U3O8Al=15763.4g poly=500.0g cont.hx=18.2 Kao H2O=  6803.8g, homgcore hx=211.0'
'Rc=14.13813cm,53419.6,Rs=31.95515cm'
arbmTHAR   3.52015   4 0 0 0   8016    5.24773
                              13027   65.53981
                              92235    5.84249
                              92238   23.36997   1  0.3783  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0459  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  5.7580e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
```

```
                              8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                              8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                              8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                              8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
```

```
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  14.13813
2  31.95515
8  51.95515
end zone
athopw15kr20,[15763.u3o8al, 921.0U235,500.0CH2,6803.8H2O]g htox=211.0
Rc=14.13813cm,53419.6,Rs=31.95515cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 15763.3703 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 23067.2006 g'
'Vol of homogenized fm              = 4478.03940 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 11837.6168 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 211.0335'
' '
```

```
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  14.13813  com='HEU core/water mixture'
sphere  2  1  31.95515  com='radius of kaolite shell'
sphere  8  1  51.95515  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.57 Case athopw15kr70_5

```
=csas25    parm=size=300000
athopw15kr70,[1995.7u3o8al, 408.0U235,500.0CH2,6803.8H2O]g
htox=476.3,Rc=12.36884cm,53419.6,Rs=31.64738cm
238groupndf5 multiregion
'U3O8Al= 1995.7g poly=500.0g cont.hx=41.1 Kao H2O=  6803.8g, homgcore hx=476.3'
'Rc=12.36884cm,53419.6,Rs=31.64738cm'
arbmTHAR   3.52095   4 0 0 0   8016    5.28002
                              13027   65.51412
                              92235   20.44410
                              92238    8.76176   1  0.0715  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0686  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.5993e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
```

```
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
```

```
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.36884
2  31.64738
8  51.64738
end zone
athopw15kr70,[1995.7u3o8al, 408.0U235,500.0CH2,6803.8H2O]g htox=476.3
Rc=12.36884cm,53419.6,Rs=31.64738cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 1995.70127 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 9299.53151 g'
'Vol of homogenized fm              =  566.80762 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7926.38510 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 476.3597'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.36884  com='HEU core/water mixture'
sphere  2  1  31.64738  com='radius of kaolite shell'
sphere  8  1  51.64738  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.58 Case athopw15kr93_5

```
=csas25    parm=size=300000
athopw15kr93,[1505.0u3o8al, 408.0U235,500.0CH2,6803.8H2O]g
htox=476.3,Rc=12.29589cm,53419.6,Rs=31.63630cm
238groupndf5 multiregion
'U3O8Al= 1505.0g poly=500.0g cont.hx=41.1 Kao H2O=  6803.8g, homgcore hx=476.3'
```

```
'Rc=12.29589cm,53419.6,Rs=31.63630cm'
arbmTHAR   3.52132   4 0 0 0   8016    5.29500
                              13027   65.50220
                              92235   27.21701
                              92238    1.98579   1  0.0549  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0698  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.7532e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                             4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                              8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                              8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                              8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                              8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                              8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                              8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                              8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                              8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.29589
2  31.63630
8  51.63630
end zone
athopw15kr93,[1505.0u3o8al, 408.0U235,500.0CH2,6803.8H2O]g htox=476.3
Rc=12.29589cm,53419.6,Rs=31.63630cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
```

```
'Minimum mass of water from Kaolite = 2204.715 g'
'                            CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                            CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 1505.00732 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 8808.83756 g'
'Vol of homogenized fm              =  427.39862 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7786.97610 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 476.3681'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.29589  com='HEU core/water mixture'
sphere  2  1  31.63630  com='radius of kaolite shell'
sphere  8  1  51.63630  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.59 Case athupw15kr93_5

```
=csas25    parm=size=300000
athupw15kr93,[ 920.5UO2MgAl, 408.0U235,500.0CH2,6803.8H2O]g
htox=476.3,Rc=12.25670cm,53419.6,Rs=31.63040cm
238groupndf5 multiregion
'UO2MgAl=  920.5g, poly=500.0g cont.hx=41.1 Kao H2O=  6803.8g, homgcore hx=476.3'
'Rc=12.25670cm,53419.6,Rs=31.63040cm'
arbmuo2mgal  2.60651  5 0 0 0  8016    6.46696
                              12000    7.61234
                              13027   38.36549
                              92235   44.32146
                              92238    3.23375   1  0.0458  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0705  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  8.8374e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
```

```
                              8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                              8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
```

```
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.25670
2  31.63040
8  51.63040
end zone
athupw15kr93,[ 920.5UO2MgAl, 408.0U235,500.0CH2,6803.8H2O]g htox=476.3
Rc=12.25670cm,53419.6,Rs=31.63040cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   =  920.54928 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 8224.37952 g'
'Vol of homogenized fm              =  353.17312 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7712.75060 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 476.3624'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
```

```
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  12.25670  com='HEU core/water mixture'
sphere  2  1  31.63040  com='radius of kaolite shell'
sphere  8  1  51.63040  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.60 Case athupw15kr20_5

```
=csas25    parm=size=300000
athupw15kr20,[9677.7UO2MgAl, 921.0U235,500.0CH2,6803.8H2O]g
htox=211.0,Rc=13.27685cm,53419.6,Rs=31.79582cm
238groupndf5 multiregion
'UO2MgAl= 9677.7g, poly=500.0g cont.hx=18.2 Kao H2O=  6803.8g, homgcore hx=211.0'
'Rc=13.27685cm,53419.6,Rs=31.79582cm'
arbmuo2mgal  3.96017  5 0 0 0  8016    6.41096
                              12000    7.61690
                              13027   38.38846
                              92235    9.51674
                              92238   38.06695   1  0.2493  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  0.0554  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  6.9528e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                               8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                          4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087    5  0.0287  293  end
```

```
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
```

```
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  13.27685
2  31.79582
8  51.79582
end zone
athupw15kr20,[9677.7UO2MgAl, 921.0U235,500.0CH2,6803.8H2O]g htox=211.0
Rc=13.27685cm,53419.6,Rs=31.79582cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 9677.70171 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 16981.5319 g'
'Vol of homogenized fm              = 2443.75916 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 9803.33664 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 211.0271'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  13.27685  com='HEU core/water mixture'
sphere  2  1  31.79582  com='radius of kaolite shell'
sphere  8  1  51.79582  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.61 Case athupw15kr09_5

```
=csas25    parm=size=300000
athupw15kr09,[19592.UO2MgAl, 922.0U235,500.0CH2,6803.8H2O]g
htox=210.7,Rc=14.32268cm,53419.6,Rs=31.99170cm
238groupndf5 multiregion
'UO2MgAl=19592.0g, poly=500.0g cont.hx=18.1 Kao H2O=  6803.8g, homgcore hx=210.7'
'Rc=14.32268cm,53419.6,Rs=31.99170cm'
arbmuo2mgal  3.95984  5 0 0 0  8016    6.40322
                               12000    7.61753
```

```
                              13027   38.39164
                              92235    4.70615
                              92238   42.88147   1  0.4020  293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                              6012   85.6202    1  0.0442  293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                              8016   88.8087    1  5.5383e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                              8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                              8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                              8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                              8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                              8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                              8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                              8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                           4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
```

```
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  14.32268
2  31.99170
8  51.99170
end zone
athupw15kr09,[19592.UO2MgAl, 922.0U235,500.0CH2,6803.8H2O]g htox=210.7
Rc=14.32268cm,53419.6,Rs=31.99170cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
```

```
'Mass of kao from Kaolite = 51214.88 g'
'                           CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   = 19592.0397 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 26895.8699 g'
'Vol of homogenized fm              = 4947.68469 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 12307.2621 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 210.7918'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UZrHx/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
sphere  1  1  14.32268  com='HEU core/water mixture'
sphere  2  1  31.99170  com='radius of kaolite shell'
sphere  8  1  51.99170  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.62 Case athbpw15kr93_5

```
=csas25    parm=size=300000
athbpw15kr93,[ 497.3uo2, 408.0U235,500.0CH2,6803.8H2O]g
htox=476.3,Rc=12.10567cm,53419.6,Rs=31.60798cm
238groupndf5 multiregion
'UO2=  497.3g poly=500.0g cont.hx=41.1 Kao H2O=  6803.8g, homgcore hx=476.3'
'Rc=12.10567cm,53419.6,Rs=31.60798cm'
arbmUO2   6.95000   3 0 0 0   8016   11.97094
                              92235   82.04308
                              92238    5.98598   1  9.6289e-03    293  end
arbmpoly   0.92000   2 0 0 0   1001   14.3798
                               6012   85.6202    1  7.3135e-02    293  end
arbmkh2o   0.9982    2 0 0 0   1001   11.1913
                               8016   88.8087    1  9.1724e-01    293  end
'kaolite 1600 shell'
arbmh2ok 1.7660e-02  2 0 0 0   1001   11.1913
                               8016   88.8087    2  1.000   293  end
arbmal2o3  0.41023   2 0 0 0   13027   52.9390
                               8016   47.0610    2  0.096   293  end
arbmsio2   0.41023   2 0 0 0   14000   46.7570
                               8016   53.2430    2  0.367   293  end
arbmfe2o3  0.41023   2 0 0 0   26000   69.9540
                               8016   30.0460    2  0.067   293  end
arbmtio2   0.41023   2 0 0 0   22000   59.9535
                               8016   40.0465    2  0.012   293  end
arbmcao    0.41023   2 0 0 0   20000   71.4815
                               8016   28.5185    2  0.307   293  end
arbmmgo    0.41023   2 0 0 0   12000   60.3169
                               8016   39.6831    2  0.131   293  end
arbmna2o   0.41023   2 0 0 0   11023   74.1961
```

```
                              8016   25.8039    2  0.020   293  end
'flooded containment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087    3  1.0     293  end
'steel: cv body, lower flange, upper flange, drum liner'
ss304                                         4  1.0     293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                              8016   88.8087    5  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                              8016   47.0610    5  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                              8016   53.2430    5  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                              8016   30.0460    5  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                              8016   40.0465    5  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                              8016   28.5185    5  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                              8016   39.6831    5  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                              8016   25.8039    5  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087    6  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610    6  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430    6  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460    6  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465    6  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185    6  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831    6  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039    6  0.020   293  end
'kaolite 1600 combined'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.191224*0.51655,  for rest = 1.191224*0.34438'
'den.mult= 1.48716e5 cm3 (actual vol.) / 1.24843e5 cm3 (model vol.)'
'actual body vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'actual plug vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
'total Kaolite volume=1.48716e5 cm3 =  1.36557e5 + 1.21592e4 cm3'
'model body vol.= 1.12246e5 cm3'
'model plug vol.= 1.25970e4 cm3'
```

```
'total model volume=1.24843e5 cm3 =  1.12246e5 + 1.25970e4 cm3'
'grams water in wet-Kaolite = 9008.5737 = 6803.85 + 2204.7237 g'
'density of water in wet-Kaolite = 0.07216 g/cm3 = 9008.5737/1.24843e5'
'grams water in baked-dry Kaolite = 2204.7237 g'
'density of water in baked-dry Kaolite = 0.01766 = 2204.7237/1.24843e5'
'VF for water in baked-dry Kaolite = 0.244736 = 2204.7237/9008.5737'
arbmh2ok   0.07216  2 0 0 0    1001   11.1913
                               8016   88.8087    7  1.000   293  end
arbmal2o3  0.41023  2 0 0 0   13027   52.9390
                               8016   47.0610    7  0.096   293  end
arbmsio2   0.41023  2 0 0 0   14000   46.7570
                               8016   53.2430    7  0.367   293  end
arbmfe2o3  0.41023  2 0 0 0   26000   69.9540
                               8016   30.0460    7  0.067   293  end
arbmtio2   0.41023  2 0 0 0   22000   59.9535
                               8016   40.0465    7  0.012   293  end
arbmcao    0.41023  2 0 0 0   20000   71.4815
                               8016   28.5185    7  0.307   293  end
arbmmgo    0.41023  2 0 0 0   12000   60.3169
                               8016   39.6831    7  0.131   293  end
arbmna2o   0.41023  2 0 0 0   11023   74.1961
                               8016   25.8039    7  0.020   293  end
'reflective water'
arbmh2or   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    8  1.0000  293  end
end comp
spherical end
1  12.10567
2  31.60798
8  51.60798
end zone
athbpw15kr93,[ 497.3uo2, 408.0U235,500.0CH2,6803.8H2O]g htox=476.3
Rc=12.10567cm,53419.6,Rs=31.60798cm
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
'Maximum mass of water from Kaolite = 9008.546 g'
'                             CHECK=> 9008.671 g'
'Minimum mass of water from Kaolite = 2204.715 g'
'                             CHECK=> 2204.746 g'
'Mass of kao from Kaolite = 51214.88 g'
'                             CHECK=> 51214.34 g'
' '
'Calculate the mass of water contained in the homogenized region'
'Mass of fm in homogenized region   =  497.29842 g'
'Mass of poly in homogenized region =  500.00000 g'
'Mass of h2o in homogenized region  = 6803.83024 g'
'Mass of homogenized region         = 7801.12866 g'
'Vol of homogenized fm              =   71.55373 cm3'
'Vol of poly                        =  543.47826 cm3'
'Vol of h2o                         = 6816.09922 cm3'
'Volume of homogenized region       = 7431.13121 cm3'
'Calculate HTOX ratio for use of 500.0 grams can pads,vinyl tape, polyethylene in CV'
'hydrogen to fissile uranium ratio  = 476.3646'
' '
'Mass of h2o in shell region        = 2204.71543 g'
'Mass of kao in shell region        = 51214.8849 g'
'Mass of kaolite in shell           = 53419.6003 g'
'Volume of kaolite in shell region  = 124843.000 cm3'
read geometry
global
unit 1001
'homogenized UO2/poly/excess water, wet-Kaolite shell, 20.0 cm refl'
```

```
sphere  1  1  12.10567  com='HEU core/water mixture'
sphere  2  1  31.60798  com='radius of kaolite shell'
sphere  8  1  51.60798  com='20.0 cm water reflector'
end geometry
end data
end
```

6.9.7.63 Case cvcrcyat11_2_2

```
=csas25    parm=size=3000000
cvcrcyat11 3cyl,1.4in thk np,(30000.0g235, 7991.5gH2O hx=  6.95),sep=0.254,fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1594.80409, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.56, CV void volume 8005.87774'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
```

```
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
```

```
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   21  1.0     293  end
end comp
cvcrcyat11 3cyl,1.4in thk np,(30000.0g235, 7991.5gH2O,hx=  6.95),sep=0.254,fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (centered) [Elev= 8.955 in.]'
 cylinder  1  1    4.114800   10.12099   0.12700    com='cylindrical content'
 cylinder  3  1    6.426200   10.24849  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   10.24849  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   10.24849  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=10.355 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'37.85956             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   39.22944   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   39.22944   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   39.22944   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
```

```
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.64 Case cvcrcyat11_11_2

```
=csas25    parm=size=3000000
cvcrcyat11 3cyl,1.4in thk np,(30000.0g235, 7991.5gH2O hx=  6.95),sep=4.826,fr=1.0e+00
238groupndf5 infhommedium
'HEU volume =1594.80409, SPACER volume  614.68012'
'HEU wrapped dry content can hx=0.56, CV void volume 8005.87774'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
```

```
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
```

```
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   21  1.0     293  end
end comp
cvcrcyat11 3cyl,1.4in thk np,(30000.0g235, 7991.5gH2O,hx=  6.95),sep=4.826,fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
```

```
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.920 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1006
'content (centered) [Elev=10.755 in.]'
 cylinder  1  1    4.114800   12.40699   2.41300    com='cylindrical content'
 cylinder  3  1    6.426200   14.82049  -0.0005  com='cv well cavity'
 cylinder  8  1    6.680200   14.82049  -0.0005  com='cv below 1st step'
 cuboid    21 1 4p24.587200   14.82049  -0.0005  com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev=12.155 in.]'
 cylinder  2  1    5.24510     3.55610   0.0     com='np spacer'
 cylinder  3  1    6.426200    3.55620  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    3.55620  -0.0001  com='cv below 1st step'
 cuboid    21 1 4p24.587200    3.55620  -0.0001  com='drum chine outer radius'
unit 1008
'top of content stack to bottom of 1st step [Elev=35.270 in.]'
'51.57556             stack height (content spacers)       CALCULATED
 cylinder  3  1    6.426200   25.51344   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   25.51344   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   25.51344   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
```

```
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1006 1007 1006 1007 1006 1008 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.65 Case cvcrpunhct11_10_15

```
=csas25    parm=size=3000000
cvcrpunhct11 10000.2gUNHc( 4709.7g235,2165.3gH2O) 6080.8gH2Ocv hx= 49.26 fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)]  2.79329 g/cm3, hx=12.0, gU/L= 461.0422'
'dry content (poly packed or wrapped) h/x=3.56, CV void volume 6091.80676 cm3'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  3.5046e-01   293  end
arbmh2oc   0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    1  5.9634e-01   293  end
arbmpoly   0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  5.3202e-02   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  5.9526e-01  2 0 0 0   1001   11.1913
                                8016   88.8087     3  1.0     293  end
```

```
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                              8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
```

```
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  1       293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                                8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   21  1.0     293  end
end comp
cvcrpunhct11 10000.2gUNHc( 4709.7g235,2165.3gH2O) 6080.8gH2Ocv,hx= 49.26 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
```

```
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.66 Case cvcrbpunhct11_24_15

(Note: For the following input file, the case name should read “cvcrbpunhct11” as opposed to “cvcrpunhct11”.)

```
=csas25    parm=size=3000000
cvcrpunhct11 24000.0gUNHc(11303.1g235,5196.7gH2O) 1077.9gH2Ocv hx= 15.97 fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)]  2.79329 g/cm3, hx=12.0'
```

```
'unhc= 24000.0 g, sat.h2o in UNHc=5196.7 g, unh h/x=12.0'
'dry content (poly bottle) h/x=1.48, CV void volume 1079.87091 cm3'
arbmunh    2.62712  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  1.0000  293  end
arbmpoly  5.4732e-02    2 0 0 0  1001   14.3798
                               6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                              8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                              8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                              8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                              8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                              8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
```

```
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
cvcrpunhct11 24000.0gUNHc(11303.1g235,5196.7gH2O) 1077.9gH2Ocv,hx= 15.97 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  71.05136 com='cavity abv UNHC'
 cylinder  1  1    6.426200   77.72400   0.63500 com='UNHC content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv UNHC'
 cylinder  1  1    6.426200    0.15240   0.0     com='UNHC content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv UNHC'
 cylinder  1  1    6.426200    0.22860   0.0     com='UNHC content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv UNHC'
 cylinder  1  1    6.426200    1.27000   0.0     com='UNHC content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
```

```
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.67 Case nciapbmflt11_1_6_4_5

```
=csas25    parm=size=3000000
nciapbmflt11,0.0in thk np, 4000.2gU( 3200.2g235) 9442.7gH2Ocv hx= 82.26 fr=0.0001
238groupndf5 infhommedium
'nciapbmflt11 - n(nct), c(np277-4), ia(infinite array),'
'               pbm (poly homogenized with broken metal),'
'               f(can location height established by packing fraction),'
'               l(designated content in can locations and gap between canned'
'               spacers, and water above content in upper can location),'
'               t11 (NCT_MD&H)'
'HEU volume = 212.11396, SPACER volume    0.01729'
'HEU wrapped dry content can hx=5.24, CV void volume 9459.75243'
'Content in can location 1'
uranium  1 den=18.85873 0.23645 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    1  1.5773e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  6.0582e-01   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
```

```
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                8016   88.8087    2  1.0000  293  end
'Content in can location 2'
uranium  3 den=18.85873 0.23645 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    3  1.5773e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    3  6.0582e-01   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                5011   81.8520    4  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                7014    0.0141
                                8016   43.4251
                               11023    0.1174
                               12000    0.3378
                               13027   39.0479
                               14000    2.4672
                               16000    0.3083
                               20000   11.8336
                               26000    0.5298    4  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                8016   88.8087    4  1.0000  293  end
'Content in can location 3'
uranium  5 den=18.85873 0.23647 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    5  1.5765e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    5  6.0588e-01   293  end
'void space internal to containment vessel above stacked content'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    6  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                7014    0.0141
                                8016   43.4251
                               11023    0.1174
                               12000    0.3378
                               13027   39.0479
                               14000    2.4672
                               16000    0.3083
                               20000   11.8336
```

```
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                                8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                                8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
```

```
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
nciapbmflt11,0.0in thk np, 4000.2gU( 3200.2g235) 9442.7gH2Ocv,hx= 82.26 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'content (collapsed) [Elev= 5.833 in.]'
' 2.30470            bottom of cv to top of 1st content      ASSIGNED
' 5.83319            elevation (inches)                       CALCULATED
' 6.426200    5.06   cv inner radius                          M2E801508A011_RvB
' 299.00051            volume of content in unit 1004           CALCULATED
 cylinder  1  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 5.833 in.]'
```

```
' 0.00020            top of 1st content to top 1st spacer    ASSIGNED
' 5.83331            elevation (inches)                       CALCULATED
'   0.00864              volume of spacer in unit 1005            CALCULATED
'   0.03028              volume of void in unit 1005              CALCULATED
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 6.741 in.]'
' 299.00051            volume of content in unit 1006           CALCULATED
 cylinder  3  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1007
'np277_4 spacer [Elev= 6.741 in.]'
'   0.00864            volume of spacer in unit 1007            CALCULATED
'   0.03028            volume of void in unit 1007              CALCULATED
 cylinder  4  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'content (collapsed) [Elev= 7.648 in.]'
' 299.00051            volume of content in unit 1008           CALCULATED
 cylinder  5  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
' 6.91469             stack height (3ccs plus 2 spacers)      CALCULATED
'35.27583            elevation (inches)                       CALCULATED
'35.27583            elevation (inches)                       VERIFIED
'9104.08949            volume of water in unit 1009             CALCULATED
 cylinder  6  1    6.426200   70.17431   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   70.17431   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   70.17431   0.0     com='void btw cv-np liner'
```

```
 cylinder  16 1    8.077200   70.17431   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   70.17431   0.0     com='np277_4'
 cylinder  16 1   11.074400   70.17431   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   70.17431   0.0     com='kaolite'
 cylinder  19 1   21.722275   70.17431   0.0     com='drum'
 cuboid    20 1 4p22.866096   70.17431   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
'  19.77167            volume of water in unit 1010            CALCULATED
 cylinder  6  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
'  29.65750            volume of water in unit 1011            CALCULATED
 cylinder  6  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
' 164.76390            volume of water in unit 1012            CALCULATED
 cylinder  6  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
```

```
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    42.62038  0.0    com='bare package'
'cuboid    21  1 4p55.067200   73.10038 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.68 Case nciapbmfdt11_1_6_4_5

```
=csas25    parm=size=3000000
nciapbmfdt11,0.0in thk np, 4000.2gU( 3200.2g235) 9442.7gH2Ocv hx= 82.26 fr=0.0001
238groupndf5 infhommedium
'nciapbmfdt11 - n(nct), c(np277-4), ia(infinite array),'
'               pbm (poly homogenized with broken metal),'
'               f(can location height established by packing fraction),'
'               d(content resides in can location and gap between canned'
'               spacer and cv, and distributed over upper can location),'
'               t11 (NCT_MD&H)'
'HEU volume = 212.11396, SPACER volume    0.01729'
'HEU wrapped dry content can hx=5.24, CV void volume 9459.75243'
'Content in can location 1'
uranium  1 den=18.85873 0.23645 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    1  1.5773e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  6.0582e-01   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'Content in can location 2'
uranium  3 den=18.85873 0.23645 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    3  1.5773e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    3  6.0582e-01   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    4  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    4  1.0000  293  end
```

```
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                  8016   88.8087    4  1.0000  293  end
'Content in can location 3'
uranium  5 den=18.85873 0.00735 293      92235  80.000
                                         92238   20.000               end
arbmh2oi     0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    5  9.7381e-01   293  end
arbmpoly     0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    5  1.8837e-02   293  end
'void space internal to containment vessel above stacked content'
arbmwicv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087    6  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                            8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                            9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                           10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
```

```
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
nciapbmfdt11,0.0in thk np, 4000.2gU( 3200.2g235) 9442.7gH2Ocv,hx= 82.26 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
```

```
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom [Elev= 4.926 in.]'
 cylinder  8  1    6.680200    0.63500   0.0     com='cv bottom'
 cylinder  15 1    7.924800    0.63500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.63500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    0.63500   0.0     com='np277_4'
 cylinder  16 1   11.074400    0.63500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    0.63500   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1004
'content (collapsed) [Elev= 5.833 in.]'
' 2.30470            bottom of cv to top of 1st content      ASSIGNED
' 5.83319            elevation (inches)                       CALCULATED
' 6.426200    5.06   cv inner radius                          M2E801508A011_RvB
' 299.00051           volume of content in unit 1004           CALCULATED
 cylinder  1  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1005
'np277_4 spacer [Elev= 5.833 in.]'
' 0.00020            top of 1st content to top of 1st spacer ASSIGNED
' 5.83331            elevation (inches)                       CALCULATED
'   0.00864            volume of spacer in unit 1005            CALCULATED
'   0.03028            volume of void in unit 1005              CALCULATED
 cylinder  2  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  1  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1006
'content (collapsed) [Elev= 6.741 in.]'
' 299.00051           volume of content in unit 1006           CALCULATED
 cylinder  3  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
```

```
unit 1007
'np277_4 spacer [Elev= 6.741 in.]'
'   0.00864            volume of spacer in unit 1007            CALCULATED
'   0.03028            volume of void in unit 1007              CALCULATED
 cylinder  4  1    5.24510     0.00010   0.0     com='np spacer'
 cylinder  3  1    6.426200    0.00020  -0.0001  com='cv well cavity'
 cylinder  8  1    6.680200    0.00020  -0.0001  com='cv below 1st step'
 cylinder  15 1    7.924800    0.00020  -0.0001  com='void btw cv-np liner'
 cylinder  16 1    8.077200    0.00020  -0.0001  com='np277_4 liner'
 cylinder  11 1   10.922000    0.00020  -0.0001  com='np277_4'
 cylinder  16 1   11.074400    0.00020  -0.0001  com='kaolite liner'
 cylinder  12 1   21.555075    0.00020  -0.0001  com='kaolite'
 cylinder  19 1   21.722275    0.00020  -0.0001  com='drum'
 cuboid    20 1 4p22.866096    0.00020  -0.0001  com='drum chine outer radius'
unit 1008
'content (collapsed) [Elev= 7.648 in.]'
' 299.00051            volume of content in unit 1008           CALCULATED
 cylinder  5  1    6.426200    2.30470  0.0      com='homog. HEU poly content'
 cylinder  8  1    6.680200    2.30470  0.0      com='cv below 1st step'
 cylinder  15 1    7.924800    2.30470  0.0      com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.30470  0.0      com='np277_4 liner'
 cylinder  11 1   10.922000    2.30470  0.0      com='np277_4'
 cylinder  16 1   11.074400    2.30470  0.0      com='kaolite liner'
 cylinder  12 1   21.555075    2.30470  0.0      com='kaolite'
 cylinder  19 1   21.722275    2.30470  0.0      com='drum'
 cuboid    20 1 4p22.866096    2.30470  0.0      com='drum chine outer radius'
unit 1009
'top of content stack to bottom of 1st step [Elev=35.276 in.]'
' 6.91469             stack height (3ccs plus 2 spacers)      CALCULATED
'35.27583            elevation (inches)                       CALCULATED
'35.27583            elevation (inches)                       VERIFIED
'9104.08949            volume of water in unit 1009             CALCULATED
 cylinder  5  1    6.426200   70.17431   0.0     com='cv well cavity'
 cylinder  8  1    6.680200   70.17431   0.0     com='cv below 1st step'
 cylinder  15 1    7.924800   70.17431   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   70.17431   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   70.17431   0.0     com='np277_4'
 cylinder  16 1   11.074400   70.17431   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   70.17431   0.0     com='kaolite'
 cylinder  19 1   21.722275   70.17431   0.0     com='drum'
 cuboid    20 1 4p22.866096   70.17431   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
'  19.77167            volume of water in unit 1010             CALCULATED
 cylinder  5  1    6.426200    0.15240   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
'  29.65750            volume of water in unit 1011             CALCULATED
 cylinder  5  1    6.426200    0.22860   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
```

```
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
' 164.76390            volume of water in unit 1012            CALCULATED
 cylinder  5  1    6.426200    1.27000   0.0     com='cavity'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
```

```
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    42.62038  0.0    com='bare package'
'cuboid    21  1 4p55.067200   73.10038 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=19 fill
1001 1002 1003 1004 1005 1006 1007 1008 1009 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.69 Case ncsrpunhct11_8_15

```
=csas25    parm=size=3000000
ncsrpunhct11  8000.1gUNHc( 3767.7g235,1732.2gH2O) 6795.6gH2Ocv hx= 63.53 fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)]  2.79329 g/cm3, hx=12.0, gU/L= 368.8310'
'dry content (poly packed or wrapped) h/x=4.45, CV void volume 6807.84362 cm3'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  2.8037e-01   293  end
arbmh2oc   0.99820  2 0 0 0  1001   11.1913
                               8016   88.8087    1  6.6643e-01   293  end
arbmpoly   0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  5.3202e-02   293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
```

```
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  6.6523e-01  2 0 0 0    1001   11.1913
                                 8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                                 8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                 8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                 8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                 8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                 8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                 8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                 8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                 8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
```

```
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
ncsrpunhct11  8000.1gUNHc( 3767.7g235,1732.2gH2O) 6795.6gH2Ocv,hx= 63.53 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
```

```
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   77.72400   0.0     com='kaolite'
 cylinder  19 1   23.329900   77.72400   0.0     com='drum'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
```

```
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
```

```
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.7.70 Case icsrpunhct12_15_15

```
=csas25    parm=size=3000000
icsrpunhct12 15000.0gUNHc( 7064.4g235,3247.9gH2O) 6397.6gH2Ocv hx= 53.28 fr=1.0e+00
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], UNHc  2.79329 g/cm3, UNH hx=12.0'
'gU/L= 443.7839 dispersed. Bottle hx=2.37 no meaning when dispersed'
'UNHc in cv   9113.74622 g. water in cv  6397.62120 g.'
'UNHc in well  5886.25378 g. water in well  4132.00248 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.31939 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                               8016   88.8087    1  0.62740 293  end
arbmpoly   0.92000  2 0 0 0  1001   14.3798
                               6012   85.6202    1  5.3202e-02   293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0    1001   11.1913
                                 8016   88.8087    3  1.0     293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                              8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
```

```
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
```

```
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
'UNHc in cv well   5886.25378 g.'
'water in cv well  4132.00248 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690   15  0.33734 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.66266 293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
icsrpunhct12 15000.0gUNHc( 7064.4g235,3247.9gH2O) 6397.6gH2Ocv,hx= 53.28 fr=1.0e+00
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
'v1002=1.36748e+01  '
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
'v1003=4.43850e+03  '
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.838092   77.72400   0.0     com='drum'
 cuboid    21 1 4p21.838092   77.72400   0.0     com='drum(chine)outer radius'
```

```
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
'v1010=8.70294e+00  '
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
'v1011=5.36220e+01  '
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
'v1012=7.43264e+01  '
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
'v1013=1.70951e+02  '
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
'v1014=1.39785e+02  '
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
'v1015=5.71136e+01  '
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
```

```
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
'v1016=6.92877e+02  '
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
'v1017=1.83014e+02  '
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
'v1018=4.14168e+02  '
'Volume cv well=6.24674e+03  '
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

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Appendix 6.9.8

Criticality Evaluation of Additional Content

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Appendix 6.9.8

Criticality Evaluation of Additional Content

This appendix presents the criticality safety evaluation of additional content for the ES-3100 package. Calculations presented herein were performed using the Monte Carlo CSAS25 criticality code sequence and 238-group ENDFB-V cross section library of SCALE 5.0 (NUREG/CR-0200, Rev. 7), executed on identical Hewlett Packard (HP) Model zx6000 Itanium workstations (CMODC and CMODD). Criticality calculations documented in Sects. 6.4–6.6 were performed using SCALE 4.4a (NUREG/CR-0200, Rev. 6) executed on an HP Model J5600 RISC workstation (CMODB). The obsolete CMODB with HP-UX 10.20 operating system was recently retired from service. No longer supported by the code developer, SCALE 4.4a is not portable to the updated computing platforms thus necessitating the use of SCALE 5.0.

SCALE5 incorporates minor improvements in the code modules for the Bondarenko and the Nordheim Integral Treatment processing of resonance cross sections and the KENO V.a module. Consequently, the USL used is validation dependent based on the SCALE-platform combination. The evaluation of the additional content based upon SCALE 5.0 calculations is documented in this appendix separate from the main body of Sect. 6 because this effort could not easily be folded into the existing SCALE 4.4a evaluation without inclusion of a patchwork of clarifications.

6.9.8.1 Description of the Criticality Design

The design features of the ES-3100 package addressed in Sect. 6.1.1 are not changed. The same codes and standards addressed in Sect. 6.1.2 apply. No change is employed in the methodology for demonstrating maximum reactivity.

The criticality safety evaluation documented in this appendix is a cursory analysis of the proposed contents listed in Table 6.9.8.1. In addition to uranium compounds, these contents comprise a variety of reactor fuel components and scrap materials composed of clad HEU metal or metal hydride, HEU alloy or oxide, or clad HEU alloy. In most cases, the HEU present in the components or scrap represents a small portion of the total mass. Because the HEU fissile material mass loading limits for the ES-3100 are specified in terms of the ^{235}U mass (Table 6.2a), package loading capacities on the order of 35,200 g of content are conceivable as physical dimensions of the content permit. The shipping limits for the contents are derived limits bounded by limits established for similar content types evaluated in Sects. 6.4–6.6, or are less restrictive limits based on further investigation using explicit models of particular components and materials. The revised fissile mass loading limits for specific contents are presented in Table 6.9.8.2 for surface only modes of transportation. The CSI is assigned as described in Sect. 6.1.4.

6.9.8.2 The Additional Content for the ES-3100 Package

A variety of materials identified in Table 6.9.8.1 from various reactor programs, including bare, clad, or canned uranium metal alloy or oxide in various shapes as pellets, rods, plates, bundled components and fuel assemblies will be shipped in the ES-3100 package. The compounds of uranium identified in Table 6.9.8.1 included uranium tetrafluoride, uranyl fluoride, uranium carbide, and uranium nitride. The physical form of these uranium compounds is described as powder, beads, and ash. Both content moisture and content uniformity are not defined.

Table 6.9.8.1. 12.1 MTU and RFS items

Name	Detailed description	Qty.	Assay	Net wt (g)	U wt (g)	^{235}U wt (g)
ARMF Idaho	Mark I Elements – 15 plates/element	14	93	5,511 ea.	192 ea	179 ea
	Mark II Elements – 8 flat and 6 bent plates/element	1	93	4,831 ea.	140 ea	131 ea
	Plates – U/Al in Al matrix overall 8.28 × 8.28 × 98 cm flat plate 7.26 × 0.12 × 64.8 cm bent plate var. × 0.12 × 64.8 cm	27	93	239 ea.	13 ea	12.185 ea
	Plate tray and items	1	37.5-93		224	207
	Total	**–**	**93**	**89,248**	**3,403**	**3,137**
BR2 Belgium	Bundles of MTR Type 2 U/Al fuel plates	29	90	7,333 ea	525.87 ea	472.95 ea
	Total	**–**	**90**	**185,926**	**15,195**	**13,658**
Bulk Shielding Reactor ORNL	Fuel assembly scrap plates. U_3O_8 outer plates, U/Al alloy inner plates and control rods	14	93	3,423	3,309	3,020
CNEA RA-2 Argentina	Bundles of MTR Type 2 U/Al fuel plates – 25 plates/ bundle flat plate 7.1 × 0.13 × 65.5 cm	35	90	4,534.9 ea	202.1 ea	181.7 ea
	Total	**–**	**90**	**78,536**	**3,716**	**3,342**
Group 1 Hanford fuel elements	Bundles of MTR Type 2 U/Al fuel plates – 11 plates/ bundle overall 27.125 × 2.5 × 2.845 in. U/Al plate 25.625 × 0.07 × 2.845 in.	21	93.18	NA	156	145.3
	Total	**–**	**93.18**	**NA**	**3,276**	**3,053**
Group 13 CERCA	Powder (sintered U_3O_8 mixed with Al) in containers	13	~45	NA	< 328 ea.	< 137 ea.
	Mixture pressed cores and powder in container	1	~45	NA	1,496	673
	Mixture of fuel plates, pressed cores and powder in containers	1	~45	NA	2,534	1,139
	Total	**15**	**45**	**–**	**6,177**	**2,764**
Group 15 Y-12 CSMO	Sintered U_3O_8 mixed with Al	5	93.2	11,665	8,013	7,464
	UAl fuel plate bundles (FGZ-046)	19	93.2	68,057	6,914.8	6,441.5
	UAl fuel plate bundles (FGZ-046)	35	93	139,646	13,575	12,646
	(ID-93-13)	15	93	34,119	23,319	21,701
	UAl fuel plate bundles (ID-93-13)	17	93.1	77,722	12,649	11,782
	UAl fuel plate bundles (ID-93-13)	16	93.1	77,823	13,282	12,372
	UAl powder in cans (ID-93-13)	15	–	–	–	–
	UAl fuel plate bundles (ID-93-13)	33	–	–	–	–
	(ID-93-13)	7	93.1	34,739	850	791

Table 6.9.8.1. 12.1 MTU and RFS items

Name	Detailed description	Qty.	Assay	Net wt (g)	U wt (g)	^{235}U wt (g)
Group 17A ORNL	Bundles of MTR Type 2 fuel U/Al fuel plates. Overall dimensions: 2.5 – 3.0 × 2.5 – 3.0 × 0.03 – 0.07 in.	7	93	–	2,142	1,996
	EU fuel elements & plates (FZB-949)	14	93.2	–	2,044	1,905
	Fuel plates (FZC-938)	2	93	–	79 ea.	67 ea.
	Fuel elements (FZB-881)	7	93.3	–	151 ea.	~140 ea.
	Total	**30**	**93**	**–**	**6,297**	**5,016**
Group 17B SNAP Reactor	Pin overall 1.25 in. OD × 12.45 in. $UZrH_2$ with Hastelloy-N cladding, 877 g H	36	93	56,048	4,976	4,627
Group 5B Georgia Tech	MTR Type 2 fuel Overall dimensions: 3.0 × 3.0 × 30 in.	5	93	–	1,005	936
		5	93	–	1,011	941
		5	93	–	1,008	939
		5	93.2	–	1,011	942
		4	93.2	–	683	636
	Total	**24**	**93**	**5,070**	**4,728**	**4,121**
Group 8 Omega West	MTR Type 2 fuel	20	93.2	–	4,977	4,638
		20	93.2	–	4,720	4,400
		15	93.2	–	3,579	3,336
		8	93.2	–	1,992	1,850
		8	93.2	–	1,316	1,225
	Total	**71**	**93.2**	**420,600**	**16,584**	**15,455**
PBF PWR	Fuel rods 0.422 in. diam × 39.9 in. Active fuel 0.374 in. diam × 36 in. Clad 0.024 in. RA-2 Zr Alloy	2	34.9	1,555.9	1,101	384
		2	93.2	1,551.0	1,095	1,021
	Total	**–**	**93**	**3,107**	**2,196**	**1,405**
Uranium compounds	Uncladded fuel fab materials from TREAT and ROVER: EU oxides (UO_2, U_3O_8), uranium compounds, uranium alloys, carbon, graphite, UF_4, UO_2F_2, UC, UN		20–100	700,000	100,000	–

Table 6.9.8.2. Fissile mass loading limits for ground transport of 12.1 MTU and RFS items

Content [a] description		Enrichment	CSI	No can spacers, [b, c, d] ^{235}U (g)	Basis for limit
HEU oxide (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, UO_2-ZrO_2)		≤ 100%	0	9,682 g ^{235}U [e] 921 g C [f]	Table 6.2a, HEU product oxides Table 6.2a, HEU skull oxides
Research reactor fuel elements and components	$UZrH_x$ [g]	≤20%	0	921 g ^{235}U	TRIGA at 20% enrichment
		>20%, ≤70%	0	408 g ^{235}U	TRIGA at 70% enrichment
		≥93%	0	11,164 g $UZrH_x$ 857 g ^{235}U	SNAP at 93% enrichment
	U-Zr	≤ 100%	–	See HEU broken metal limits in Table 6.2a [h]	
	U-Al	≤ 100%	0	7,333 g U-Al [i] 525 g U [i] 473 g ^{235}U [i]	BR-2 MTR Type 2
		≤ 100%	0	7,194 g U-Al [i] 1,117 g U [i] 1050 g ^{235}U [i]	1 MIT U/Al element or bundled plates (up to 30 plates)
	U_3O_8-Al	≤ 100%	0	See HEU oxide limits above	
	UO_2	≤ 100%	0	21,937 g UO_2 19,308 g ^{235}U	
	Oxides of U-Zr [j]	≤ 100%	–	See HEU oxide limits above	
	UO_2-Mg	≤ 100%	0	See HEU oxide limits above	
	U_3Si_2-Al	≤ 100%	0	5.825 kg U_3Si_2-Al [i] 2.277 kg U [i] 450 g ^{235}U [i]	1 element with 12 plates or bundled plates (up to 30)
Uranium compounds	UF_4	≤ 100%	0	3,000 g UF_4 2,267 g ^{235}U	
	UO_2F_2	≤ 100%	0	3,000 g UO_2F_2 2,067 g ^{235}U	
	UC	≤ 100%	0	2,000 g UC 1,815 g ^{235}U	
	UN	≤ 100%	0	2,000 g UN 1,888 g ^{235}U	
	TRISO	≤ 100%	0	2,000 g UC_x 1,815 g ^{235}U	Bounded by UC compounds
	U_3Si_2	≥19.7%, <40%	0	13 kg U_3Si_2	
		≥40%, ≤60%	0	7 kg U_3Si_2	

[a] Content in solution form is not permitted for shipment in the ES-3100.
[b] All limits are expressed in g ^{235}U unless otherwise indicated.
[c] The mass loading limit cannot be rounded up.
[d] 277-4 can spacers as described on Drawing M2E801580A043 (Appendix 1.3.7) not required but are optional as dunnage.
[e] Non-uranium metallic constituents (e.g., aluminum, zirconium, or magnesium) are evaluated further in Appendix 6.9.11.
[f] As discussed in App. 6.9.11, the carbon limit of 921 g does not apply to HEU product oxide for ground transport.
[g] For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
[h] Mass limits for alloys are evaluated further in Appendix 6.9.11.
[i] Mass limit is the most restrictive of the three values shown.
[j] Oxides of U-Zr are UO_2-Zr and UO_2-ZrO_2.

A general description of the Bulk Shielding Reactor-1 reveals that the core consisted of 30 subassemblies (MTR type stacked plates, 18 plates per subassembly), each subassembly with overall dimensions of 3.125 × 3 × 34.5 in., arranged into a parallelepiped with an active core ~15 × 18 × 24 in. The core contained 3,850-g ^{235}U (*Nuclear Reactor Plant Data*, Bulk Shielding Reactor, pp. 33–35).

A general description of the Oak Ridge Research Reactor reveals that the core consisted of 20–30 subassemblies (MTR type stacked plates, 19 plates per subassembly), each subassembly with overall dimensions of 3.015 × 3.15 × 38.375 in., arranged in 7 × 9 grid with an active core ~12 × 21 × 24 in. The core contained 3.5–4 kg ^{235}U (*Nuclear Reactor Plant Data*, Oak Ridge Research Reactor, pp. 102–110).

A general description of the Omega West Reactor reveals that the core consisted of 36 subassemblies (MTR type stacked plates, 18 plates per subassembly), each subassembly with overall dimensions of 2.966 × 3.069 × 30 in., arranged in 6 × 9 grid with an active core ~14 × 28 × 24 in. The core contained ~4-kg ^{235}U (Omega West Reactor).

Uranium tetrafluoride (UF_4), often called green-salt because of its characteristic color, is an intermediate product in the conversion of UF_6 to either uranium oxide (U_3O_8 or UO_2) or uranium metal. UF_4 is a solid composed of agglomerating particles with a texture similar to baking soda. It is non-volatile and non-hygroscopic, but only slightly soluble in water. After exposure to water, UF_4 slowly dissolves and undergoes hydrolysis, forming several possible uranium compounds and hydrogen fluoride (HF). The density of solid UF_4 is 6.7 g/cm^3.

Uranyl fluoride (UO_2F_2) is an intermediate product in the conversion of uranium hexafluoride (UF_6) to an uranium oxide. UO_2F_2 is a direct product of the reaction of UF_6 with moisture in the air. UO_2F_2 is very soluble in water and hygroscopic in air. It changes in color from brilliant orange to yellow after reacting with water. Deliquescence studies show that in room air (~50–60% relative humidity), deposits of UO_2F_2 reach an equilibrium point of hydration ($H/U \leq 4$) with the formation of uranyl fluoride dihydrate ($UO_2F_2 \cdot 2H_2O$) [JE/ER-4]. UO_2F_2 is reported to be stable in air to 300°C, above which slow decomposition to U_3O_8 occurs. When heated to decomposition, UO_2F_2 emits toxic fluoride fumes. The densities for UO_2F_2 and $UO_2F_2 \cdot 2H_2O$ are 6.37 and 4.76 g/cm^3, respectively (Barber).

Uranium carbide is a hard refractive ceramic material. It comes in several stoichiometries (UC_x) such as uranium monocarbide (UC), uranium sesquicarbide (U_2C_3), and uranium dicarbide (UC_2). Typically, uranium carbide is used as a nuclear fuel in gas-cooled fast reactors. Uranium carbide is a dull, dark charcoal-gray or flat black colored powder. Theoretical densities for UC, U_2C_3, and UC_2 are 13.63, 12.7, and 11.3 g/cm^3, respectively.

Uranium nitride (UN) is a ceramic material with a high uranium density and melting point (2805°C). These properties make it suitable for both liquid-metal cooled reactor and in-core nuclear thermionic applications. One process for the production of UN powder is hydride-dehydride-nitride process where the starting material is oxide-free uranium metal. Material testing of isostatically pressed and sintered UN cylinders has revealed the presence of uranium sesquinitride (U_2N_3). The theoretical densities for UN and U_2N_3 are 14.32 and 11.24 g/cm^3, respectively. The fact that U_2N_3 has a lower density than UN and decomposes into UN and nitrogen gas at 900°C eliminates it as a potential reactor fuel (ORNL-4608).

Other uranium compounds consist primarily of finished tristructural-isotropic (TRISO) micro fuel particles; however, also included are pure/impure scrap materials generated during various stages of the manufacturing process. These materials have a ^{235}U assay $\leq$ 93.17% and are typically in a solid crystalline or granular form. A finished TRISO fuel particle consists of a kernel composed of UO_X (or sometimes UC or UCO) coated with four exterior layers of three isotropic materials. The four layers are a porous buffer layer made of carbon, followed by a dense inner layer of pyrolytic carbon (PyC), followed

by a ceramic layer of SiC to retain fission products at elevated temperatures and to give the TRISO particle more structural integrity, followed by a dense outer layer of PyC. TRISO fuel particles are designed not to crack due to the stresses from processes (such as differential thermal expansion or fission gas pressure) at temperatures beyond 1600°C, and therefore can contain the fuel in the worst of accident scenarios in a properly designed reactor. TRISO fuel particles were originally developed in Germany for high-temperature gas-cooled reactors. Two current reactor designs are the pebble bed reactor (PBR) in which thousands of TRISO fuel particles are dispersed into graphite pebbles, and the prismatic-block gas-cooled reactor (such as the GT-MHR) in which the TRISO fuel particles are fabricated into compacts and placed in a graphite block matrix. Both of these reactor designs are very high temperature reactors (formally known as the high-temperature gas-cooled reactors).

The convenience cans, Teflon and polyethylene bottles, 277-4 canned spacers described in Sect. 6.2.2, and the packing materials described in Sect. 6.2.3 are not affected by inclusion of the package contents. Other than a reference made to Table 6.9.8.2, the Packing Content Loading Restrictions stated in Sect. 6.2.4 are unchanged.

6.9.8.3 General Considerations

General considerations expressed in Sect. 6.3 regarding both assumptions made about the ES-3100 packaging and the calculation methodology for the evaluation are maintained. No changes are required to the calculation models of the containment vessel, the single-unit packaging (Sect. 6.3.1.1), the damaged packaging (Sect. 6.3.1.3), or the catastrophically-damaged packaging (Sect. 6.3.1.4). However, the array packaging calculation model used with some of the content models employs the explicit triangular-pitch geometry specification also used in the evaluation of small array configurations (Sect. 6.3.1.2). Both the ETP and the reduced diameter square-pitch configuration for simulating triangular pitch spacing in an array of packages yields acceptable (and comparable) results. Finally, the material properties specification for the content models are addressed in Sect. 6.9.8.3.2.

6.9.8.3.1 Model configuration for supplemental contents

Reactor Fuel Components and Scrap Materials

A variety of materials identified in Table 6.9.8.1 from various reactor programs include bare, clad or canned uranium metal alloy, and bare or clad HEU oxide. These items will be shipped in the ES-3100 package as pellets, rods, plates, bundled components and fuel assemblies.

The calculation model for the U/Al fuel plates is based on the BR-2 MTR Type 2 fuel plate. Plate dimensions are 7.1 cm width × 0.1561 cm depth × 65.5 cm height based on data for the CNEA MTR Type 2 fuel. With an overall depth of 5.4627 cm, thirty-five BR-2 plates bundled together can be accommodated in the ES-3100 containment vessel. Data for Bundle 29 provides the basis for the calculation model. The net weight is 7,309 g, the uranium mass is 525.19 g, and the ^{235}U mass is 473.09 g. Three loading configurations are analyzed for evaluation of the effect of plate separation. One configuration models a compact array of 35 fuel plates side-by-side inside the containment vessel. The two other configurations model the plates with 0.06- and 0.12-cm separation between the plates. The bundle of plates intersect the containment vessel wall at 0.18-cm separation between the plates.

The Massachusetts Institute of Technology (MIT) U/Al fuel plate aluminum cladding outer dimensions are 2.552-in. (6.48208-cm) wide × 0.08-in. (0.2032-cm) deep (thickness) × 23-in. (58.42-cm) high. An element consists of 15 MIT fuel plates with 0.082 in. (0.20828 cm) separation between plates for an overall depth (thickness) of 2.348 in. (5.96392 cm) for the 0.082-in. (as designed/built) separation. With the as-fabricated element/grid structure, only one MIT fuel element can be accommodated in the ES-3100 containment vessel. If the MIT fuel plates were removed from the element structure and

bundled together with no separation between plates, the bundle of plates would be ~1.2-in. (3.048-cm) thick. Since the designed separation distance between plates is slightly larger than the fuel plates themselves (0.082 and 0.080 in., respectively), up to 30 loose fuel plates could be bundled together; in this configuration, 30 plates would occupy approximately the same volume as 15 plates in the fuel element structure. For conservatism, the uranium is modeled as HEU at 94% enrichment [U(94)] and the remainder is modeled as aluminum. Given that ~525-g ^{235}U is present in the fuel element, the 3,597 g of U/Al in the 15 MIT fuel plates would contain 558.5-g U(94). For two sets of fuel element plates bundled together without the fuel element grid structure, the 30 fuel plates would have ~1,050-g ^{235}U [1,117-g U(94)]. The evaluation in Sect. 6.9.8.5.1 covers both a single intact MIT U/Al element with 15 fuel plates and a bundled arrangement of up to 30 MIT U/Al fuel plates.

A uranium silicide (U_3Si_2) fuel plate measures 2.79-in. (7.0866 cm) wide × 0.05-in. (0.127-cm) deep (thickness) × 25-in. (63.5-cm) high. The fuel is 0.02-in. thick with 0.015-in. thick cladding on all sides. A fuel element consists of twelve plates, each plate weighing 161.6 g and containing on average 12.5-g ^{235}U, 63.27-g U (19.7), 5.13-g Si, and 93.4 g of 6061-T0 aluminum cladding. The 12 fuel plates (net weight 1,942 g) bundled together contains 150-g ^{235}U [759-g U(19.7)]. A bundle of 36 fuel plates (net weight 5,825 g) contains 450-g ^{235}U [2,277-g U(19.7)]. U_3Si_2 fuel having similar dimensions and less fissile content is bounded by MIT U/Al fuel.

The evaluation of HEU oxide in Sects. 6.4.3, 6.5.3, and 6.6.3, focuses on product and skull oxides characterized as loose material with bulk densities ranging from 2.0 to 6.54 g/cm^3. Unlike bulk oxides, reactor components of HEU oxide consist of compressed, sintered pellets with densities approaching the theoretical 10.96 g/cm^3. Pellets measuring 1.25 in. in diameter and 3.5 in. in height are stacked into clad-tubing of various lengths. Calculation models consider both bare rods and rods clad with ~2-mil (0.002-in.) thickness of aluminum, stainless-steel or zirconium. Dimensions for a bare rod are 1.8288 cm (0.7200 in.) in diameter and 63.5000 cm (25.0 in.) in length. Dimensions for a clad rod are 1.8388 cm (0.7239 in.) in diameter and 63.5100 cm (25.0039 in.) in length. Seven different rod arrangements shown in Figs. 6.9.8.3.1-1a through 6.9.8.3.1-1g are analyzed for determining the most reactive configuration. Twelve rods in the containment vessel contain 19,308.9 g ^{235}U in 21,937.6 g UO_2.

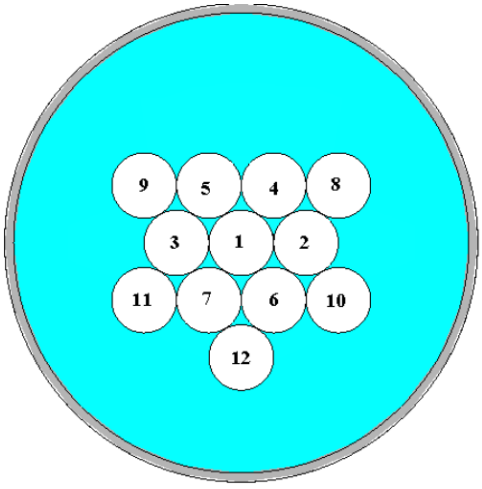


Fig. 6.9.8.3.1-1a. Config. "UO2_A."

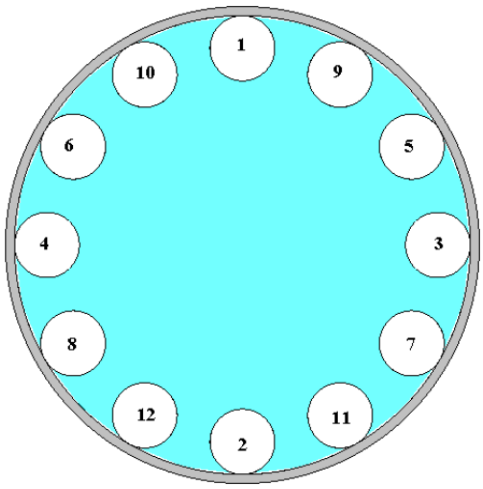


Fig. 6.9.8.3.1-1b. Config. "UO2_B."

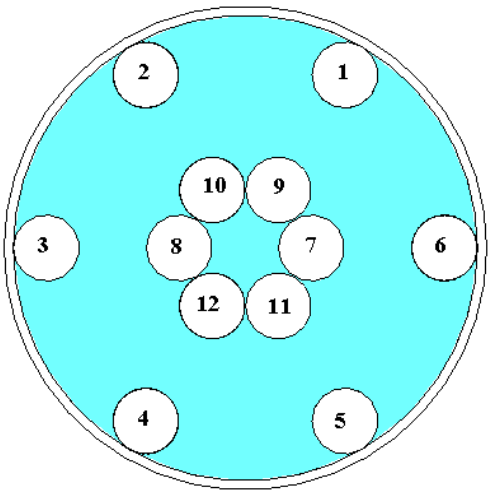


Fig. 6.9.8.3.1-1c. Config. "UO2_C."

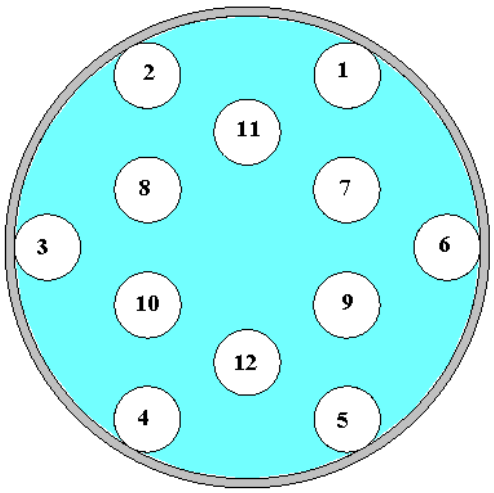


Fig. 6.9.8.3.1-1d. Config. "UO2_D."

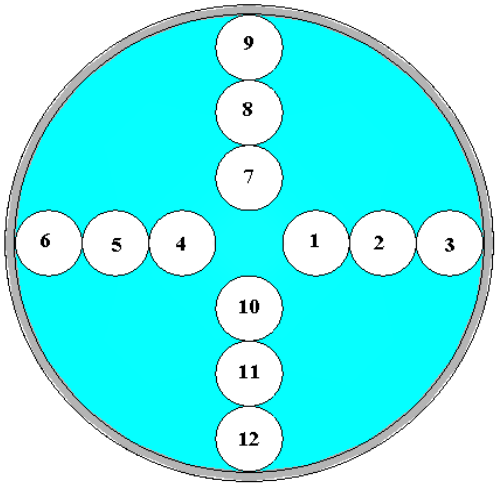


Fig. 6.9.8.3.1-1e. Config. "UO2_E."

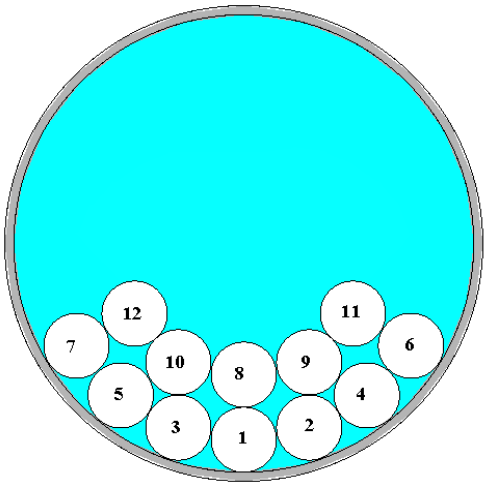


Fig. 6.9.8.3.1-1f. Config. "UO2_F."

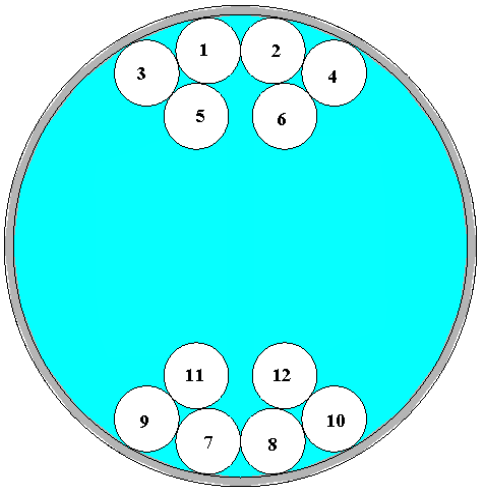


Fig. 6.9.8.3.1-1g. Config. "UO2_G."

Other proposed contents are U/Al alloy fuel plates and Al-clad HEU fuel plates. Alloys of uranium are not explicitly evaluated in Sects. 6.4.1, 6.4.2, 6.5.1, 6.5.2, 6.6.1, and 6.6.2. Instead, the uranium alloy is conservatively assessed by counting the neutron scattering constituents (aluminum, molybdenum, zirconium, etc.) as multiplying media (^{235}U). When the aluminum alloy or aluminum component of a fuel plate is conservatively assumed to be 100 wt % ^{235}U, then the loading capacity is severely limited by limits given for HEU broken metal. The U/Al or aluminum clad plates are explicitly modeled as a homogenized mixture of 93% enriched uranium and aluminum distributed evenly throughout the plate.

A SNAP reactor fuel pin composed of $UZrH_2$ is ~1.25 in. in diameter and ~12.45 in. long. The calculation model for the TRIGA fuel ($UZrH_{1.6}$) was adapted for use by changing the pin dimensions, the enrichment to 93 wt % ^{235}U, and the hydrogen component from 1.6 to 2.0.

Uranium Compounds

UF_4, UO_2F_2, $UO_2F_2 \cdot 2H_2O$, and U_3Si_2 powder are conservatively modeled as water soluble compounds like the UNH content (Sects. 6.4.4, 6.5.4, and 6.6.4). An assumed maximum of 500 g of polyethylene represents Teflon or polyethylene bottles, and hydrogenous material used for packing. A solution formed by UF_4, UO_2F_2, $UO_2F_2 \cdot 2H_2O$, or U_3Si_2 powder dissolved in water fills the entire volume of the containment vessel. The amounts of uranium compound and evaluation water in the containment vessel determines the most reactive content condition. Both flooding of the containment vessel and a partial load of uranium compound is required to achieve the most reactive configuration.

Uranium carbide, uranium nitride, and uranium silicide are known to have been fabricated into reactor fuel pellets, fuel plates, and cylinders as solid shapes. The physical form and the moisture content of these materials is not known. These uranium compounds are assumed to be a loose, granular or powdered material. UC, U_2C_3, UC_2, UN, and U_3Si_2 are conservatively modeled both as granular compounds like HEU oxide (Sects. 6.4.3, 6.5.3, and 6.6.3) and as water-soluble compounds like the UNH content (Sects. 6.4.4, 6.5.4, and 6.6.4). An assumed maximum of 500 g of polyethylene is included to represent hydrogenous packing material.

6.9.8.3.2 Content model material specifications

Material properties specification for the content models are presented in Table 6.9.8.3.

6.9.8.4 Computer Codes and Cross-Section Libraries

Calculations presented herein were performed using the Monte Carlo CSAS25 criticality code sequence and 238-group ENDFB-V cross section library of SCALE 5.0 (NUREG/CR-0200, Rev. 7), executed on identical Hewlett Packard (HP) Model zx6000 Itanium workstations (CMODC and CMODD) of the Y-12 Safety Analysis Engineering organization in Oak Ridge, Tennessee. Criticality calculations documented in Sects. 6.4–6.6 were performed using SCALE 4.4a (NUREG/CR-0200, Rev. 6) executed on an HP Model J5600 RISC workstation (CMODB). The obsolete CMODB with HP-UX 10.20 operating system was recently retired from service. SCALE 4.4a no longer supported by the code developer is not portable to the updated computing platforms thus necessitating the use of SCALE 5.0.

Table 6.9.8.3. Material compositions for the content calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
Fissile material contents							
Uranium/aluminum	1	2.91688	1.0	Al	26.9818	92.5645	6.02620E-02
				^{235}U	235.0441	6.9150	5.16786E-04
				^{238}U	238.0510	0.5205	3.84064E-05
Uranium/aluminum (MIT U/Al fuel plates)	1	4.03371	1.0	Al	26.9818	61.4529	5.53257E-02
				^{235}U	235.0441	36.2343	3.74478E-03
				^{238}U	238.0510	2.3128	2.36009E-04
Uranium oxide (UO_2)	1	10.96000	1.0	O	15.9904	11.9827	4.46663E-02
				^{235}U	235.0441	88.0173	2.47161E-02
Aluminum (clad)	4	2.70200	1.0	Al	26.9818	100.0000	6.03067E-02
Stainless steel (clad)	4	7.94000	1.0	C	12.0111	0.0800	3.18477E-04
				Si	28.0853	1.0000	1.70252E-03
				P	30.9741	0.0450	6.94681E-05
				Cr	51.9957	19.0000	1.74726E-02
				Mn	54.9381	2.0000	1.74072E-03
				Fe	55.8447	68.3750	5.85446E-02
				Ni	58.6871	9.5000	7.74021E-03
Zirconium (clad)	4	6.49000	1.0	Zr	91.2196	100.0000	4.28457E-02
93% enriched $UZrH_2$ (11,1647 g)	1	7.43210	1.0	H	1.0078	1.9835	8.80884E-02
				Zr	91.2196	89.7628	4.40422E-02
				^{235}U	235.0441	7.6738	1.46124E-03
				^{238}U	238.0510	0.5799	1.09029E-04
Uranium tetrafluoride (UF_4) (8,000 g) with 500 g polyethylene	1	1.12580	1.0	H	1.0078	0.6252	4.20577E-03
				C	12.0111	3.7226	2.10311E-03
				O	15.9954	0.0000	2.61845E-22
				F	18.9982	23.3698	8.33945E-03
				^{235}U	235.0441	72.2823	2.08486E-03
				^{238}U	238.0510	0.0000	2.72408E-25
Uranyl fluoride (UO_2F_2) (14,000 g) with 500 g polyethylene	1	1.41940	1.0	H	1.0078	0.4959	4.20577E-03
				C	12.0111	2.9525	2.10311E-03
				O	15.9954	10.1258	2.61845E-22
				F	18.9982	12.0271	5.41137E-03
				^{235}U	235.0441	74.3989	2.70569E-03
				^{238}U	238.0510	0.0000	3.46697E-25
Uranyl fluoride (UO_2F_2) (14,000 g) with 500 g poly and 7,439 g water in CV	1	2.14760	1.0	H	1.0078	4.1225	5.29052E-02
				C	12.0111	1.9513	2.10311E-03
				O	15.9954	36.8057	2.97600E-02
				F	18.9982	7.9489	5.41137E-03
				^{235}U	235.0441	49.1716	2.70569E-03
				^{238}U	238.0510	0.0000	3.46697E-25

Table 6.9.8.3. Material compositions for the content calculation models

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm)
Uranyl fluoride dihydrate ($UO_2F_2 \cdot 2H_2O$) (14,000 g) with 500 g of polyethylene	1	1.41940	1.0	H	1.0078	1.6371	1.38857E-02
				C	12.0000	2.9524	2.10311E-03
				O	15.9954	18.1130	9.67957E-03
				F	18.9982	10.7570	4.83996E-03
				^{235}U	235.0441	66.5411	2.41997E-03
				^{238}U	238.0510	0.0000	3.46705E-25
Uranyl fluoride dihydrate ($UO_2F_2 \cdot 2H_2O$) (14,000 g) with 500 g poly and 6,693 g water in CV	1	2.07460	1.0	H	1.0078	4.6544	5.77001E-02
				C	12.0000	2.0200	2.10311E-03
				O	15.9954	40.4389	3.15860E-02
				F	18.9982	7.3598	4.83996E-03
				^{235}U	235.0441	45.5270	2.41997E-03
				^{238}U	238.0510	0.0000	3.46705E-25
Uranium carbide (UC) (2,000 g) with 500 g poly and 8,656 g water in CV	1	2.17160	1.0	H	1.0078	4.9889	6.47374E-02
				C	12.0000	15.6704	1.70774E-02
				O	15.9954	22.5678	1.84509E-02
				^{235}U	235.0441	56.7729	3.15875E-03
				^{238}U	238.0510	0.0000	3.27808E-25
Uranium sesquicarbide (U_2C_3) (2,000 g) with 500 g poly and 8656 g water in CV	1	2.16460	1.0	H	1.0078	4.9690	6.42726E-02
				C	12.0000	17.0712	1.85444E-02
				O	15.9954	22.3551	1.82185E-02
				^{235}U	235.0441	56.7729	3.08385E-03
				^{238}U	238.0510	0.0000	3.27808E-25
Uranium dicarbide (UC_2) (2,000 g) with 500 g poly and 8656 g water in CV	1	2.15200	1.0	H	1.0078	4.9326	6.34293E-02
				C	12.0000	18.4667	1.99435E-02
				O	15.9954	21.9657	1.77969E-02
				^{235}U	235.0441	54.6351	3.01242E-03
				^{238}U	238.0510	0.0000	3.27808E-25
Uranium silicide (U_3Si_2) (7,000 g) with 500 g poly and 8656 g water in CV	1	1.62670	1.0	H	1.0078	6.5728	6.38895E-02
				C	12.0000	2.5763	2.10312E-03
				O	15.9954	48.7247	2.98408E-02
				^{235}U	235.0441	23.4195	9.76075E-04
				^{238}U	238.0510	15.6132	6.42506E-04
				Si	28.0853	3.0936	1.07905E-03

[a] The theoretical density input parameter is specified for each material such that the required (or desired) mass of material is represented in the KENO V.a calculation model. The mass of material is computed by KENO V.a as the product of the theoretical density input parameter times the volume fraction times the volume of the geometry region in which the material resides in the calculation model.

The SCALE 4.4a criticality codes and cross-section library are addressed in Sect. 6.3.3. The 238-group ENDF/B-V cross-section library used by SCALE 5.0 is unchanged from the previous version SCALE 4.4a. Also, most of the modular codes in CSAS25 control sequence of SCALE 5.0 are unchanged except for the cross-section processing functional module NITAWL-III.

NITAWL-III applies the Nordheim integral treatment to perform neutron cross-section processing in the resonance energy range for nuclides that have ENDF/B resonance parameter data. This technique involves the numerical integration of ENDF/B resonance parameters using a calculated flux distribution, which is based on the calculated collision density across each resonance and subsequent weighing of the reaction cross section to the desired broad group structure. In the CSAS sequence, NITAWL-III assembles the group-to-group transfer arrays from the elastic and inelastic scattering components and performs other tasks to produce a problem-dependent working cross-section library which can be used by KENO V.a.

As noted in the user manual, several extensions to the Nordheim calculation have been implemented into the algorithm contained in NITAWL-III:

- Elements containing more than one isotope can be treated.
- Self-shielding is applied to resonance scattering. Transfer matrices are adjusted.
- g-, f-, d-, and p-wave as well as s-wave levels can be treated.
- The asymptotic approximation for the flux in the thermal energy range is assumed to have a Maxwellian energy distribution.
- A refined procedure for generating the energy mesh over which reaction rates are integrated has been developed.

As with the SCALE 4.4a calculations, the k_{eff} values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data. The convergence of the KENO V.a calculation is related to trends in the average calculated k_{eff}. In general, the KENO V.a output table of k_{eff} by generation skipped is reviewed for trends. If no trends are observed, the calculation is accepted, and the reported value of k_{eff} is the one with the most neutron histories. There is usually no statistically significant difference between this result and the one with the smallest standard deviation.

No manual cross-section adjustment is performed for the criticality evaluation. Cross-section processing is performed automatically in the CSAS25 code sequence. Modeling the contents as precisely as possible improves the accuracy of cross-section processing.

The CSAS25 control module, the associated functional modules, the cross section library, and databases used in this evaluation reside in the verified configuration control area designated **/vcc/scale5** on CMODC and CMODD. Also, the computer input and output files for the criticality safety evaluation of the ES-3100 shipping package with the additional content reside in a configuration controlled area **/archive/sppkg_801940a002** on CMODC.

6.9.8.5 Single Package Evaluation (NCT and HAC)

The analyses presented in Sect. 6.4 demonstrate that the calculated $k_{eff} \pm 2\sigma$ values increase as a function of increasing MOIFR. Therefore, a fully flooded, reflected package is used to calculate the neutron multiplication factors for the single package analysis.

Reactor Fuel Components and Scrap Materials

6.9.8.5.1 U/Al fuel plates (Table 6.9.8.8-1a)

Uranium alloys may be loaded to the broken metal mass limits by assuming the mass of the alloy is all ^{235}U. An explicit evaluation is performed for deriving less restrictive limits for contents where the constituents of the alloy are predominately non-fissile.

The calculation model for bundled U/Al fuel plates at 93% enrichment is based on the BR-2 MTR Type 2 fuel plate described in Sect. 6.9.8.3.1. Four configurations were developed for the analysis. Case **5cvsrualfp_1_1_15** represents a tight-packed bundle of 35 fuel plates side-by-side inside a flooded containment vessel reflected on all sides by 30.48 cm water. A very small portion of the total 7,333 g of U/Al in a bundle is ^{235}U (~473 g). Cases **5cvsrualfp_2_1_15**, **5cvsrualfp_3_1_15**, and **5cvsrualfp_4_1_15** model the plates with uniform spacing of 0.06 cm, 0.12 cm, and 0.18 cm separation between the plates, respectively. The calculated $k_{eff} \pm 2\sigma$ values range from 0.265 to 0.384. A result is not calculated for the fourth configuration because the bundle of plates intersects the containment vessel wall in the geometry model.

Similarly, the NCT Cases **5ncsrualfp_1_1_15**, **5ncsrualfp_2_1_15**, and **5ncsrualfp_3_1_15** model the U/Al plate configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values range from 0.228 to 0.323. Comparison of NCT single package results with corresponding case results for the flooded, reflected containment vessel demonstrates that ES-3100 packaging is not as an effective moderator as full water reflection.

HAC Cases **5hcsrualfp_1_1_15**, **5hcsrualfp_2_1_15**, and **5hcsrualfp_3_1_15** model the U/Al plate configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

A single flooded, fully water reflected ES-3100 package, either undamaged or damaged, loaded with U/Al fuel plates (net weight 7,333 g) containing ~473 g of ^{235}U will remain adequately subcritical below the USL of 0.924.

Six loading configurations are analyzed for evaluation of the effect of plate separation for a 15-plate U/Al MIT fuel element. One configuration models a compact array of 15 fuel plates with no separation inside the containment vessel. The five other configurations model the plates with 0.020-, 0.050-, 0.082- (actual design value), 0.147- and 0.211-in. (maximum) separation between the plates. The two outermost plates would start to intersect the containment vessel wall with larger separation distances between the plates.

Case **5cvcrmitfpt11_1_1_15** represents a tight-packed bundle of 15 fuel plates face-to-face inside a flooded containment vessel that is reflected on all sides by 30.48 cm of water. Cases **5cvcrmitfpt11_2_1_15** through **5cvcrmitfpt11_6_1_15** model the same plates with uniform spacing of 0.020-, 0.050-, 0.082-, 0.147-, and 0.211-in. separation between the plates, respectively. The calculated $k_{eff} \pm 2\sigma$ values range from 0.270 to 0.473. These same separation values are used in all of the other calculation models for the 15-plate MIT element evaluation.

Similarly, the NCT Cases **5ncsrmitfpt11_1_1_15** through **5ncsrmitfpt11_6_1_15** model the MIT fuel plate configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values range from 0.249 to 0.421.

HAC Cases **5hcsrmitfpt12_1_1_15** through **5hcsrmitfpt12_6_1_15** model the MIT 15-plate configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single

package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

Two loading configurations are analyzed for evaluation of the effect of plate separation for a 30-plate bundle of MIT fuel. One configuration models a compact array of 30 fuel plates with no separation inside the containment vessel. The other configuration models the plates with 0.065-in. separation between the plates. The two outermost plates would start to intersect the containment vessel wall with larger separation distances between the plates.

Case **5cvcr30mitfpt11_1_1_15** represents a tight-packed bundle of 30 fuel plates face-to-face inside a flooded containment vessel which is reflected on all sides by 30.48-cm water. Case **5cvcr30mitfpt11_6_1_15** models the same 30 plates with the maximum possible uniform spacing within the containment vessel of 0.065-in. separation between the plates. The calculated $k_{eff} \pm 2\sigma$ values for these two extremes are 0.305 and 0.443. These same separation values are used in all of the other calculation models for the evaluation of the 30-plate bundle of MIT U/Al fuel plates.

Similarly, the NCT Cases **5ncsr30mitfpt11_1_1_15** and **5ncsrmitfpt11_6_1_15** model the MIT fuel plate configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values for these two extremes (tight-packed and maximum possible uniform spacing) are 0.265 and 0.372.

HAC Cases **5hcsr30mitfpt12_1_1_15** and **5hcsr30mitfpt12_6_1_15** model the MIT 30-plate bundle configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

A single flooded, fully water reflected ES-3100 package, either undamaged or damaged, loaded with a single MIT element consisting of 15 U/Al fuel plates (net weight 3,597 g) containing ~525 g of ^{235}U, or loaded with a bundle of up to 30 MIT fuel plates (net weight 7,194 g) containing ~1,050 g of ^{235}U, will remain adequately subcritical below the USL of 0.924.

6.9.8.5.2 Reactor components of HEU oxide (Table 6.9.8.8-2)

Twelve UO_2 oxide rods in a containment vessel are modeled to determine whether the clad or unclad rods are the most reactive. Case **5cvsroxt11_1_4_1_15** models unclad UO_2 rods as shown in Fig. 6.9.8.3.1-1d. Case **5cvsroxt11_1_4_2_15** models Al-clad UO_2 rods. Case **5cvsroxt11_1_4_3_15** models Zr-clad rods. Case **5cvsroxt11_1_4_4_15** is for unclad UO_2 rods. The calculated $k_{eff} \pm 2\sigma$ values for unclad, Al-clad, SS304-clad, and Zr-clad UO_2 rods range from 0.799 to 0.801. The unclad UO_2 rods are the most reactive configuration.

The single unit analysis is performed with unclad rods modeled in the various rod arrangements shown in Figs. 6.9.8.3.1-1a through 6.9.8.3.1-1g. For NCT Cases **5ncsroxt11_1_1_1_15** through **5ncsroxt11_1_7_1_15,** the calculated $k_{eff} \pm 2\sigma$ values range from 0.604 to 0.745. For HAC Cases **5hcsroxt12_1_1_1_15** through **5hcsroxt12_1_7_1_15**, the calculated $k_{eff} \pm 2\sigma$ values range from 0.603 to 0.750. Configuration "**UO2_D**" shown in Fig. 6.9.8.3.1-1d is the most reactive one represented by Cases **5ncsroxt11_1_4_1_15** and **5hcsroxt12_1_4_1_15**. A single flooded, fully water reflected ES-3100 package with up to 12 clad or unclad UO_2 fuel rods, each containing ~1,609 g of ^{235}U are adequately subcritical, below the USL of 0.924.

6.9.8.5.3 $UZrH_2$ fuel (Table 6.9.8.8-3)

SNAP fuel elements are modeled as 12.45-in.-tall cylinders of $UZrH_2$. The analysis assumes that three SNAP fuel elements each are packed into both the bottom and middle can locations of the ES-3100, rather than the fuel being size reduced to fit into 10-in. or 8-3/4 in.-tall convenience cans. The top can location is assumed void. For calculations where canned spacers are modeled, two canned spacers are assumed present in the containment vessel. For configurations where canned spacers are not used, the $UZrH_2$ content is assumed stacked end-to-end. The three cylinders of the active fuel are modeled in triangular-pitch configuration within a radial boundary of 4.25 in. The pitch used in the criticality calculation models for the NCT and HAC ground transport is 4.9809 cm (1.96 in.).

NCT Cases **5ncsrsnap_93_1_15_15** and **5ncsrsnap_93_1_1_15** model the $UZrH_2$ cylinders inside a flooded or dry containment vessel in flooded ES-3100 packaging under full water reflection. The calculated $k_{eff} \pm 2\sigma$ values are 0.568 and 0.240, respectively. Cases **5ncsrsnap_93_2_15_15** and **5ncsrsnap_93_2_1_15** model the presence of canned spacers. The calculated $k_{eff} \pm 2\sigma$ values are 0.539 and 0.223, respectively.

HAC Cases **5hcsrsnap_93_1_15_15** and **5hcsrsnap_93_1_1_15** model the $UZrH_2$ cylinders inside a flooded or dry containment vessel in flooded damaged ES-3100 packaging under full water reflection. The calculated $k_{eff} \pm 2\sigma$ values are 0.568 and 0.244, respectively. The 1.4-in.-thick canned spacers are modeled in Cases **5hcsrsnap_93_2_15_15** and **5hcsrsnap_93_2_1_15**. The calculated $k_{eff} \pm 2\sigma$ values are 0.540 and 0.225, respectively. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

10 CFR 71.55(d)(2) requires the geometric form of a package's content not be substantially altered under the NCT. Also, 10 CFR 7155(e)(1) requires that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration. However, conclusions about damage to the fuel content cannot be extrapolated from test data because a mock (test weight) content rather than actual SNAP content is evaluated in the NCT and HAC tests of 10 CFR 71.71 and 10 CFR 71.73. Consequently, one way for addressing these requirements is to model the content in an extremely damaged condition and make a determination of subcriticality through a series of criticality calculations. Case **5ncsr9355d2_1_15_15** models the $UZrH_2$ homogenized with the water of a flooded containment vessel and dispersed over the free volume of the containment vessel, where the undamaged ES-3100 packaging is flooded and reflected by 30.48 cm of water. Similarly, Case **5ncsr9355d2_1_1_15** models the $UZrH_2$ dispersed over the free volume of a dry containment vessel of the ES-3100 packaging. The calculated $k_{eff} \pm 2\sigma$ values are 0.674 and 0.158, respectively. Cases **5ncsr9355d2_2_15_15** and **5ncsr9355d2_2_1_15** model the presence of the canned spacers. The calculated $k_{eff} \pm 2\sigma$ values for these cases are 0.645 and 0.151, respectively. These results indicate that extremely damaged content is more reactive than the unaltered configuration. Nevertheless, each set of cases is adequately below the USL of 0.924 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to HAC do no result in an appreciable change in neutron multiplication for the single package, similar results are expected for the cases demonstrating compliance with 10 CFR 71.55(e)(1). Conclusions regarding compliance with 10 CFR 71.55(d)(2) equally apply regarding compliance with 10 CFR 71.55(e)(1).

A single flooded, fully water reflected ES-3100 package, either undamaged or damaged, loaded with $UZrH_2$ (net weight 11,164 g) containing ~857 g ^{235}U will remain adequately subcritical below the USL of 0.924.

6.9.8.5.4 UZr fuel plates

As an alloy, UZr fuel plates may be loaded to the broken metal mass limits by assuming the mass of the alloy is all uranium.

Uranium Compounds

UF_4, UO_2F_2, and $UO_2F_2 \cdot 2H_2O$ are conservatively modeled as water soluble compounds like the UNH content (Sects. 6.4.4, 6.5.4, and 6.6.4). UC, U_2C_3, UC_2, and UN are conservatively modeled both as granular compounds like HEU oxide (Sects. 6.4.3, 6.5.3, and 6.6.3) and as water-soluble compounds like the UNH content (Sects. 6.4.4, 6.5.4, and 6.6.4). An assumed maximum of 500 g of polyethylene represents Teflon or polyethylene bottles, and hydrogenous material used for packing.

6.9.8.5.5 UF compounds (Tables 6.9.8.8-5a, 6.9.8.8-5b)

Consider the flooded, water reflected containment vessel with the UF_4 content in solution and homogenized with 500 g polyethylene. The UF_4 content ranges from 24,000 to 1,000 g. For Cases **5cvcrpuf4t11_24_15** through **5cvcrpuf4t11_1_15** (Table 6.9.8.8-5a), the $k_{eff} \pm 2\sigma$ values range from 0.863 to 0.709 and optimum concentration occurs at ~11,000 g UF_4 ($k_{eff} \pm 2\sigma = 0.890$).

Consider a single, flooded ES-3100 package loaded with UF_4 content in solution and homogenized with 500 g polyethylene. The UF_4 content ranges from 24,000 to 1,000 g. For Cases **5ncsrpuf4t11_24_15** through **5ncsrpuf4t11_1_15**, the $k_{eff} \pm 2\sigma$ values range from 0.747 to 0.629 and optimum concentration occurs at ~9,000 g UF_4 ($k_{eff} \pm 2\sigma = 0.783$). Given that the water-reflected containment vessel is more reactive than the water-reflected package, the result for Case **5cvcrpuf4t11_11_15** is reported [10 CFR 71.55(b)].

Consider the flooded, water reflected containment vessel with the UO_2F_2 content in solution and homogenized with 500 g polyethylene. The UO_2F_2 content ranges from 24,000 to 1,000 g. For Cases **5cvcrpuofct11_24_15** through **5cvcrpuofct11_1_15** (Table 6.9.8.8-5b), the $k_{eff} \pm 2\sigma$ values range from 0.851 to 0.710 and optimum concentration occurs at ~8,000 g UO_2F_2 ($k_{eff} \pm 2\sigma = 0.887$). Consider $UO_2F_2 \cdot 2H_2O$ content in solution and homogenized with 500 g polyethylene. The $UO_2F_2 \cdot 2H_2O$ content ranges from 24,000 to 1,000 g. For Cases **5cvcrpuofhct11_24_15** through **5cvcrpuofhct11_1_15** (Table 6.9.8.8-5b), the $k_{eff} \pm 2\sigma$ values range from 0.898 to 0.696 and optimum concentration occurs at ~14,000 g $UO_2F_2 \cdot 2H_2O$ ($k_{eff} \pm 2\sigma = 0.907$). Given that $UO_2F_2 \cdot 2H_2O$ is more reactive than UO_2F_2, calculations with $UO_2F_2 \cdot 2H_2O$ are bounding.

Consider a single, flooded ES-3100 package loaded with $UO_2F_2 \cdot 2H_2O$ content in solution and homogenized with 500 g polyethylene. For Cases **5ncsrpuofhct11_24_15** through **5ncsrpuofhct11_1_15** (Table 6.9.8.8-5b), the $k_{eff} \pm 2\sigma$ values range from 0.787 to 0.614 and optimum concentration occurs at ~14,000 g $UO_2F_2 \cdot 2H_2O$ ($k_{eff} \pm 2\sigma = 0.798$). The water-reflected containment vessel is more reactive than the water-reflected package; therefore the result for Case **5cvcrpuofhct11_14_15** is reported [10 CFR 71.55(b)].

6.9.8.5.6 UC and UN compounds (Tables 6.9.8.8-6a, 6.9.8.8-6b)

Consider the flooded, water reflected containment vessel with 500 g polyethylene homogenized with bulk saturated UC, U_2C_3, UC_2, or UN compound. These uranium compounds are evaluated over the range from 10,000 to 1,000 g. For Cases **5cvcrpuct11_1_10** through **5cvcrpuct11_1_1** (Table 6.9.8.8-6a), the $k_{eff} \pm 2\sigma$ values for UC content decrease from 0.945 to 0.648. For Cases **5cvcrpuct11_2_10** through **5cvcrpuct11_2_1**, the $k_{eff} \pm 2\sigma$ values for U_2C_3 decrease from 0.910 to 0.643. For Cases **5cvcrpuct11_3_10** through **5cvcrpuct11_3_1**, the $k_{eff} \pm 2\sigma$ values for UC_2 decrease from 0.901 to 0.637. For Cases **5cvcrpunt11_10** through **5cvcrpunt11_1** (Table 6.9.8.8-6b), the $k_{eff} \pm 2\sigma$ values for UN decrease from 0.909 to 0.646.

Consider a single ES-3100 package loaded with 500 g polyethylene homogenized with bulk saturated UC, U_2C_3, UC_2, or UN compound. These uranium compounds are evaluated over the range from 10,000 to 1,000 g. For Cases **5ncsrpuct11_1_10_15** through **5ncsrpuct11_1_1_15** (Table 6.9.8.8-6a), the $k_{eff} \pm 2\sigma$ values for UC content decrease from 0.814 to 0.575. For Cases **5ncsrpuct11_2_10_15** through **5ncsrpuct11_2_1_15**, the $k_{eff} \pm 2\sigma$ values for U_2C_3 decrease from 0.811 to 0.575. For Cases **5ncsrpuct11_3_10_15** through **5ncsrpuct11_3_1_15**, the $k_{eff} \pm 2\sigma$ values for UC_2 decrease from 0.802 to 0.570. For Cases **5ncsrpunt11_10_15** through **5ncsrpunt11_1_15** (Table 6.9.8.8-6b), the $k_{eff} \pm 2\sigma$ values for UN content decrease from 0.814 to 0.574. The water-reflected containment vessel cases are more reactive than the corresponding cases for the water-reflected package.

Consider a single ES-3100 package loaded with 500 g polyethylene homogenized with 2,000 g bulk saturated UC or UN compound. The water inside the containment vessel is varied from the flooded to the dry condition. For Cases **5ncsrpuct11_1_2_15** through **5ncsrpuct11_1_2_1** (Table 6.9.8.8-6a), the $k_{eff} \pm 2\sigma$ values for UC content decrease from 0.657 to 0.617. For Cases **5ncsrpunt11_2_15** through **5ncsrpunt11_2_1** (Table 6.9.8.8-6b), the $k_{eff} \pm 2\sigma$ values for UN content decrease from 0.657 to 0.615. These cases reveal that the addition of water in the void region of the containment vessel above the homogenized water saturated content has little effect on neutron multiplication.

6.9.8.5.7 U_3Si_2 powder (Tables 6.9.8.8-7a, 6.9.8.8-7b)

Consider the flooded, water-reflected containment vessel loaded with 500-g polyethylene homogenized with bulk saturated U_3Si_2. This content is evaluated from 13,000- to 7,000-g U_3Si_2 over a density range of 7 to 2 g/cm^3. For Cases **5cvcrpdusit11_8_7_13_15** through **5cvcrpdusit11_8_2_13_15** (Table 6.9.8.8-7a), the $k_{eff} \pm 2\sigma$ values for U_3Si_2 content increase from 0.849 to 0.920 as the density decreases. For Cases **5cvcrdpust11_8_7_13_15** through **5cvcrdpust11_8_2_13_15** where the same content is dispersed over the internal volume of the containment vessel, $k_{eff} \pm 2\sigma = 0.929$. The uniform configuration—a column of 8656-g water is mixed with 13-kg U_3Si_2 and 500-g polyethylene—is more reactive than the discrete configuration—13-kg U_3Si_2 (plus 5,490-g saturation water) and 500-g polyethylene separated from the 3,166 g of water filling the remaining volume of the containment vessel.

For Cases **5cvcrdpustt11_8_7_13_15** through **5cvcrpdusit11_8_7_7_15** (Table 6.9.8.8-7a), the $k_{eff} \pm 2\sigma$ values for U_3Si_2 content decrease from 0.929 to 0.915 as the mass of U_3Si_2 decreases from 13- to 7-kg U_3Si_2.

For Cases **5cvcrpdusit11_8_7_13_15** through **5cvcrpdusit11_1_7_13_15** (Table 6.9.8.8-7a), the $k_{eff} \pm 2\sigma$ values decrease from 0.849 to 0.624 as the enrichment decreases from 100 to 19.7% in the content (13-kg U_3Si_2 plus 5,490-g saturation water and 500-g polyethylene). Similarly for Cases **5cvcrdpust11_8_7_13_15** through **5cvcrdpust11_1_7_13_15**, the $k_{eff} \pm 2\sigma$ values decrease from 0.929 to 0.763 where this content is dispersed over the containment vessel. The same trend is evident in Cases **5cvcrdpust11_8_7_7_15** through **5cvcrdpust11_1_7_7_15** for a reduced amount of content, the $k_{eff} \pm 2\sigma$ values decrease from 0.915 to 0.724.

For Cases **5cvcrdpustt11_1_7_13_15** through **5cvcrpdusit11_1_7_7_15** (Table 6.9.8.8-7a), the $k_{eff} \pm 2\sigma$ values for U_3Si_2 content decrease from 0.763 to 0.724 as the mass of U_3Si_2 decreases from 13- to 7-kg U_3Si_2 at 19.7% enrichment.

Consider a single ES-3100 package loaded with 500-g polyethylene homogenized with bulk saturated U_3Si_2. This content is evaluated from 13,000- to 7,000-g U_3Si_2 over a density range of 7 to 2 g/cm^3. For Cases **5ncsrpdusit11_8_7_13_15** through **5ncsrpdusit11_8_2_13_15** (Table 6.9.8.8-7b), the $k_{eff} \pm 2\sigma$ values for U_3Si_2 content increase from 0.769 to 0.820 as the density decreases. For Cases **5ncsrdpust11_8_7_13_15** through **5ncsrdpust11_8_2_13_15** where the same content is dispersed over the internal volume of the containment vessel, $k_{eff} \pm 2\sigma = 0.824$. For Cases **5ncsrdpust11_8_7_13_15**

through **5ncsrdpust11_8_7_7_15** (Table 6.9.8.8-7b), the $k_{eff} \pm 2\sigma$ values for U_3Si_2 content decrease from 0.824 to 0.809 as the mass of U_3Si_2 decreases from 13- to 7-kg U_3Si_2.

For Cases **5ncsrpdusit11_8_7_13_15** through **5ncsrpdusit11_1_7_13_15** (Table 6.9.8.8-7b), the $k_{eff} \pm 2\sigma$ values decrease from 0.769 to 0.521 as the enrichment decreases from 100 to 19.7% in the content (13-kg U_3Si_2 plus 5,490-g saturation water and 500-g polyethylene). Similarly for Cases **5ncsrdpust11_8_7_13_15** through **5ncsrdpust11_1_7_13_15**, the $k_{eff} \pm 2\sigma$ values decrease from 0.824 to 0.662 where this content is dispersed over the containment vessel. The same trend is evident in Cases **5ncsrdpust11_8_7_7_15** through **5ncsrdpust11_1_7_7_15** for a reduced amount of content, the $k_{eff} \pm 2\sigma$ values decrease from 0.809 to 0.633.

The same trend observed for the flooded reflected containment vessel is apparent for the flooded reflected package; however, the water-reflected containment vessel cases are more reactive than the corresponding cases for the water-reflected package. The result for Case **5cvcrdpust11_8_7_7_15** (Table 6.9.8.8-7a) is reported [10 CFR 71.55(b)].

6.9.8.6 Array Package Evaluation (NCT and HAC)

The analyses presented in Sects. 6.5 and 6.6 demonstrate that maximum reactivity occurs in an array of packages when the containment vessel is flooded (MOCFR = 1.0) and the ES-3100 packaging is dry (MOIFR = 1e-04). A water fraction of MOIFR = 1e-04 pertains specifically to NCT or HAC packages where both the neutron poison of the body weldment liner inner cavity and the Kaolite are dry and both the recesses of the package external to the containment vessel and the interstitial space between drums of the array do no contain any residual moisture.

The analyses presented in Sects. 6.4, 6.5, and 6.6 demonstrate that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values for undamaged packages in NCT and damaged packages in HAC. Therefore, the HAC array analysis is redundant and not fully developed in this appendix.

Reactor Fuel Components and Scrap Materials

6.9.8.6.1 U/Al fuel plates (Tables 6.9.8.8-1a, 6.9.8.8-1b)

As stated in Sect. 6.9.8.5.1, an explicit evaluation is performed for deriving less-restrictive loading limits for contents where the constituents of the U-Al alloy are predominately non-fissile. The infinite array packaging calculation model for bundled U/Al fuel plates at 93% enrichment is based on the BR-2 MTR Type 2 fuel plate described in Sect. 6.8.8.3.1. NCT Cases **5nciaualfp_1_1_3**, **5nciaualfp_2_1_3**, and **5nciaualfp_3_1_3** model infinite arrays of undamaged ES-3100 packages with the U/Al plates uniformly spaced at 0.0 cm, 0.06 cm, and 0.12 cm separation between plates. The ES-3100 packaging is dry while the containment vessel with content is flooded. A water fraction of MOIFR = 1e-04 signifies dry NCT packaging where both the neutron poison of the body weldment liner inner cavity and the Kaolite are dry (in the as-manufactured condition) and both the recesses of the package external to the containment vessel and the interstitial space between drums of the array do no contain any residual moisture. The calculated $k_{eff} \pm 2\sigma$ values range from 0.276 to 0.382.

HAC Cases **5hciaualfp_1_1_3** through **5hciaualfp_3_1_3** model the U/Al plate configurations inside damaged ES-3100 packages. The calculated $k_{eff} \pm 2\sigma$ values range from 0.275 to 0.380. Comparison of HAC array package results with corresponding HAC results reaffirms the insignificant difference observed between the calculated $k_{eff} \pm 2\sigma$ values.

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with U/Al fuel plates (net weight 7,333 g) containing ≤473 g of ^{235}U may be shipped under a CSI = 0.

The infinite array NCT Cases **5nciamitfpt11_1_1_3** through **5nciamitfpt11_6_1_3** model the MIT U/Al single element/15-plate configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values range from 0.285 to 0.472.

HAC Cases **5hciamitfpt12_1_1_3** through **5hciamitfpt12_6_1_3** model the MIT single element/15-plate configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

The infinite array NCT Cases **5ncia30mitfpt11_1_1_3** and **5ncia30mitfpt11_6_1_3** model the 30 MIT U/Al fuel plates configurations inside a flooded ES-3100 package with full water reflection. The calculated $k_{eff} \pm 2\sigma$ values are 0.316 and 0.429.

HAC Cases **5hcia30mitfpt12_1_1_3** through **5hcia30mitfpt12_6_1_3** model the MIT 30-plate configurations inside a damaged ES-3100 package with full water reflection. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with one MIT U/Al element with 15 fuel plates (net weight 3,597 g) containing ~525-g ^{235}U or up to 30 bundled MIT U/Al fuel plates (net weight 7,194 g) containing ~1,050 g of ^{235}U may be shipped under a CSI = 0.

6.9.8.6.2 Reactor components of HEU oxide (Table 6.9.8.8-2)

Unclad UO_2 rods are used in the infinite array analysis like the single unit analysis. Each rod arrangement (Figs. 6.9.8.3.1-1a through 6.9.8.3.1-1g) is evaluated for confirmation that Configuration "**UO2_D**" is the most reactive one. For NCT Cases **5nciaoxt11_1_1_1_3** through **5nciaoxt11_1_7_1_3**, the calculated $k_{eff} \pm 2\sigma$ values range from 0.715 to 0.885. For HAC Cases **5hciaoxt12_1_1_1_15** through **5hciaoxt12_1_7_1_15,** the calculated $k_{eff} \pm 2\sigma$ values range from 0.708 to 0.877. The most reactive configuration is **UO2_D** represented by Cases **5nciaoxt11_1_4_1_15** and **5hciaoxt12_1_4_1_15**. Calculation results for the configurations evaluated indicate adequate subcriticality below the USL of 0.924. The ES-3100 packages loaded with 12 UO_2 (net weight 21,938 g) containing $\leq$ 19,308 g of ^{235}U may be shipped under a CSI = 0.

6.9.8.6.3 $UZrH_2$ fuel (Table 6.9.8.8-3)

NCT Cases **5nciasnap_93_1_15_3** and **5nciasnap_93_1_1_3** model infinite arrays of undamaged ES-3100 packages with $UZrH_2$ cylinders inside a flooded or dry containment vessels. The calculated $k_{eff} \pm 2\sigma$ values are 0.619 and 0.298, respectively. Cases **5nciasnap_93_2_15_3** and **5nciasnap_93_2_1_3** model the presence of canned spacers. The calculated $k_{eff} \pm 2\sigma$ values are 0.591 and 0.284, respectively.

HAC Cases **5hciasnap_93_1_15_3** and **5hciasnap_93_1_1_3** model infinite arrays of damaged ES-3100 packages with $UZrH_2$ cylinders inside a flooded or dry containment vessels. The calculated $k_{eff} \pm 2\sigma$ values are 0.620 and 0.298, respectively. The 1.4-in.-thick canned spacers are modeled in Cases **5hciasnap_93_2_15_3** and **5hcsrsnap_93_2_1_3**. The calculated $k_{eff} \pm 2\sigma$ values are 0.590 and 0.286, respectively. Comparison of HAC single package results with corresponding NCT results reaffirms that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values.

Case **5ncia9355d2_1_15_3** models infinite arrays of dry, undamaged ES-3100 packages with the $UZrH_2$ homogenized with the water of a flooded containment vessel and dispersed over the free volume of the containment vessel. Similarly, Case **5ncia9355d2_1_1_3** models the $UZrH_2$ dispersed over the

free volume of a dry containment vessel of the dry ES-3100 packaging. The calculated $k_{eff} \pm 2\sigma$ values are 0.6744 and 0.1577, respectively. Cases **5ncia9355d2_2_15_15** and **5ncia9355d2_2_1_1**5 model the presence of the canned spacers. The calculated $k_{eff} \pm 2\sigma$ values for these cases are 0.6449 and 0.1509, respectively. These results indicate that extremely damaged content is more reactive than the unaltered configuration. Nevertheless, each set of cases is adequately below the USL of 0.924 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to HAC do no result in an appreciable change in neutron multiplication for the single package, similar results are expected for the cases demonstrating compliance with 10 CFR 71.55(e)(1). Conclusions regarding compliance with 10 CFR 71.55(d)(2) equally apply regarding compliance with 10 CFR 7155(e)(1).

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with $UZrH_2$ (net weight 11,164 g) containing $\leq$ 857 g ^{235}U may be shipped under a CSI = 0.

6.9.8.6.4 UZr fuel plates

As stated in Sect. 6.9.8.5.4, UZr fuel plates may be loaded to the broken metal mass limits by assuming the mass of the alloy is all ^{235}U.

6.9.8.6.5 UF compounds (Tables 6.9.8.8-5a, 6.9.8.8-5b)

Cases **5nciapuf4t11_24_1** through **5nciapuf4t11_24_15** (Table 6.9.8.8-5a) model infinite arrays of ES-3100 packages each loaded with 24,000 g UF_4 in solution and homogenized with 500 g polyethylene. The $k_{eff} \pm 2\sigma$ values decrease from 0.981 to 0.765 as the packaging external to the containment vessel and the interstitial space between the packages of the array floods. Comparison of results for Cases **5ncsrpuf4t11_24_15** through **5nciapuf4t11_24_15** confirms that flooded packages in a flooded array are nearly neutronically isolated from each other.

Consider an array of flooded ES-3100 packages loaded with UF_4 content in solution and homogenized with 500 g polyethylene. The UF_4 content ranges from 5,000 to 1,000 g. For Cases **5nciapuf4t11_5_3** through **5nciapuf4t11_1_3**, the $k_{eff} \pm 2\sigma$ value decreases from 0.947 to 0.738.

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with 3000 g UF_4 containing $\leq$ 2,267 g ^{235}U may be shipped under a CSI = 0.

Cases **5nciapuofhct11_24_1** through **5nciapuofhct11_24_15** (Table 6.9.8.8-5b) model infinite arrays of ES-3100 packages each loaded with 24,000-g $UO_2F_2 \cdot 2H_2O$ in solution and homogenized with 500-g polyethylene. The $k_{eff} \pm 2\sigma$ values decrease from 1.048 to 0.813 as the packaging external to the containment vessel and the interstitial space between the packages of the array floods. Comparison of results for Cases **5ncsrpuofhct11_24_15** and **5nciapuofhct11_24_15** confirms that flooded packages in a flooded array are nearly neutronically isolated from each other.

Consider an array of flooded ES-3100 packages loaded with $UO_2F_2 \cdot 2H_2O$ content in solution and homogenized with 500 g polyethylene. The $UO_2F_2 \cdot 2H_2O$ content ranges from 5,000 to 1,000 g. For Cases **5nciapuofhct11_5_3** through **5nciapuofhctt11_1_3**, the $k_{eff} \pm 2\sigma$ value decreases from 0.949 to 0.719.

Given that the results indicate adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with 3000 g $UO_2F_2 \cdot 2H_2O$ containing $\leq$ 2,067 g ^{235}U may be shipped under a CSI = 0.

6.9.8.6.6 UC and UN compounds (Tables 6.9.8.8-6a, 6.9.8.8-6b)

As shown in Table 6.9.8.8-6a, UC content bounds the other forms of uranium carbide compounds. Consider an array of flooded ES-3100 packages loaded with UC content homogenized with

500 g polyethylene. For Cases **5nciapuct11_1_10_3** through **5nciapuct11_1_1_3**, the UC content is conservatively modeled as granular compound like HEU oxide. Over the range of 10,000 to 1,000 g UC, the $k_{eff} \pm 2\sigma$ value decreases from 0.914 to 0.577. For Cases **5nciadpuct11_1_10_15_3** through **5nciadpuct11_1_1_15_3**, the UC content is conservatively modeled as a water-soluble compound dispersed over the free volume of the containment vessel, like the UNX, UF_4, UO_2F_2, and $UO_2F_2 \cdot 2H_2O$ contents. Over the range of 10,000 to 1,000 g UC, the $k_{eff} \pm 2\sigma$ value decreases from 1.031 to 0.785.

Given that the UC content may not be well characterized as bulk material like the HEU oxide content, the latter model is used for establishing the loading limits. On the basis of calculation results indicating adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with 2,000 g UC, U_2C_3, or UC_2 containing $\leq$ 1,903 g ^{235}U may be shipped under a CSI = 0.

Consider an array of flooded ES-3100 packages loaded with UN content homogenized with 500 g polyethylene. For Cases **5nciapunt11_10_3** through **5nciapuct11_1_3**, the UN content is conservatively modeled as granular compound like HEU oxide. Over the range of 10,000 to 1,000 g UN, the $k_{eff} \pm 2\sigma$ value decreases from 0.927 to 0.578. For Cases **5nciadpunt11_10_15_3** through **5nciadpunt11_1_15_3**, the UN content is conservatively modeled as a water-soluble compound dispersed over the free volume of the containment vessel. Over the range of 10,000 to 1,000 g UN, the $k_{eff} \pm 2\sigma$ value decreases from 1.027 to 0.780.

Given that the UN content may not be well characterized as bulk material like the HEU oxide content, the latter model is used for establishing the loading limits. On the basis of calculation results indicating adequate subcriticality below the USL of 0.924, ES-3100 packages loaded with 2,000 g UN containing $\leq$ 1,888 g ^{235}U may be shipped under a CSI = 0.

6.9.8.6.7 U_3Si_2 powder (Table 6.9.8.8-7c)

Consider an infinite array of ES-3100 packages loaded with saturated bulk U_3Si_2 content homogenized with 500 g of polyethylene in flooded containment vessels. The packaging external to the containment vessels and the interstitial void space between packages in the infinite array is assumed dry for maximizing neutronic interaction. For Cases **5nciapdusit11_8_7_13_3** through **5nciapdusit11_8_2_13_3** (Table 6.9.8.8-7c) where 13 kg of U_3Si_2 content is evaluated over a density range of 7 to 2 g/cm^3, the $k_{eff} \pm 2\sigma$ values increase from 0.831 to 0.963 as the density decreases. For Cases **5nciadpust11_8_7_13_3** through **5nciadpust11_8_2_13_3** where this same content is dispersed over the internal volume of the containment vessel, $k_{eff} \pm 2\sigma = 1.037$. In the latter set of cases, the density of the saturated content does not have an effect on neutron multiplication because the amount of water within which the content is dispersed is constant.

For Cases **5nciapdusit11_8_2_13_3** through **5nciapdusit11_8_2_7_3** (Table 6.9.8.8-7c), the $k_{eff} \pm 2\sigma$ values for U_3Si_2 content decrease from 0.964 to 0.863 as the mass of U_3Si_2 decreases from 13 to 7 kg. Similarly for Cases **5nciadpust11_8_7_13_3** through **5nciadpust11_8_7_7_3** (Table 6.9.8.8-7c), the $k_{eff} \pm 2\sigma$ values decrease from 1.037 to 1.006. While the discrete configuration modeled in Cases **5nciapdusit11** indicates that potentially high content loadings can be achieved, the uniform configuration modeled in Cases **5nciadpust11** indicates the contrary.

For Cases **5nciapdusit11_8_2_13_3** through **5nciapdusit11_1_2_13_3**, the $k_{eff} \pm 2\sigma$ values decrease from 0.964 to 0.739 as the enrichment decreases from 100 to 19.7% in the content (13-kg U_3Si_2 plus 5,490-g saturation water and 500-g polyethylene). For Cases **5nciadpust11_8_7_13_3** through **5nciadpust11_1_7_13_3** where content is dispersed over the internal volume of the flooded containment vessel, the $k_{eff} \pm 2\sigma$ values decrease from 1.037 to 0.7993.

The last set of cases presented in Table 6.9.8.8-7c ranks the results for the uniform content configuration model Cases **5nciadpust11** and corresponding discrete configuration model

Cases **5nciapdusit11** according to decreased neutron multiplication factor. Given that the U_3Si_2 content may not be as well characterized as bulk HEU oxide content, the uniform model is used for establishing the loading limits. On the basis of calculation results indicating adequate subcriticality below the USL of 0.924, ES-3100 packages may be shipped under a CSI = 0 for:

(A) loading not exceeding 7-kg U_3Si_2 at enrichments ≥40% but ≤ 60% and

(B) loading not exceeding 13-kg U_3Si_2 at enrichments ~19.7 but < 40%.

6.9.8.7 Benchmark Experiments and the Criticality Validation

The criticality validation for SCALE 5.0 is a repetition of the SCALE 4.4a validation based on benchmark experiments documented in the Organization for Economic Cooperation and Development (OECD) Handbook [NEA/NSC/DOC(95)03]. Validation cases for SCALE 4.4a were executed on an HP Model J5600 RISC workstation under the HP-UX 10.20 operating system. For SCALE 5.0, these same validation cases were executed on an HP Model zx6000 Itanium workstation (CMODC).

The validation of CSAS25 control module of SCALE 5.0 with the 238-group ENDF/B-V cross-section library is documented in Y/DD-1220 and Y/DD-1221. Like Y/DD-896/R1, Y/DD-1220 addresses the establishment of bias, bias trends, and uncertainty associated with the use of SCALE 5.0 for performance of criticality calculations. Like Y/DD-972R1, Y/DD-1221 addresses determining USL and for incorporating uncertainty and margin into this USL.

SCALE5 incorporates minor improvements in the code modules for the Bondarenko and the Nordheim Integral Treatment processing of resonance cross sections and the KENO V.a module. Consequently, the USL used is validation dependent based on the SCALE-platform combination. The evaluation of the contents based upon SCALE 5.0 calculations is documented in this appendix separate from the main body of Sect. 6 because this effort could not easily be folded into the existing SCALE 4.4a evaluation without inclusion of a patchwork of clarifications.

The USL is based on the non-parametric statistics-based lower tolerance limit (LTL) for greater than 0.99/99% where there is a probability of greater than 0.99 that 99% of the population is greater than a specified result, reduced by additional margin. From Table 1 of Y/DD-1221, the LTL combining bias and bias uncertainty is 0.974 for uranium systems, including HEU metal. Tables 4.2, 4.3, and 4.4 of Y/DD-1220 list the maximum (positive) and minimum (negative) biases for HEU (metal, compound, solution), IEU (metal, compound) and LEU (compound, solution) systems. Since the positive bias is conservatively treated as a "zero" bias in the validation analysis, the negative bias is applied to determine the USL for the systems. The minimum bias given for HEU, IEU, and LEU systems is given as −0.0230, −0.0055 and −0.0260, respectively.

The minimum bias given for HEU systems in Table 4.2 of Y/DD-1220 is -0.1423. However, this result is from one of the four k-infinite models which are somewhat different than the usual benchmark experiments. As discussed in Sect. 5.3 of Y/DD-1220, the four outlier results are for benchmark experiments that were modeled as infinite in extent, thereby amplifying the effects of imperfections in cross section data. The models also required additional interpretation and adjustment from the actual finite experimental configuration to create an infinite benchmark model. After eliminating outlier models from the bias determination, the minimum bias was determined to be -0.023 for HEU systems.

The global minimum bias results for these systems (−0.0260) is applied to all uranium enrichments. Ordinarily, the USL would be 0.954 where an additional margin of subcriticality of 0.02 is subtracted from the LTL of 0.974. However, NUREG/CR-5661 provides guidance that the USL should be established with a minimum margin of subcriticality of 0.05. Thus, the USL is equal to 0.95 plus the minimum bias (−0.026), giving a value of 0.924.

6.9.8.8 Calculation Results Tables

Tables 6.9.8.8-1a through 6.9.8.8-7c contain a summary of the calculation results for the additional contents to be shipped in the ES-3100 shipping package. Table 6.9.8.8-4 has been omitted until such time when the Uranium Zirconium alloys are explicitly modeled. Currently these content items are to be treated as broken metal and shipped under these limits accordingly.

Table 6.9.8.8-1a. Results for uranium aluminum fuel plate content, no polyethylene, no can spacers in the CV or ES-3100 packaging calculation models

case name	plates per bundle	plate spacing (in.)	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
flooded containment vessel (mocfr=1.0), reflected										
5cvcrualfpt11_1_1_15	35	0.00	1.0E+00	0.26346	0.00082	0.26511				
5cvcrualfpt11_2_1_15	35	0.02	1.0E+00	0.32679	0.00085	0.32849				
5cvcrualfpt11_3_1_15	35	0.05	1.0E+00	0.38130	0.00116	0.38362				
5cvcrualfpt11_4_1_15	35	0.07	1.0E+00	–	–	–				
case name	**plates per bundle**	**plate spacing (in.)**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**case name**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
		NCT						**HAC**		
content in flooded CV (mocfr=1.0), single package, reflected										
5ncsrualfpt11_1_1_15	35	0.00	1.0E+00	0.22621	0.00088	0.22798	5hcsrualfpt12_1_1_15	0.22703	0.00075	0.22852
5ncsrualfpt11_2_1_15	35	0.02	1.0E+00	0.27915	0.00119	0.28153	5hcsrualfpt12_2_1_15	0.27905	0.00092	0.28090
5ncsrualfpt11_3_1_15	35	0.05	1.0E+00	0.32203	0.00091	0.32386	5hcsrualfpt12_3_1_15	0.32153	0.00097	0.32348
content in flooded CV (mocfr=1.0), infinite array of packages										
5nciaualfpt11_1_1_3	35	0.00	1.0E-04	0.27420	0.00087	0.27594	5hciaualfpt12_1_1_3	0.27367	0.00083	0.27533
5nciaualfpt11_2_1_3	35	0.02	1.0E-04	0.33182	0.00088	0.33358	5hciaualfpt12_2_1_3	0.33267	0.00111	0.33488
5nciaualfpt11_3_1_3	35	0.05	1.0E-04	0.38011	0.00094	0.38199	5hciaualfpt12_3_1_3	0.37838	0.00093	0.38024

Table 6.9.8.8-1b. Results for MIT uranium aluminum fuel element and plate bundles, no polyethylene, no can spacers in the CV or ES-3100 packaging calculation models

		Case suffix	Gap (in.)	moifr	NCT			HAC		
					k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ
15 fuel plates	Containment vessel				5cvcrmitfpt11					
		_1_1_15	0.000	1.00E+00	0.26824	0.00088	0.27000			
		_2_1_15	0.020	1.00E+00	0.29481	0.00105	0.29691			
		_3_1_15	0.050	1.00E+00	0.33087	0.00095	0.33278			
		_4_1_15	0.082	1.00E+00	0.36892	0.00098	0.37088			
		_5_1_15	0.147	1.00E+00	0.42964	0.00117	0.43198			
		_6_1_15	0.211	1.00E+00	0.47026	0.00130	0.47286			
	Single unit				5ncsrmitfpt11			5hcsrmitfpt12		
		_1_1_15	0.000	1.00E+00	0.24690	0.00088	0.24865	0.24797	0.00087	0.24970
		_2_1_15	0.020	1.00E+00	0.27020	0.00086	0.27193	0.26973	0.00102	0.27176
		_3_1_15	0.050	1.00E+00	0.30386	0.00145	0.30676	0.30559	0.00093	0.30746
		_4_1_15	0.082	1.00E+00	0.33648	0.00111	0.33869	0.33850	0.00097	0.34045
		_5_1_15	0.147	1.00E+00	0.39116	0.00123	0.39361	0.39128	0.00109	0.39345
		_6_1_15	0.211	1.00E+00	0.41826	0.00115	0.42056	0.41894	0.00119	0.42132
	Infinite array				5nciamitfpt11			5hciamitfpt12		
		_1_1_3	0.000	1.00E-04	0.28290	0.00087	0.28465	0.28164	0.00105	0.28373
		_2_1_3	0.020	1.00E-04	0.30900	0.00086	0.31072	0.30697	0.00107	0.30911
		_3_1_3	0.050	1.00E-04	0.34843	0.00098	0.35040	0.34618	0.00097	0.34813
		_4_1_3	0.082	1.00E-04	0.38429	0.00104	0.38636	0.38492	0.00098	0.38688
		_5_1_3	0.147	1.00E-04	0.44035	0.00108	0.44251	0.44168	0.00117	0.44402
		_6_1_3	0.211	1.00E-04	0.46934	0.00141	0.47215	0.47218	0.00117	0.47453

Table 6.9.8.8-1b. Results for MIT uranium aluminum fuel element and plate bundles, no polyethylene, no can spacers in the CV or ES-3100 packaging calculation models

		Case suffix	Gap (in.)	moifr	NCT			HAC		
					k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ
30 fuel plates	Containment vessel				5cvcr30mitfpt11					
		_1_1_15	0.000	1.00E+00	0.30325	0.00110	0.30545			
		_6_1_15	0.065	1.00E+00	0.44049	0.00105	0.44259			
	Single unit				5ncsr30mitfpt11			5hcsr30mitfpt12		
		_1_1_15	0.000	1.00E+00	0.26307	0.00107	0.26521	0.26464	0.00096	0.26655
		_6_1_15	0.065	1.00E+00	0.36977	0.00109	0.37195	0.37233	0.00107	0.37446
	Infinite array				5ncia30mitfpt11			5hcia30mitfpt12		
		_1_1_3	0.000	1.00E-04	0.31460	0.00089	0.31639	0.31507	0.00097	0.31701
		_6_1_3	0.065	1.00E-04	0.42644	0.00135	0.42915	0.42690	0.00100	0.42890

Table 6.9.8.8-2. Results for uranium oxide fuel pin content, no polyethylene, no can spacers in the CV or ES-3100 packaging calculation models

case name	rod config.	Cladding	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$	case name	k_{eff}	σ	$k_{eff}+2\sigma$
flooded containment vessel (mocfr=1.0), reflected										
5cvsroxt11_1_4_1_15	UO2_D	none	1.0E+00	0.79880	0.00113	0.80106				
5cvsroxt11_1_4_2_15	UO2_D	Al	1.0E+00	0.79780	0.00143	0.80066				
5cvsroxt11_1_4_3_15	UO2_D	SS304	1.0E+00	0.79704	0.00135	0.79974				
5cvsroxt11_1_4_4_15	UO2_D	Zr	1.0E+00	0.79706	0.00133	0.79972				
case name	**rod config.**	**Cladding**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**	**case name**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
		NCT						**HAC**		
content in flooded CV (mocfr=1.0), single package, reflected										
5ncsroxt11_1_1_1_15	UO2_A	none	1.0E+00	0.63776	0.00113	0.64002	5hcsroxt12_1_1_1_15	0.63955	0.00102	0.64159
5ncsroxt11_1_2_1_15	UO2_B	none	1.0E+00	0.67647	0.00099	0.67844	5hcsroxt12_1_2_1_15	0.68016	0.00121	0.68258
5ncsroxt11_1_3_1_15	UO2_C	none	1.0E+00	0.71717	0.00117	0.71951	5hcsroxt12_1_3_1_15	0.72166	0.00133	0.72432
5ncsroxt11_1_4_1_15	UO2_D	none	1.0E+00	0.74420	0.00138	0.74697	5hcsroxt12_1_4_1_15	0.74679	0.00140	0.74959
5ncsroxt11_1_5_1_15	UO2_E	none	1.0E+00	0.69214	0.00115	0.69445	5hcsroxt12_1_5_1_15	0.69182	0.00128	0.69439
5ncsroxt11_1_6_1_15	UO2_F	none	1.0E+00	0.60129	0.00123	0.60374	5hcsroxt12_1_6_1_15	0.60188	0.00122	0.60433
5ncsroxt11_1_7_1_15	UO2_G	none	1.0E+00	0.60245	0.00098	0.60441	5hcsroxt12_1_7_1_15	0.60159	0.00123	0.60406
content in flooded CV (mocfr=1.0), infinite array of packages										
5nciaoxt11_1_1_1_3	UO2_A	none	1.0E-04	0.72525	0.00114	0.72753	5hciaoxt12_1_1_1_3	0.71979	0.00110	0.72199
5nciaoxt11_1_2_1_3	UO2_B	none	1.0E-04	0.83897	0.00121	0.84138	5hciaoxt12_1_2_1_3	0.83380	0.00097	0.83575
5nciaoxt11_1_3_1_3	UO2_C	none	1.0E-04	0.84091	0.00106	0.84304	5hciaoxt12_1_3_1_3	0.83516	0.00121	0.83758
5nciaoxt11_1_4_1_3	UO2_D	none	1.0E-04	0.88193	0.00130	0.88454	5hciaoxt12_1_4_1_3	0.87513	0.00116	0.87746
5nciaoxt11_1_5_1_3	UO2_E	none	1.0E-04	0.80570	0.00128	0.80827	5hciaoxt12_1_5_1_3	0.79920	0.00117	0.80154
5nciaoxt11_1_6_1_3	UO2_F	none	1.0E-04	0.79000	0.00148	0.79297	5hciaoxt12_1_6_1_3	0.78673	0.00115	0.78904
5nciaoxt11_1_7_1_3	UO2_G	none	1.0E-04	0.71258	0.00101	0.71461	5hciaoxt12_1_7_1_3	0.70523	0.00114	0.70750

Table 6.9.8.8-3. Results for $UZrH_2$ content at 93 wt % ^{235}U, no polyethylene in the CV or ES-3100 packaging calculation models

case name (5ncsrsnap_93)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$	case name (5hcsrsnap_93)	k_{eff}	σ	$k_{eff}+2\sigma$
NCT									**HAC**			
content in flooded containment vessel (mocfr=1.0), single package reflected												
no can spacers (np thickness = 0.0 in.)												
_1_15_15	11,164	856.8	8,697.5	265.00	1.0E+00	0.56482	0.00132	0.56745	_1_15_15	0.56496	0.00153	0.56802
_1_15_1	11,164	856.8	8,697.5	265.00	1.0E-20	0.52691	0.00140	0.52971	_1_15_1	0.52716	0.00115	0.52946
content in dry containment vessel (mocfr=1.0E-20), single package reflected												
no can spacers (np thickness = 0.0 in.)												
_1_1_15	11,164	856.8	0.0	0.00	1.0E+00	0.23835	0.00065	0.23965	_1_1_15	0.24210	0.00086	0.24382
_1_1_1	11,164	856.8	0.0	0.00	1.0E-20	0.14965	0.00071	0.15107	_1_1_1	0.15269	0.00062	0.15392
content in flooded containment vessel (mocfr=1.0), single package reflected												
can spacers (np thickness = 1.4 in.)												
_2_15_15	11,164	856.8	8,083.9	246.30	1.0E+00	0.53615	0.00136	0.53887	_2_15_15	0.53767	0.00121	0.54010
_2_15_1	11,164	856.8	8,083.9	246.30	1.0E-20	0.49949	0.00124	0.50197	_2_15_1	0.50098	0.00147	0.50391
content in dry containment vessel (mocfr=1.0E-20), single package reflected												
can spacers (np thickness = 1.4 in.)												
_2_1_15	11,164	856.8	0.0	0.00	1.0E+00	0.22128	0.00085	0.22297	_2_1_15	0.22299	0.00099	0.22497
_2_1_1	11,164	856.8	0.0	0.00	1.0E-20	0.14380	0.00076	0.14532	_2_1_1	0.14446	0.00059	0.14564

Table 6.9.8.8-3. Results for $UZrH_2$ content at 93 wt % ^{235}U, no polyethylene in the CV or ES-3100 packaging calculation models

case name (5nciasnap_93)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$	case name (5hciasnap_93)	k_{eff}	σ	$k_{eff}+2\sigma$
NCT									**HAC**			
content in flooded or dry containment vessel, infinite array of packages (moifr=1.0E-04)												
no can spacers (np thickness = 0.0 in.)												
_1_15_3	11,164	856.8	8,697.5	265	1.0E+00	0.61697	0.00116	0.61929	_1_15_3	0.61768	0.00126	0.62021
_1_1_3	11,164	856.8	0.0	0	1.0E-20	0.29625	0.00088	0.29800	_1_1_3	0.29628	0.00078	0.29784
can spacers (np thickness = 1.4 in.												
_2_15_3	11,164	856.8	8,083.9	246.3	1.0E+00	0.58841	0.00140	0.59121	_2_15_3	0.58719	0.00116	0.58952
_2_1_3	11,164	856.8	0.0	0	1.0E-20	0.28234	0.00082	0.28399	_2_1_3	0.28400	0.00090	0.28580
case name (5ncsrs9355d2)	**$UZrH_x$ (g)**	**^{235}U (g)**	**H_2O (g)**	**h/x**	**mocfr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**				
NCT												
content in flooded or dry containment vessel, single package, reflected												
no can spacers (np thickness = 0.0 in.)												
_1_15_15	11,164	857	8,697.5	265.00	1.0E+00	0.67173	0.00134	0.67441				
_1_1_15	11,164	857	0.0	0.00	1.0E-20	0.15644	0.00064	0.15773				
content in flooded or dry containment vessel, infinite array of NCT packages (moifr=1.0E-04)												
can spacers (np thickness = 1.4 in.)												
_2_15_15	11,164	857	8,083.9	246.30	1.0E+00	0.64224	0.00135	0.64494				
_2_1_15	11,164	857	0.0	0.00	1.0E-20	0.14967	0.00059	0.15085				

Table 6.9.8.8-3. Results for $UZrH_2$ content at 93 wt % ^{235}U, no polyethylene in the CV or ES-3100 packaging calculation models

case name (5ncias9355d2)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$	
NCT									
content in flooded or dry containment vessel, infinite array of NCT packages (moifr=1.0E-04)									
no can spacers (np thickness = 0.0 in.)									
_1_15_3	11,164	857	8,697.5	265.00	1.0E+00	0.77961	0.00125	0.78212	
_1_1_3	11,164	857	0.0	0.00	1.0E-20	0.19477	0.00064	0.19606	
content in flooded or dry containment vessel, infinite array of NCT packages (moifr=1.0E-04)									
can spacers (np thickness = 1.4 in.)									
_2_15_3	11,164	857	8,083.9	246.30	1.0E+00	0.73142	0.00125	0.73392	
_2_1_3	11,164	857	0.0	0.00	1.0E-20	0.18427	0.00066	0.18559	

Table 6.9.8.8-5a. Results for uranium tetrafluoride (UF_4) in the CV or ES-3100 packaging calculation models

case name	UF_4 (g)	^{235}U (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UF_4 content and 500 g polyethylene, flooded containment vessel, reflected								
					mocfr			
5cvcrpuf4t11_24_15	24,000	18,136	6,045	9.62	1.0E+00	0.85970	0.00145	0.86260
5cvcrpuf4t11_23_15	23,000	17,380	6,195	10.27	1.0E+00	0.86175	0.00129	0.86433
5cvcrpuf4t11_22_15	22,000	16,625	6,345	10.97	1.0E+00	0.86372	0.00151	0.86674
5cvcrpuf4t11_21_15	21,000	15,869	6,496	11.74	1.0E+00	0.86321	0.00152	0.86626
5cvcrpuf4t11_20_15	20,000	15,113	6,646	12.59	1.0E+00	0.86843	0.00121	0.87086
5cvcrpuf4t11_19_15	19,000	14,358	6,797	13.52	1.0E+00	0.87167	0.00120	0.87407
5cvcrpuf4t11_18_15	18,000	13,602	6,947	14.56	1.0E+00	0.86974	0.00152	0.87278
5cvcrpuf4t11_17_15	17,000	12,846	7,097	15.73	1.0E+00	0.87451	0.00130	0.87711
5cvcrpuf4t11_16_15	16,000	12,091	7,248	17.03	1.0E+00	0.87724	0.00175	0.88073
5cvcrpuf4t11_15_15	15,000	11,335	7,398	18.52	1.0E+00	0.87801	0.00156	0.88114
5cvcrpuf4t11_14_15	14,000	10,579	7,549	20.21	1.0E+00	0.88119	0.00147	0.88413
5cvcrpuf4t11_13_15	13,000	9,823	7,699	22.16	1.0E+00	0.88028	0.00136	0.88300
5cvcrpuf4t11_12_15	12,000	9,068	7,850	24.44	1.0E+00	0.88385	0.00139	0.88664
5cvcrpuf4t11_11_15	**11,000**	**8,312**	**8,000**	**27.14**	**1.0E+00**	**0.88690**	**0.00131**	**0.88952**
5cvcrpuf4t11_10_15	10,000	7,556	8,150	30.37	1.0E+00	0.88487	0.00144	0.88776
5cvcrpuf4t11_9_15	9,000	6,801	8,301	34.32	1.0E+00	0.88487	0.00179	0.88845
5cvcrpuf4t11_8_15	8,000	6,045	8,451	39.26	1.0E+00	0.88594	0.00132	0.88859
5cvcrpuf4t11_7_15	7,000	5,289	8,602	45.61	1.0E+00	0.88213	0.00157	0.88526
5cvcrpuf4t11_6_15	6,000	4,534	8,752	54.08	1.0E+00	0.87761	0.00155	0.88070
5cvcrpuf4t11_5_15	5,000	3,778	8,902	65.93	1.0E+00	0.87255	0.00120	0.87494
5cvcrpuf4t11_4_15	4,000	3,022	9,053	83.71	1.0E+00	0.86186	0.00130	0.86446
5cvcrpuf4t11_3_15	3,000	2,267	9,203	113.36	1.0E+00	0.84540	0.00143	0.84827
5cvcrpuf4t11_2_15	2,000	1,511	9,354	172.62	1.0E+00	0.80743	0.00150	0.81044
5cvcrpuf4t11_1_15	1,000	756	9,504	350.39	1.0E+00	0.70654	0.00129	0.70913

Table 6.9.8.8-5a. Results for uranium tetrafluoride (UF_4) in the CV or ES-3100 packaging calculation models

case name	UF_4 (g)	^{235}U (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UF_4 content with 500 g polyethylene in containment vessel, flooded package, reflected								
5ncsrpuf4t11_24_15	24,000	18,136	6,045	9.62	1.0E+00	0.74487	0.00125	0.74738
5ncsrpuf4t11_23_15	23,000	17,380	6,195	10.27	1.0E+00	0.74674	0.00139	0.74953
5ncsrpuf4t11_22_15	22,000	16,625	6,345	10.97	1.0E+00	0.75066	0.00122	0.75310
5ncsrpuf4t11_21_15	21,000	15,869	6,496	11.74	1.0E+00	0.74939	0.00118	0.75175
5ncsrpuf4t11_20_15	20,000	15,113	6,646	12.59	1.0E+00	0.75270	0.00158	0.75587
5ncsrpuf4t11_19_15	19,000	14,358	6,797	13.52	1.0E+00	0.75465	0.00128	0.75720
5ncsrpuf4t11_18_15	18,000	13,602	6,947	14.56	1.0E+00	0.76103	0.00170	0.76442
5ncsrpuf4t11_17_15	17,000	12,846	7,097	15.73	1.0E+00	0.76089	0.00112	0.76312
5ncsrpuf4t11_16_15	16,000	12,091	7,248	17.03	1.0E+00	0.76404	0.00162	0.76727
5ncsrpuf4t11_15_15	15,000	11,335	7,398	18.52	1.0E+00	0.76718	0.00124	0.76966
5ncsrpuf4t11_14_15	14,000	10,579	7,549	20.21	1.0E+00	0.76630	0.00137	0.76904
5ncsrpuf4t11_13_15	13,000	9,823	7,699	22.16	1.0E+00	0.77064	0.00126	0.77316
5ncsrpuf4t11_12_15	12,000	9,068	7,850	24.44	1.0E+00	0.77019	0.00161	0.77340
5ncsrpuf4t11_11_15	11,000	8,312	8,000	27.14	1.0E+00	0.77412	0.00140	0.77691
5ncsrpuf4t11_10_15	10,000	7,556	8,150	30.37	1.0E+00	0.77743	0.00135	0.78013
5ncsrpuf4t11_9_15	9,000	6,801	8,301	34.32	1.0E+00	0.77855	0.00244	0.78344
5ncsrpuf4t11_8_15	8,000	6,045	8,451	39.26	1.0E+00	0.77398	0.00155	0.77709
5ncsrpuf4t11_7_15	7,000	5,289	8,602	45.61	1.0E+00	0.77431	0.00151	0.77733
5ncsrpuf4t11_6_15	6,000	4,534	8,752	54.08	1.0E+00	0.77174	0.00141	0.77455
5ncsrpuf4t11_5_15	5,000	3,778	8,902	65.93	1.0E+00	0.76857	0.00139	0.77135
5ncsrpuf4t11_4_15	4,000	3,022	9,053	83.71	1.0E+00	0.75863	0.00138	0.76139
5ncsrpuf4t11_3_15	3,000	2,267	9,203	113.36	1.0E+00	0.74294	0.00135	0.74563
5ncsrpuf4t11_2_15	2,000	1,511	9,354	172.62	1.0E+00	0.71219	0.00191	0.71600
5ncsrpuf4t11_1_15	1,000	756	9,504	350.39	1.0E+00	0.62599	0.00150	0.62899

Table 6.9.8.8-5a. Results for uranium tetrafluoride (UF_4) in the CV or ES-3100 packaging calculation models

case name	UF_4 (g)	^{235}U (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UF_4 content with 500 g poly, flooded containment vessel, infinite array of packages								
					moifr			
5nciapuf4t11_24_1	24,000	18,136	6,045	9.62	1.0E-20	0.97902	0.00126	0.98155
5nciapuf4t11_24_2	24,000	18,136	6,045	9.62	1.0E-05	0.97881	0.00120	0.98121
5nciapuf4t11_24_3	24,000	18,136	6,045	9.62	1.0E-04	0.97816	0.00107	0.98030
5nciapuf4t11_24_4	24,000	18,136	6,045	9.62	1.0E-03	0.97536	0.00113	0.97762
5nciapuf4t11_24_5	24,000	18,136	6,045	9.62	1.0E-02	0.95053	0.00135	0.95323
5nciapuf4t11_24_6	24,000	18,136	6,045	9.62	1.0E-01	0.82769	0.00123	0.83014
5nciapuf4t11_24_8	24,000	18,136	6,045	9.62	3.0E-01	0.75894	0.00131	0.76155
5nciapuf4t11_24_15	24,000	18,136	6,045	9.62	1.0E+00	0.76205	0.00140	0.76486
5nciapuf4t11_5_3	5,000	3,778	8,902	65.93	1.0E-04	0.94398	0.00143	0.94684
5nciapuf4t11_4_3	4,000	3,022	9,053	83.71	1.0E-04	0.92856	0.00174	0.93205
5nciapuf4t11_3_3	**3,000**	**2,267**	**9,203**	**113.36**	**1.0E-04**	**0.90021**	**0.00130**	**0.90280**
5nciapuf4t11_2_3	2,000	1,511	9,354	172.62	1.0E-04	0.85169	0.00129	0.85426
5nciapuf4t11_1_3	1,000	756	9,504	350.39	1.0E-04	0.73511	0.00144	0.73800

Table 6.9.8.8-5b. Results for uranyl fluoride (UO_2F_2) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models

case name	UO_2F_2 or $UO_2F_2 \cdot 2H_2O$ (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UO_2F_2 content and 500-g polyethylene, flooded containment vessel, reflected									
						mocfr			
5cvcrpuofct11_24_15	24,000	18,493		5,857	9.17	1.0E+00	0.84805	0.00126	0.85056
5cvcrpuofct11_23_15	23,000	17,722		6,015	9.80	1.0E+00	0.85040	0.00128	0.85295
5cvcrpuofct11_22_15	22,000	16,952		6,173	10.49	1.0E+00	0.85175	0.00121	0.85417
5cvcrpuofct11_21_15	21,000	16,181		6,332	11.25	1.0E+00	0.85382	0.00131	0.85644
5cvcrpuofct11_20_15	20,000	15,411		6,490	12.08	1.0E+00	0.85633	0.00119	0.85872
5cvcrpuofct11_19_15	19,000	14,640		6,648	13.00	1.0E+00	0.85906	0.00171	0.86249
5cvcrpuofct11_18_15	18,000	13,870		6,806	14.02	1.0E+00	0.86443	0.00141	0.86725
5cvcrpuofct11_17_15	17,000	13,099		6,964	15.16	1.0E+00	0.86435	0.00148	0.86731
5cvcrpuofct11_16_15	16,000	12,329		7,123	16.44	1.0E+00	0.86719	0.00135	0.86988
5cvcrpuofct11_15_15	15,000	11,558		7,281	17.89	1.0E+00	0.87051	0.00155	0.87361
5cvcrpuofct11_14_15	14,000	10,787		7,439	19.55	1.0E+00	0.87447	0.00125	0.87698
5cvcrpuofct11_13_15	13,000	10,017		7,597	21.47	1.0E+00	0.87165	0.00112	0.87388
5cvcrpuofct11_12_15	12,000	9,246		7,756	23.71	1.0E+00	0.87889	0.00139	0.88167
5cvcrpuofct11_11_15	11,000	8,476		7,914	26.35	1.0E+00	0.87819	0.00144	0.88107
5cvcrpuofct11_10_15	10,000	7,705		8,072	29.52	1.0E+00	0.88027	0.00153	0.88333
5cvcrpuofct11_9_15	9,000	6,935		8,230	33.39	1.0E+00	0.88126	0.00141	0.88409
5cvcrpuofct11_8_15	**8,000**	**6,164**		**8,389**	**38.24**	**1.0E+00**	**0.88397**	**0.00130**	**0.88656**
5cvcrpuofct11_7_15	7,000	5,394		8,547	44.47	1.0E+00	0.87931	0.00143	0.88216
5cvcrpuofct11_6_15	6,000	4,623		8,705	52.77	1.0E+00	0.87723	0.00133	0.87990
5cvcrpuofct11_5_15	5,000	3,852		8,863	64.40	1.0E+00	0.87189	0.00128	0.87446
5cvcrpuofct11_4_15	4,000	3,082		9,022	81.83	1.0E+00	0.86035	0.00130	0.86296
5cvcrpuofct11_3_15	3,000	2,311		9,180	110.90	1.0E+00	0.84392	0.00129	0.84650

Table 6.9.8.8-5b. Results for uranyl fluoride (UO_2F_2) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models

case name	UO_2F_2 or $UO_2F_2 \cdot 2H_2O$ (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
5cvcrpuofct11_2_15	2,000	1,541		9,338	169.02	1.0E+00	0.80710	0.00149	0.81008
5cvcrpuofct11_1_15	1,000	771		9,496	343.36	1.0E+00	0.70780	0.00112	0.71005
$UO_2F_2 \cdot 2H_2O$ content and 500-g polyethylene, flooded containment vessel, reflected									
5cvcrpuofhct11_24_15	24,000	16,540	2,534	4,578	12.24	1.0E+00	0.89612	0.00117	0.89845
5cvcrpuofhct11_23_15	23,000	15,851	2,429	4,789	12.94	1.0E+00	0.89625	0.00162	0.89949
5cvcrpuofhct11_22_15	22,000	15,161	2,323	5,000	13.71	1.0E+00	0.89566	0.00151	0.89867
5cvcrpuofhct11_21_15	21,000	14,472	2,217	5,212	14.56	1.0E+00	0.90107	0.00128	0.90363
5cvcrpuofhct11_20_15	20,000	13,783	2,112	5,424	15.49	1.0E+00	0.89826	0.00199	0.90224
5cvcrpuofhct11_19_15	19,000	13,094	2,006	5,635	16.51	1.0E+00	0.89957	0.00136	0.90230
5cvcrpuofhct11_18_15	18,000	12,405	1,901	5,847	17.65	1.0E+00	0.89897	0.00131	0.90160
5cvcrpuofhct11_17_15	17,000	11,716	1,795	6,058	18.93	1.0E+00	0.89947	0.00145	0.90236
5cvcrpuofhct11_16_15	16,000	11,026	1,689	6,270	20.36	1.0E+00	0.89980	0.00123	0.90226
5cvcrpuofhct11_15_15	15,000	10,337	1,584	6,481	21.99	1.0E+00	0.90038	0.00137	0.90312
5cvcrpuofhct11_14_15	**14,000**	**9,648**	**1,478**	**6,693**	**23.84**	**1.0E+00**	**0.90268**	**0.00196**	**0.90661**
5cvcrpuofhct11_13_15	13,000	8,959	1,373	6,904	25.99	1.0E+00	0.90135	0.00156	0.90446
5cvcrpuofhct11_12_15	12,000	8,270	1,267	7,116	28.49	1.0E+00	0.90033	0.00137	0.90306
5cvcrpuofhct11_11_15	11,000	7,580	1,161	7,328	31.44	1.0E+00	0.90064	0.00155	0.90373
5cvcrpuofhct11_10_15	10,000	6,891	1,056	7,539	34.99	1.0E+00	0.90163	0.00127	0.90418
5cvcrpuofhct11_9_15	9,000	6,202	950	7,751	39.32	1.0E+00	0.90041	0.00143	0.90327
5cvcrpuofhct11_8_15	8,000	5,513	844	7,962	44.73	1.0E+00	0.89433	0.00159	0.89751
5cvcrpuofhct11_7_15	7,000	4,824	739	8,174	51.70	1.0E+00	0.89222	0.00163	0.89547
5cvcrpuofhct11_6_15	6,000	4,135	633	8,385	60.98	1.0E+00	0.88507	0.00142	0.88791
5cvcrpuofhct11_5_15	5,000	3,445	528	8,597	73.98	1.0E+00	0.87613	0.00179	0.87972
5cvcrpuofhct11_4_15	4,000	2,756	422	8,808	93.48	1.0E+00	0.86244	0.00121	0.86486

Table 6.9.8.8-5b. Results for uranyl fluoride (UO_2F_2) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models

case name	UO_2F_2 or $UO_2F_2 \cdot 2H_2O$ (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
5cvcrpuofhct11_3_15	3,000	2,067	316	9,020	125.98	1.0E+00	0.84181	0.00137	0.84456
5cvcrpuofhct11_2_15	2,000	1,378	211	9,231	190.97	1.0E+00	0.79635	0.00128	0.79892
5cvcrpuofhct11_1_15	1,000	689	105	9,443	385.88	1.0E+00	0.69241	0.00157	0.69554
$UO_2F_2 \cdot 2H_2O$ content and 500-g polyethylene, flooded containment vessel, package reflected									
						moifr			
5ncsrpuofhct11_24_1	24,000	16,540	2,534	0	5.01	1.0E-20	0.49256	0.00113	0.49483
5ncsrpuofhct11_24_2	24,000	16,540	2,534	0	5.01	1.0E-05	0.49385	0.00104	0.49593
5ncsrpuofhct11_24_3	24,000	16,540	2,534	0	5.01	1.0E-04	0.49252	0.00089	0.49430
5ncsrpuofhct11_24_4	24,000	16,540	2,534	5	5.02	1.0E-03	0.49420	0.00095	0.49609
5ncsrpuofhct11_24_5	24,000	16,540	2,534	46	5.09	1.0E-02	0.49714	0.00115	0.49945
5ncsrpuofhct11_24_6	24,000	16,540	2,534	458	5.74	1.0E-01	0.52171	0.00098	0.52366
5ncsrpuofhct11_24_8	24,000	16,540	2,534	1,373	7.18	3.0E-01	0.58684	0.00114	0.58913
5ncsrpuofhct11_24_15	24,000	16,540	2,534	4,578	12.24	1.0E+00	0.78391	0.00172	0.78736
5ncsrpuofhct11_23_15	23,000	15,851	2,429	4,789	12.94	1.0E+00	0.78964	0.00172	0.79308
5ncsrpuofhct11_22_15	22,000	15,161	2,323	5,000	13.71	1.0E+00	0.78880	0.00124	0.79129
5ncsrpuofhct11_21_15	21,000	14,472	2,217	5,212	14.56	1.0E+00	0.78867	0.00131	0.79129
5ncsrpuofhct11_20_15	20,000	13,783	2,112	5,424	15.49	1.0E+00	0.78987	0.00144	0.79274
5ncsrpuofhct11_19_15	19,000	13,094	2,006	5,635	16.51	1.0E+00	0.78903	0.00171	0.79245
5ncsrpuofhct11_18_15	18,000	12,405	1,901	5,847	17.65	1.0E+00	0.79165	0.00153	0.79471
5ncsrpuofhct11_17_15	17,000	11,716	1,795	6,058	18.93	1.0E+00	0.79090	0.00142	0.79373
5ncsrpuofhct11_16_15	16,000	11,026	1,689	6,270	20.36	1.0E+00	0.79393	0.00145	0.79682
5ncsrpuofhct11_15_15	15,000	10,337	1,584	6,481	21.99	1.0E+00	0.79337	0.00139	0.79615
5ncsrpuofhct11_14_15	14,000	9,648	1,478	6,693	23.84	1.0E+00	0.79414	0.00172	0.79759
5ncsrpuofhct11_13_15	13,000	8,959	1,373	6,904	25.99	1.0E+00	0.79139	0.00126	0.79390

Table 6.9.8.8-5b. Results for uranyl fluoride (UO_2F_2) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models

case name	UO_2F_2 or $UO_2F_2 \cdot 2H_2O$ (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
5ncsrpuofhct11_12_15	12,000	8,270	1,267	7,116	28.49	1.0E+00	0.79345	0.00138	0.79622
5ncsrpuofhct11_11_15	11,000	7,580	1,161	7,328	31.44	1.0E+00	0.79315	0.00194	0.79702
5ncsrpuofhct11_10_15	10,000	6,891	1,056	7,539	34.99	1.0E+00	0.79148	0.00161	0.79470
5ncsrpuofhct11_9_15	9,000	6,202	950	7,751	39.32	1.0E+00	0.79130	0.00138	0.79407
5ncsrpuofhct11_8_15	8,000	5,513	844	7,962	44.73	1.0E+00	0.78925	0.00147	0.79219
5ncsrpuofhct11_7_15	7,000	4,824	739	8,174	51.70	1.0E+00	0.78731	0.00167	0.79066
5ncsrpuofhct11_6_15	6,000	4,135	633	8,385	60.98	1.0E+00	0.78183	0.00158	0.78500
5ncsrpuofhct11_5_15	5,000	3,445	528	8,597	73.98	1.0E+00	0.77586	0.00153	0.77893
5ncsrpuofhct11_4_15	4,000	2,756	422	8,808	93.48	1.0E+00	0.76058	0.00162	0.76382
5ncsrpuofhct11_3_15	3,000	2,067	316	9,020	125.98	1.0E+00	0.74131	0.00163	0.74457
5ncsrpuofhct11_2_15	2,000	1,378	211	9,231	190.97	1.0E+00	0.70445	0.00111	0.70667
5ncsrpuofhct11_1_15	1,000	689	105	9,443	385.88	1.0E+00	0.61078	0.00155	0.61388
$UO_2F_2 \cdot 2H_2O$ content, 500-g polyethylene, flooded containment vessel, infinite array of packages									
5nciapuofhct11_24_1	24,000	16,540	2,534	4578	12.24	1.0E-20	1.01183	0.00147	1.01477
5nciapuofhct11_24_2	24,000	16,540	2,534	4578	12.24	1.0E-05	1.01204	0.00140	1.01484
5nciapuofhct11_24_3	24,000	16,540	2,534	4578	12.24	1.0E-04	1.01068	0.00131	1.01331
5nciapuofhct11_24_4	24,000	16,540	2,534	4578	12.24	1.0E-03	1.01093	0.00141	1.01376
5nciapuofhct11_24_5	24,000	16,540	2,534	4578	12.24	1.0E-02	0.98858	0.00125	0.99109
5nciapuofhct11_24_6	24,000	16,540	2,534	4578	12.24	1.0E-01	0.86983	0.00146	0.87275
5nciapuofhct11_24_8	24,000	16,540	2,534	4578	12.24	3.0E-01	0.80292	0.00136	0.80563
5nciapuofhct11_24_15	24,000	16,540	2,534	4578	12.24	1.0E+00	0.80947	0.00166	0.81279
5nciapuofhct11_5_3	5,000	3,445	528	8597	73.98	1.0E-04	0.94605	0.00142	0.94889
5nciapuofhct11_4_3	4,000	2,756	422	8808	93.48	1.0E-04	0.92472	0.00122	0.92717

Table 6.9.8.8-5b. Results for uranyl fluoride (UO_2F_2) and dihydrate ($UO_2F_2 \cdot 2H_2O$) in the CV or ES-3100 packaging calculation models

case name	UO_2F_2 or $UO_2F_2 \cdot 2H_2O$ (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
5nciapuofhct11_3_3	**3,000**	**2,067**	**316**	**9020**	**125.98**	**1.0E-04**	**0.89532**	**0.00125**	**0.89782**
5nciapuofhct11_2_3	2,000	1,378	211	9231	190.97	1.0E-04	0.84144	0.00123	0.84391
5nciapuofhct11_1_3	1,000	689	105	9443	385.88	1.0E-04	0.71661	0.00117	0.71896

Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models

case name	UC_x (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UC content and 500 g polyethylene, flooded containment vessel, reflected									
						mocfr			
5cvcrpuct11_1_10	10,000	9,514	4,259	4,663	26.24	1.0E+00	0.91168	0.00161	0.91491
5cvcrpuct11_1_9	9,000	8,563	3,833	5,163	29.38	1.0E+00	0.90134	0.00158	0.90450
5cvcrpuct11_1_8	8,000	7,612	3,407	5,662	33.30	1.0E+00	0.89789	0.00126	0.90041
5cvcrpuct11_1_7	7,000	6,660	2,981	6,161	38.34	1.0E+00	0.88176	0.00129	0.88435
5cvcrpuct11_1_6	6,000	5,709	2,555	6,660	45.07	1.0E+00	0.86805	0.00174	0.87154
5cvcrpuct11_1_5	5,000	4,757	2,129	7,159	54.49	1.0E+00	0.84990	0.00147	0.85284
5cvcrpuct11_1_4	4,000	3,806	1,704	7,658	68.61	1.0E+00	0.82598	0.00192	0.82982
5cvcrpuct11_1_3	3,000	2,854	1,278	8,157	92.15	1.0E+00	0.78650	0.00210	0.79070
5cvcrpuct11_1_2	2,000	1,903	852	8,656	139.22	1.0E+00	0.73220	0.00137	0.73494
5cvcrpuct11_1_1	1,000	952	426	9,155	280.42	1.0E+00	0.64502	0.00133	0.64769
U_2C_3 content and 500 g polyethylene, flooded containment vessel, reflected									
5cvcrpuct11_2_10	10,000	9,289	4,205	4,663	26.73	1.0E+00	0.90748	0.00130	0.91008
5cvcrpuct11_2_9	9,000	8,360	3,784	5,163	29.94	1.0E+00	0.89950	0.00134	0.90218
5cvcrpuct11_2_8	8,000	7,431	3,364	5,662	33.96	1.0E+00	0.89139	0.00134	0.89408
5cvcrpuct11_2_7	7,000	6,502	2,944	6,161	39.12	1.0E+00	0.87929	0.00146	0.88220
5cvcrpuct11_2_6	6,000	5,573	2,523	6,660	46.02	1.0E+00	0.86494	0.00134	0.86763
5cvcrpuct11_2_5	5,000	4,644	2,102	7,159	55.66	1.0E+00	0.84909	0.00165	0.85239
5cvcrpuct11_2_4	4,000	3,716	1,682	7,658	70.12	1.0E+00	0.81915	0.00155	0.82225
5cvcrpuct11_2_3	3,000	2,787	1,262	8,157	94.24	1.0E+00	0.78499	0.00137	0.78773
5cvcrpuct11_2_2	2,000	1,858	841	8,656	142.46	1.0E+00	0.72911	0.00158	0.73227
5cvcrpuct11_2_1	1,000	929	421	9,155	287.08	1.0E+00	0.64063	0.00142	0.64347

Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models

case name	UC_x (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UC_2 content and 500 g polyethylene, flooded containment vessel, reflected									
5cvcrpuct11_3_10	10,000	9,074	4,108	4,663	27.08	1.0E+00	0.89850	0.00141	0.90132
5cvcrpuct11_3_9	9,000	8,166	3,697	5,163	30.37	1.0E+00	0.88960	0.00148	0.89255
5cvcrpuct11_3_8	8,000	7,259	3,286	5,662	34.48	1.0E+00	0.88297	0.00163	0.88623
5cvcrpuct11_3_7	7,000	6,352	2,875	6,161	39.77	1.0E+00	0.87224	0.00126	0.87476
5cvcrpuct11_3_6	6,000	5,444	2,465	6,660	46.83	1.0E+00	0.85667	0.00180	0.86028
5cvcrpuct11_3_5	5,000	4,537	2,054	7,159	56.70	1.0E+00	0.83768	0.00164	0.84095
5cvcrpuct11_3_4	4,000	3,630	1,643	7,658	71.51	1.0E+00	0.81450	0.00137	0.81724
5cvcrpuct11_3_3	3,000	2,722	1,232	8,157	96.19	1.0E+00	0.77746	0.00141	0.78028
5cvcrpuct11_3_2	2,000	1,815	822	8,656	145.55	1.0E+00	0.72120	0.00129	0.72377
5cvcrpuct11_3_1	1,000	908	411	9,155	293.60	1.0E+00	0.63468	0.00121	0.63711
UC content with 500 g polyethylene, flooded containment vessel, flooded package, reflected									
						mocfr			
5ncsrpuct11_1_10_15	10,000	9,514	4,259	4,663	26.24	1.0E+00	0.81163	0.00116	0.81395
5ncsrpuct11_1_9_15	9,000	8,563	3,833	5,163	29.38	1.0E+00	0.80769	0.00145	0.81060
5ncsrpuct11_1_8_15	8,000	7,612	3,407	5,662	33.30	1.0E+00	0.79915	0.00170	0.80254
5ncsrpuct11_1_7_15	7,000	6,660	2,981	6,161	38.34	1.0E+00	0.78922	0.00142	0.79207
5ncsrpuct11_1_6_15	6,000	5,709	2,555	6,660	45.07	1.0E+00	0.77601	0.00157	0.77915
5ncsrpuct11_1_5_15	5,000	4,757	2,129	7,159	54.49	1.0E+00	0.75825	0.00153	0.76130
5ncsrpuct11_1_4_15	4,000	3,806	1,704	7,658	68.61	1.0E+00	0.73808	0.00130	0.74068
5ncsrpuct11_1_3_15	3,000	2,854	1,278	8,157	92.15	1.0E+00	0.70280	0.00142	0.70564

Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models

case name	UC_x (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
						moifr			
5ncsrpuct11_1_2_15	2,000	1,903	852	8,656	139.22	1.0E+00	0.65451	0.00136	0.65724
5ncsrpuct11_1_2_8	2,000	1,903	852	2,597	56.11	3.0E-01	0.62741	0.00153	0.63046
5ncsrpuct11_1_2_6	2,000	1,903	852	866	32.37	1.0E-01	0.61746	0.00123	0.61991
5ncsrpuct11_1_2_5	2,000	1,903	852	87	21.68	1.0E-02	0.61244	0.00119	0.61482
5ncsrpuct11_1_2_4	2,000	1,903	852	9	20.61	1.0E-03	0.61168	0.00122	0.61413
5ncsrpuct11_1_2_3	2,000	1,903	852	1	20.51	1.0E-04	0.61271	0.00127	0.61524
5ncsrpuct11_1_2_2	2,000	1,903	852	0	20.50	1.0E-05	0.61238	0.00127	0.61493
5ncsrpuct11_1_2_1	2,000	1,903	852	0	20.50	1.0E-20	0.61350	0.00158	0.61667
5ncsrpuct11_1_1_15	1,000	952	426	9,155	280.42	1.0E+00	0.57240	0.00136	0.57511
U_2C_3 content with 500 g polyethylene, flooded containment vessel, flooded package, reflected									
						moifr			
5ncsrpuct11_2_10_15	10,000	9,289	4,205	4,663	26.73	1.0E+00	0.80860	0.00134	0.81128
5ncsrpuct11_2_9_15	9,000	8,360	3,785	5,163	29.94	1.0E+00	0.80156	0.00146	0.80447
5ncsrpuct11_2_8_15	8,000	7,431	3,364	5,662	33.96	1.0E+00	0.79658	0.00136	0.79931
5ncsrpuct11_2_7_15	7,000	6,502	2,944	6,161	39.12	1.0E+00	0.78449	0.00152	0.78753
5ncsrpuct11_2_6_15	6,000	5,573	2,523	6,660	46.02	1.0E+00	0.77423	0.00147	0.77717
5ncsrpuct11_2_5_15	5,000	4,644	2,103	7,159	55.66	1.0E+00	0.75640	0.00143	0.75925
5ncsrpuct11_2_4_15	4,000	3,716	1,682	7,658	70.12	1.0E+00	0.73260	0.00131	0.73522
5ncsrpuct11_2_3_15	3,000	2,787	1,262	8,157	94.24	1.0E+00	0.70111	0.00164	0.70438
5ncsrpuct11_2_2_15	2,000	1,858	841	8,656	142.46	1.0E+00	0.65046	0.00117	0.65280
5ncsrpuct11_2_1_15	1,000	929	421	9,155	287.08	1.0E+00	0.57215	0.00122	0.57458

Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models

case name	UC_x (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UC_2 content with 500 g polyethylene, flooded containment vessel, flooded package, reflected									
						moifr			
5ncsrpuct11_3_10_15	10,000	9,074	4,108	4,663	27.08	1.0E+00	0.79965	0.00134	0.80232
5ncsrpuct11_3_9_15	9,000	8,166	3,697	5,163	30.37	1.0E+00	0.79317	0.00125	0.79568
5ncsrpuct11_3_8_15	8,000	7,259	3,286	5,662	34.48	1.0E+00	0.78608	0.00155	0.78918
5ncsrpuct11_3_7_15	7,000	6,352	2,875	6,161	39.77	1.0E+00	0.77715	0.00129	0.77973
5ncsrpuct11_3_6_15	6,000	5,444	2,465	6,660	46.83	1.0E+00	0.76221	0.00128	0.76476
5ncsrpuct11_3_5_15	5,000	4,537	2,054	7,159	56.70	1.0E+00	0.74673	0.00139	0.74950
5ncsrpuct11_3_4_15	4,000	3,630	1,643	7,658	71.51	1.0E+00	0.72415	0.00126	0.72666
5ncsrpuct11_3_3_15	3,000	2,722	1,232	8,157	96.19	1.0E+00	0.69399	0.00134	0.69666
5ncsrpuct11_3_2_15	2,000	1,815	822	8,656	145.55	1.0E+00	0.64590	0.00152	0.64895
5ncsrpuct11_3_1_15	1,000	908	411	9,155	293.60	1.0E+00	0.56666	0.00165	0.56995
UC content, 500 g poly, flooded containment vessel, infinite array of packages									
						moifr			
5nciapuct11_1_9_3	9,000	8,563	3,833	5,163	29.38	1.0E-04	0.90795	0.00136	0.91066
5nciapuct11_1_8_3	8,000	7,612	3,407	5,662	33.30	1.0E-04	0.89136	0.00139	0.89414
5nciapuct11_1_7_3	7,000	6,660	2,981	6,161	38.34	1.0E-04	0.87019	0.00131	0.87281
5nciapuct11_1_6_3	6,000	5,709	2,555	6,660	45.07	1.0E-04	0.84331	0.00140	0.84610
5nciapuct11_1_5_3	5,000	4,757	2,129	7,159	54.49	1.0E-04	0.81542	0.00127	0.81796
5nciapuct11_1_4_3	4,000	3,806	1,704	7,658	68.61	1.0E-04	0.78005	0.00139	0.78283
5nciapuct11_1_3_3	3,000	2,854	1,278	8,157	92.15	1.0E-04	0.73291	0.00130	0.73550

Table 6.9.8.8-6a. Results for uranium carbide compounds in the CV or ES-3100 packaging calculation models

case name	UC_x (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
5nciaputt11_1_2_3	2,000	1,903	852	8,656	139.22	1.0E-04	0.67136	0.00129	0.67394
5nciaputt11_1_1_3	1,000	952	426	9,155	280.42	1.0E-04	0.57485	0.00114	0.57712

case name	UC_x (g)	^{235}U (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UC content, 500 g poly, dispersed in flooded containment vessel, infinite array of packages								
5nciadputt11_1_9_15_3	9,000	8,563	8,995	29.38	1.0E-04	1.02430	0.00136	1.02702
5nciadputt11_1_8_15_3	8,000	7,612	9,069	33.30	1.0E-04	1.01560	0.00151	1.01862
5nciadputt11_1_7_15_3	7,000	6,660	9,142	38.34	1.0E-04	1.00614	0.00147	1.00907
5nciadputt11_1_6_15_3	6,000	5,709	9,215	45.07	1.0E-04	0.99808	0.00135	1.00078
5nciadputt11_1_5_15_3	5,000	4,757	9,288	54.49	1.0E-04	0.98482	0.00115	0.98712
5nciadputt11_1_4_15_3	4,000	3,806	9,362	68.61	1.0E-04	0.96658	0.00121	0.96899
5nciadputt11_1_3_15_3	3,000	2,854	9,435	92.15	1.0E-04	0.94085	0.00131	0.94347
5nciadputt11_1_2_15_3	**2,000**	**1,903**	**9,508**	**139.22**	**1.0E-04**	**0.89104**	**0.00175**	**0.89453**
5nciadputt11_1_1_15_3	1,000	952	9,581	280.42	1.0E-04	0.78231	0.00129	0.78488

Table 6.9.8.8-6b. Results for uranium nitride in the CV or ES-3100 packaging calculation models

case name	UN (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
UN content and 500 g polyethylene, flooded containment vessel, reflected									
						mocfr			
5cvcrpunt11_10	10,000	9,438	4,294	4,663	26.55	1.0E+00	0.90649	0.00145	0.90939
5cvcrpunt11_9	9,000	8,494	3,864	5,163	29.71	1.0E+00	0.90302	0.00131	0.90563
5cvcrpunt11_8	8,000	7,550	3,435	5,662	33.67	1.0E+00	0.89305	0.00115	0.89534
5cvcrpunt11_7	7,000	6,607	3,006	6,161	38.75	1.0E+00	0.88246	0.00212	0.88671
5cvcrpunt11_6	6,000	5,663	2,576	6,660	45.53	1.0E+00	0.86740	0.00137	0.87014
5cvcrpunt11_5	5,000	4,719	2,147	7,159	55.03	1.0E+00	0.84695	0.00158	0.85011
5cvcrpunt11_4	4,000	3,775	1,718	7,658	69.26	1.0E+00	0.82223	0.00148	0.82518
5cvcrpunt11_3	3,000	2,831	1,288	8,157	93.00	1.0E+00	0.78572	0.00124	0.78819
5cvcrpunt11_2	2,000	1,888	859	8,656	140.45	1.0E+00	0.73107	0.00156	0.73418
5cvcrpunt11_1	1,000	944	430	9,155	282.79	1.0E+00	0.64271	0.00170	0.64611
UN content with 500 g polyethylene, flooded containment vessel, flooded package, reflected									
						moifr			
5ncsrpunt11_10_1	10,000	9,438	4,294	0.00	13.65	1.0E-20	0.80847	0.00142	0.81131
5ncsrpunt11_10_2	10,000	9,438	4,294	0.00	13.65	1.0E-05	0.80937	0.00123	0.81184
5ncsrpunt11_10_3	10,000	9,438	4,294	0.50	13.65	1.0E-04	0.80771	0.00139	0.81048
5ncsrpunt11_10_4	10,000	9,438	4,294	4.70	13.67	1.0E-03	0.80868	0.00145	0.81158
5ncsrpunt11_10_5	10,000	9,438	4,294	46.60	13.78	1.0E-02	0.80964	0.00140	0.81243
5ncsrpunt11_10_6	10,000	9,438	4,294	466	14.94	1.0E-01	0.80771	0.00167	0.81105
5ncsrpunt11_10_8	10,000	9,438	4,294	1,399	17.52	3.0E-01	0.81176	0.00165	0.81506
5ncsrpunt11_10_15	10,000	9,438	4,294	4,663	26.55	1.0E+00	0.81120	0.00138	0.81395
5ncsrpunt11_9_15	9,000	8,494	3,864	5,163	29.71	1.0E+00	0.80784	0.00147	0.81079
5ncsrpunt11_8_15	8,000	7,550	3,435	5,662	33.67	1.0E+00	0.79743	0.00124	0.79990

Table 6.9.8.8-6b. Results for uranium nitride in the CV or ES-3100 packaging calculation models

case name	UN (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
5ncsrpunt11_7_15	7,000	6,607	3,006	6,161	38.75	1.0E+00	0.78734	0.00139	0.79012
5ncsrpunt11_6_15	6,000	5,663	2,576	6,660	45.53	1.0E+00	0.77284	0.00207	0.77698
5ncsrpunt11_5_15	5,000	4,719	2,147	7,159	55.03	1.0E+00	0.76092	0.00146	0.76383
5ncsrpunt11_4_15	4,000	3,775	1,718	7,658	69.26	1.0E+00	0.73456	0.00132	0.73719
5ncsrpunt11_3_15	3,000	2,831	1,288	8,157	93.00	1.0E+00	0.70343	0.00120	0.70583
5ncsrpunt11_2_15	2,000	1,888	859	8,656	140.45	1.0E+00	0.65433	0.00136	0.65706
5ncsrpunt11_2_8	2,000	1,888	859	2,597	56.67	3.0E-01	0.62697	0.00121	0.62939
5ncsrpunt11_2_6	2,000	1,888	859	866	32.73	1.0E-01	0.61816	0.00117	0.62050
5ncsrpunt11_2_5	2,000	1,888	859	86.60	21.96	1.0E-02	0.61304	0.00124	0.61553
5ncsrpunt11_2_4	2,000	1,888	859	8.70	20.88	1.0E-03	0.61327	0.00134	0.61594
5ncsrpunt11_2_3	2,000	1,888	859	0.90	20.77	1.0E-04	0.61276	0.00152	0.61581
5ncsrpunt11_2_2	2,000	1,888	859	0.10	20.76	1.0E-05	0.61295	0.00136	0.61568
5ncsrpunt11_2_1	2,000	1,888	859	0.00	20.76	1.0E-20	0.61292	0.00107	0.61505
5ncsrpunt11_1_15	1,000	944	430	9,155	282.79	1.0E+00	0.57154	0.00116	0.57387
UN content, 500 g poly, flooded containment vessel, infinite array of packages									
						moifr			
5nciapunt11_10_3	10,000	9,438	4,294	4,663	26.55	1.0E-04	0.92423	0.00151	0.92725
5nciapunt11_9_3	9,000	8,494	3,864	5,163	29.71	1.0E-04	0.90687	0.00131	0.90950
5nciapunt11_8_3	8,000	7,550	3,435	5,662	33.67	1.0E-04	0.88819	0.00172	0.89163
5nciapunt11_7_3	7,000	6,607	3,006	6,161	38.75	1.0E-04	0.86369	0.00147	0.86662
5nciapunt11_6_3	6,000	5,663	2,576	6,660	45.53	1.0E-04	0.84576	0.00143	0.84862
5nciapunt11_5_3	5,000	4,719	2,147	7,159	55.03	1.0E-04	0.81575	0.00130	0.81835
5nciapunt11_4_3	4,000	3,775	1,718	7,658	69.26	1.0E-04	0.77916	0.00132	0.78181
5nciapunt11_3_3	3,000	2,831	1,288	8,157	93.00	1.0E-04	0.73422	0.00140	0.73702

Table 6.9.8.8-6b. Results for uranium nitride in the CV or ES-3100 packaging calculation models

case name	UN (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr or moifr	k_{eff}	σ	$k_{eff}+2\sigma$
5nciapunt11_2_3	2,000	1,888	859	8,656	140.45	1.0E-04	0.67190	0.00129	0.67448
5nciapunt11_1_3	1,000	944	430	9,155	282.79	1.0E-04	0.57515	0.00132	0.57778
case name	**UN (g)**	**^{235}U (g)**		**CV H_2O (g)**	**h/x**	**moifr**	**k_{eff}**	**σ**	**$k_{eff}+2\sigma$**
UN and 500 g poly dispersed inside flooded containment vessel, infinite array of packages									
						moifr			
5nciadpunt11_10_15_3	10,000	9,438		8,957	26.55	1.0E+00	1.02413	0.00140	1.02692
5nciadpunt11_9_15_3	9,000	8,494		9,027	29.71	1.0E+00	1.01877	0.00156	1.02190
5nciadpunt11_8_15_3	8,000	7,550		9,097	33.67	1.0E+00	1.01312	0.00134	1.01581
5nciadpunt11_7_15_3	7,000	6,607		9,166	38.75	1.0E+00	1.00582	0.00149	1.00879
5nciadpunt11_6_15_3	6,000	5,663		9,236	45.53	1.0E+00	0.99488	0.00139	0.99766
5nciadpunt11_5_15_3	5,000	4,719		9,306	55.03	1.0E+00	0.98037	0.00152	0.98341
5nciadpunt11_4_15_3	4,000	3,775		9,376	69.26	1.0E+00	0.96456	0.00166	0.96787
5nciadpunt11_3_15_3	3,000	2,831		9,445	93.00	1.0E+00	0.93621	0.00125	0.93872
5nciadpunt11_2_15_3	**2,000**	**1,888**		**9,515**	**140.45**	**1.0E+00**	**0.88902**	**0.00129**	**0.89159**
5nciadpunt11_1_15_3	1,000	944		9,585	282.79	1.0E+00	0.77903	0.00149	0.78200

Table 6.9.8.8-7a. Results for uranium silicide in the CV calculation models

case name (5cvcrpdusit11)	U_3Si_2 (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	variable	k_{eff}	σ	$k_{eff}+2\sigma$	case name (5cvcrdpust11)	k_{eff}	σ	$k_{eff}+2\sigma$
13 kg sat. U_3Si_2 and 500 g poly in flooded CV, density from 7 to 2 g/cm^3										**Content dispersed in flooded CV**			
_8_7_13_15	13,000	12,041	856	7,801	20.16	7	0.84659	0.00129	0.84917	_8_7_13_15	0.92539	0.00156	0.92852
_8_6_13_15	13,000	12,041	1,165	7,492	20.16	6	0.85534	0.00136	0.85806	_8_6_13_15	0.92539	0.00156	0.92852
_8_5_13_15	13,000	12,041	1,597	7,059	20.16	5	0.86758	0.00115	0.86987	_8_5_13_15	0.92539	0.00156	0.92852
_8_4_13_15	13,000	12,041	2,246	6,410	20.16	4	0.88301	0.00147	0.88595	_8_4_13_15	0.92539	0.00156	0.92852
_8_3_13_15	13,000	12,041	3,327	5,329	20.16	3	0.89897	0.00133	0.90163	_8_3_13_15	0.92539	0.00156	0.92852
_8_2_13_15	13,000	12,041	5,490	3,166	20.16	2	0.91671	0.00154	0.91978	_8_2_13_15	0.92539	0.00156	0.92852
From 13 to 7 kg sat. U_3Si_2 at 7 g/cm^3 and 500 g poly in flooded CV										**Content dispersed in flooded CV**			
_8_7_13_15	13,000	12,041	856	7,801	20.16	-	0.84659	0.00129	0.84917	_8_7_13_15	0.92539	0.00156	0.92852
	12,000	11,115	790	7,943	22.02					_8_7_12_15	0.92346	0.00136	0.92619
	11,000	10,189	724	8,086	24.22					_8_7_11_15	0.92254	0.00144	0.92542
	10,000	9,262	658	8,228	26.85					_8_7_10_15	0.92257	0.00141	0.92539
	9,000	8,336	592	8,371	30.08					_8_7_9_15	0.91555	0.00187	0.91929
	8,000	7,410	527	8,514	34.11					_8_7_8_15	0.91645	0.00169	0.91984
	7,000	6,484	461	8,656	39.29					_8_7_7_15	0.91284	0.00124	0.91532
13 kg sat. U_3Si_2 at 7 g/cm^3 and 500 g poly in flooded CV, enrichment from 100 to 19.7 wt % ^{235}U										**Content dispersed in flooded CV**			
_8_7_13_15	13,000	12,041	856	7,801	20.16	100	0.84659	0.00129	0.84917	_8_7_13_15	0.92539	0.00156	0.92852
_7_7_13_15	13,000	11,440	856	7,801	21.22	95	0.83163	0.00132	0.83427	_7_7_13_15	0.91534	0.00129	0.91791
_6_7_13_15	13,000	10,838	856	7,801	22.39	90	0.81948	0.00126	0.82200	_6_7_13_15	0.90311	0.00132	0.90574
_5_7_13_15	13,000	9,635	856	7,801	25.19	80	0.79868	0.00135	0.80139	_5_7_13_15	0.88874	0.00134	0.89142
_4_7_13_15	13,000	8,431	856	7,801	28.79	70	0.77451	0.00126	0.77702	_4_7_13_15	0.87598	0.00127	0.87853
_3_7_13_15	13,000	7,227	856	7,801	33.58	60	0.75204	0.00113	0.75431	_3_7_13_15	0.86402	0.00155	0.86712
_2_7_13_15	13,000	4,819	856	7,801	50.36	40	0.69967	0.00122	0.70211	_2_7_13_15	0.82956	0.00140	0.83237
_1_7_13_15	13,000	2,290	856	7,801	106.01	19.7	0.62192	0.00116	0.62424	_1_7_13_15	0.76076	0.00137	0.76349

Table 6.9.8.8-7a. Results for uranium silicide in the CV calculation models

case name (5cvcrpdusit11)	U_3Si_2 (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	variable	k_{eff}	σ	$k_{eff}+2\sigma$	case name (5cvcrdpust11)	k_{eff}	σ	$k_{eff}+2\sigma$
7 kg sat. U_3Si_2 at 7 g/cm^3 and 500 g poly in flooded CV, enrichment from 100 to 19.7 wt % ^{235}U										**Content dispersed in flooded CV**			
	7,000	6,484	461	8,656	39.29	100				_8_7_7_15	0.91284	0.00124	0.91532
	7,000	6,160	461	8,656	41.35	95				_7_7_7_15	0.90261	0.00143	0.90547
	7,000	5,836	461	8,656	43.65	90				_6_7_7_15	0.89613	0.00137	0.89886
	7,000	5,188	461	8,656	49.10	80				_5_7_7_15	0.87984	0.00178	0.88339
	7,000	4,540	461	8,656	56.11	70				_4_7_7_15	0.86767	0.00166	0.87099
	7,000	3,892	461	8,656	65.46	60				_3_7_7_15	0.85292	0.00168	0.85627
	7,000	2,595	461	8,656	98.16	40				_2_7_7_15	0.81300	0.00139	0.81579
	7,000	1,233	461	8,656	206.62	19.7				_1_7_7_15	0.72136	0.00111	0.72358
From 13 to 7 kg sat. U_3Si_2 at 19.7 wt % ^{235}U and 7 g/cm^3, and 500 g poly in flooded CV										**Content dispersed in flooded CV**			
_1_7_13_15	13,000	2,290	856	7,801	106.01	19.7	0.62192	0.00116	0.62424	_1_7_13_15	0.76076	0.00137	0.76349
	12,000	2,113	790	7,943	115.79	19.7				_1_7_12_15	0.75612	0.00133	0.75878
	11,000	1,937	724	8,086	127.35	19.7				_1_7_11_15	0.75182	0.00127	0.75437
	10,000	1,761	658	8,228	141.22	19.7				_1_7_10_15	0.75022	0.00124	0.75270
	9,000	1,585	592	8,371	158.18	19.7				_1_7_9_15	0.74197	0.00116	0.74428
	8,000	1,409	527	8,514	179.38	19.7				_1_7_8_15	0.73321	0.00114	0.73549
	7,000	1,233	461	8,656	206.62	19.7				_1_7_7_15	0.72136	0.00111	0.72358

Table 6.9.8.8-7b. Results for uranium silicide in the ES-3100 packaging calculation models

case name (5ncsrpdusit11)	U_3Si_2 (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	variable	k_{eff}	σ	$k_{eff}+2\sigma$	case name (5ncsrdpust11)	k_{eff}	σ	$k_{eff}+2\sigma$
13 kg sat. U_3Si_2 and 500 g poly, density from 7 to 2 g/cm^3, flooded packaging										**Content dispersed in flooded CV**			
_8_7_13_15	13,000	12,041	856	7,801	20.16	7	0.76684	0.00127	0.76937	_8_7_13_15	0.82110	0.00168	0.82447
_8_6_13_15	13,000	12,041	1,165	7,492	20.16	6	0.77522	0.00120	0.77761	_8_6_13_15	0.82110	0.00168	0.82447
_8_5_13_15	13,000	12,041	1,597	7,059	20.16	5	0.78285	0.00135	0.78556	_8_5_13_15	0.82110	0.00168	0.82447
_8_4_13_15	13,000	12,041	2,246	6,410	20.16	4	0.79399	0.00181	0.79760	_8_4_13_15	0.82110	0.00168	0.82447
_8_3_13_15	13,000	12,041	3,327	5,329	20.16	3	0.80614	0.00139	0.80892	_8_3_13_15	0.82110	0.00168	0.82447
_8_2_13_15	13,000	12,041	5,490	3,166	20.16	2	0.81686	0.00139	0.81964	_8_2_13_15	0.82110	0.00168	0.82447
From 13 to 7 kg sat. U_3Si_2 at 7 g/cm^3 and 500 g poly, flooded packaging										**Content dispersed in flooded CV**			
	13,000	12,041	856	7,801	20.16					_8_7_13_15	0.82110	0.00168	0.82447
	12,000	11,115	790	7,943	22.02					_8_7_12_15	0.81912	0.00152	0.82215
	11,000	10,189	724	8,086	24.22					_8_7_11_15	0.81836	0.00127	0.82089
	10,000	9,262	658	8,228	26.85					_8_7_10_15	0.81763	0.00161	0.82084
	9,000	8,336	592	8,371	30.08					_8_7_9_15	0.81283	0.00174	0.81632
	8,000	7,410	527	8,514	34.11					_8_7_8_15	0.81090	0.00166	0.81422
	7,000	6,484	461	8,656	39.29					_8_7_7_15	0.80563	0.00159	0.80881
13 kg sat. U_3Si_2 at 7 g/cm^3 and 500 g poly, 100% to 19.7 wt % ^{235}U, flooded packaging										**Content dispersed in flooded CV**			
_8_7_13_15	13,000	12,041	856	7,801	20.16	100	0.76684	0.00127	0.76937	_8_7_13_15	0.82110	0.00168	0.82447
_7_7_13_15	13,000	11,440	856	7,801	21.22	95	0.75001	0.00114	0.75229	_7_7_13_15	0.81010	0.00128	0.81266
_6_7_13_15	13,000	10,838	856	7,801	22.39	90	0.73588	0.00131	0.73851	_6_7_13_15	0.79989	0.00136	0.80261
_5_7_13_15	13,000	9,635	856	7,801	25.19	80	0.71293	0.00128	0.71548	_5_7_13_15	0.78850	0.00156	0.79162
_4_7_13_15	13,000	8,431	856	7,801	28.79	70	0.68734	0.00121	0.68976	_4_7_13_15	0.77146	0.00176	0.77498
_3_7_13_15	13,000	7,227	856	7,801	33.58	60	0.66250	0.00104	0.66458	_3_7_13_15	0.75908	0.00138	0.76185
_2_7_13_15	13,000	4,819	856	7,801	50.36	40	0.60190	0.00110	0.60410	_2_7_13_15	0.72556	0.00126	0.72807
_1_7_13_15	13,000	2,290	856	7,801	106.01	19.7	0.51868	0.00099	0.52066	_1_7_13_15	0.65956	0.00122	0.66199

Table 6.9.8.8-7b. Results for uranium silicide in the ES-3100 packaging calculation models

case name (5ncsrpdusit11)	U_3Si_2 (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	variable	k_{eff}	σ	$k_{eff}+2\sigma$	case name (5ncsrdpust11)	k_{eff}	σ	$k_{eff}+2\sigma$
7 kg sat. U_3Si_2 at 7 g/cm^3 and 500 g poly, 100 to 19.7 wt % ^{235}U, flooded packaging										**Content dispersed in flooded CV**			
	7,000	6,484	461	8,656	39.29	100				_8_7_7_15	0.80563	0.00159	0.80881
	7,000	6,160	461	8,656	41.35	95				_7_7_7_15	0.79796	0.00165	0.80127
	7,000	5,836	461	8,656	43.65	90				_6_7_7_15	0.79084	0.00143	0.79371
	7,000	5,188	461	8,656	49.10	80				_5_7_7_15	0.77879	0.00148	0.78175
	7,000	4,540	461	8,656	56.11	70				_4_7_7_15	0.76685	0.00132	0.76949
	7,000	3,892	461	8,656	65.46	60				_3_7_7_15	0.74828	0.00130	0.75087
	7,000	2,595	461	8,656	98.16	40				_2_7_7_15	0.71419	0.00146	0.71711
	7,000	1,233	461	8,656	206.62	19.7				_1_7_7_15	0.63031	0.00137	0.63304
From 13 to 7 kg sat. U_3Si_2 at 19.7 wt % ^{235}U and 7 g/cm^3, and 500 g poly, flooded packaging										**Content dispersed in flooded CV**			
	13,000	2,290	856	7,801	106.01	19.7				_1_7_13_15	0.65956	0.00122	0.66199
	12,000	2,113	790	7,943	115.79	19.7				_1_7_12_15	0.65808	0.00126	0.66061
	11,000	1,937	724	8,086	127.35	19.7				_1_7_11_15	0.65479	0.00129	0.65737
	10,000	1,761	658	8,228	141.22	19.7				_1_7_10_15	0.65377	0.00130	0.65636
	9,000	1,585	592	8,371	158.18	19.7				_1_7_9_15	0.64727	0.00141	0.65010
	8,000	1,409	527	8,514	179.38	19.7				_1_7_8_15	0.64207	0.00122	0.64450
	7,000	1,233	461	8,656	206.62	19.7				_1_7_7_15	0.63031	0.00137	0.63304

Table 6.9.8.8-7c. Results for uranium silicide in infinite array packaging calculation models

case name (5nciapdusit11)	U_3Si_2 (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	variable	k_{eff}	σ	$k_{eff}+2\sigma$	case name (5nciadpust11)	k_{eff}	σ	$k_{eff}+2\sigma$
13 kg sat. U_3Si_2 and 500 g poly, density from 7 to 2 g/cm^3, flooded CV, dry packaging										**Content dispersed in flooded CV**			
_8_7_13_3	13,000	12,041	856	7,801	20.16	7	0.82896	0.00118	0.83132	_8_7_13_3	1.03457	0.00130	1.03718
_8_6_13_3	13,000	12,041	1,165	7,492	20.16	6	0.84437	0.00109	0.84654	_8_6_13_3	1.03457	0.00130	1.03718
_8_5_13_3	13,000	12,041	1,597	7,059	20.16	5	0.86019	0.00124	0.86266	_8_5_13_3	1.03457	0.00130	1.03718
_8_4_13_3	13,000	12,041	2,246	6,410	20.16	4	0.88450	0.00126	0.88701	_8_4_13_3	1.03457	0.00130	1.03718
_8_3_13_3	13,000	12,041	3,327	5,329	20.16	3	0.91535	0.00125	0.91785	_8_3_13_3	1.03457	0.00130	1.03718
_8_2_13_3	13,000	12,041	5,490	3,166	20.16	2	0.96155	0.00120	0.96394	_8_2_13_3	1.03457	0.00130	1.03718
From 13 to 7 kg sat. U_3Si_2 at 2 g/cm^3 and 500 g poly, flooded CV, dry packaging										**Content dispersed in flooded CV**			
_8_2_13_3	13,000	12,041	5,490	3,166	20.16		0.96155	0.00120	0.96394	_8_7_13_3	1.03457	0.00130	1.03718
_8_2_12_3	12,000	11,115	5,068	3,665	22.02		0.94644	0.00133	0.94911	_8_7_12_3	1.03086	0.00130	1.03347
_8_2_11_3	11,000	10,189	4,646	4,164	24.22		0.93327	0.00127	0.93582	_8_7_11_3	1.03002	0.00144	1.03290
_8_2_10_3	10,000	9,262	4,223	4,663	26.85		0.91583	0.00134	0.91851	_8_7_10_3	1.02139	0.00141	1.02422
_8_2_9_3	9,000	8,336	3,801	5,163	30.08		0.90106	0.00154	0.90414	_8_7_9_3	1.01603	0.00133	1.01869
_8_2_8_3	8,000	7,410	3,379	5,662	34.11		0.87888	0.00127	0.88142	_8_7_8_3	1.00932	0.00134	1.01201
_8_2_7_3	7,000	6,484	2,956	6,161	39.29		0.86058	0.00128	0.86314	_8_7_7_3	1.00313	0.00155	1.00622
13 kg sat. U_3Si_2 at 7 g/cm^3 and 500 g poly in flooded CV, enrichment from 100 to 19.7 wt % ^{235}U										**Content dispersed in flooded CV**			
_8_2_13_3	13,000	12,041	5,490	3,166	20.16	100	0.96155	0.00120	0.96394	_8_7_13_3	1.03457	0.00130	1.03718
_7_2_13_3	13,000	11,440	5,490	3,166	21.22	95	0.94505	0.00185	0.94876	_7_7_13_3	1.01921	0.00142	1.02206
_6_2_13_3	13,000	10,838	5,490	3,166	22.39	90	0.93320	0.00114	0.93548	_6_7_13_3	1.00777	0.00148	1.01073
_5_2_13_3	13,000	9,635	5,490	3,166	25.19	80	0.91090	0.00142	0.91374	_5_7_13_3	0.98358	0.00113	0.98585
_4_2_13_3	13,000	8,431	5,490	3,166	28.79	70	0.89033	0.00116	0.89266	_4_7_13_3	0.96399	0.00144	0.96687
_3_2_13_3	13,000	7,227	5,490	3,166	33.58	60	0.86922	0.00140	0.87203	_3_7_13_3	0.94189	0.00119	0.94427
_2_2_13_3	13,000	4,819	5,490	3,166	50.36	40	0.81852	0.00119	0.82089	_2_7_13_3	0.88761	0.00140	0.89041
_1_2_13_3	13,000	2,290	5,490	3,166	106.01	19.7	0.73631	0.00133	0.73897	_1_7_13_3	0.79676	0.00126	0.79927

Table 6.9.8.8-7c. Results for uranium silicide in infinite array packaging calculation models

case name (5nciapdusit11)	U_3Si_2 (g)	^{235}U (g)	Sat. H_2O (g)	CV H_2O (g)	h/x	variable	k_{eff}	σ	$k_{eff}+2\sigma$	case name (5nciadpust11)	k_{eff}	σ	$k_{eff}+2\sigma$
Sat. U_3Si_2 at 2 g/cm^3 and 500 g poly in flooded CV, enrichment from 60 to 19.7 wt % ^{235}U										Content dispersed in flooded CV			
_3_2_7_3	**7,000**	**3,892**	**2,956**	**6,161**	**65.46**	**60**	**0.77671**	**0.00138**	**0.77946**	**_3_7_7_3**	**0.91662**	**0.00139**	**0.91940**
_2_2_12_3	12,000	4,448	5,068	3,665	55.01	40	0.80799	0.00121	0.81040	_2_7_12_3	0.88898	0.00169	0.89237
_2_2_13_3	13,000	4,819	5,490	3,166	50.36	40	0.81852	0.00119	0.82089	_2_7_13_3	0.88761	0.00140	0.89041
_2_2_11_3	11,000	4,078	4,646	4,164	60.50	40	0.79496	0.00136	0.79768	_2_7_11_3	0.88471	0.00127	0.88725
2_2_10_3	10,000	3,707	4,223	4,663	67.09	40	0.77941	0.00193	0.78326	_2_7_10_3	0.88229	0.00129	0.88488
_2_2_9_3	9,000	3,336	3,801	5,163	75.15	40	0.76650	0.00132	0.76914	_2_7_9_3	0.87546	0.00124	0.87793
_2_2_8_3	8,000	2,966	3,379	5,662	85.22	40	0.75084	0.00119	0.75323	_2_7_8_3	0.87016	0.00146	0.87307
_2_2_7_3	7,000	2,595	2,956	6,161	98.16	40	0.73288	0.00134	0.73556	_2_7_7_3	0.86217	0.00131	0.86480
_1_2_13_3	13,000	2,290	5,490	3,166	106.01	19.7	0.73631	0.00133	0.73897	_1_7_13_3	0.79676	0.00126	0.79927
_1_2_12_3	12,000	2,113	5,068	3,665	115.79	19.7	0.72483	0.00112	0.72707	_1_7_12_3	0.79291	0.00125	0.79541
_1_2_11_3	11,000	1,937	4,646	4,164	127.35	19.7	0.71315	0.00131	0.71577	_1_7_11_3	0.78832	0.00135	0.79102
_1_2_10_3	10,000	1,761	4,223	4,663	141.22	19.7	0.69947	0.00113	0.70172	_1_7_10_3	0.78068	0.00149	0.78365
_1_2_9_3	9,000	1,585	3,801	5,163	158.18	19.7	0.68896	0.00163	0.69221	_1_7_9_3	0.77294	0.00120	0.77535
_1_2_8_3	8,000	1,409	3,379	5,662	179.38	19.7	0.67532	0.00117	0.67767	_1_7_8_3	0.76297	0.00117	0.76531
_1_2_7_3	7,000	1,233	2,956	6,161	206.62	19.7	0.65751	0.00119	0.65988	_1_7_7_3	0.75056	0.00113	0.75282

Appendix 6.9.9

Criticality Evaluation for Increasing the Fissile Loading Limit for HEU Oxide

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Appendix 6.9.9

Criticality Evaluation for Increasing the Fissile Loading Limit for HEU Oxide

This appendix presents the criticality safety evaluation for increasing the fissile loading limit for highly enriched uranium (HEU) oxide content in the ES-3100 package using SCALE5 as the criticality analysis tool. Calculations presented herein were performed using the Monte Carlo CSAS25 [Criticality Safety Analysis Sequence] code and 238-group ENDFB-V cross section library of SCALE 5.0 (NUREG/CR-0200, rev. 7), executed on identical Hewlett Packard (HP) Model zx6000 Itanium workstations (CMODC and CMODD). Criticality calculations documented in Sects. 6.4 – 6.6 were performed using SCALE 4.4a (NUREG/CR-0200, rev. 6) executed on an HP Model J5600 RISC workstation (CMODB). The obsolete CMODB with HP-UX 10.20 operating system was recently retired from service. No longer supported by the code developer, SCALE 4.4a is not portable to the new computing platforms, thus necessitating the use of SCALE 5.0.

SCALE5 incorporates minor improvements in the code modules for the Bondarenko and the Nordheim Integral Treatment processing of resonance cross sections and the KENO V.a module. Consequently, the upper subcritical limit (USL) used is validation dependent based on the SCALE-platform combination. The criticality evaluation based upon SCALE 5.0 calculations is documented in this appendix separate from the main body of Sect. 6 because this new work could not easily be folded into the existing SCALE 4.4a evaluation without inclusion of a patchwork of clarifications.

6.9.9.1 Description of the Criticality Design

The design features of the ES-3100 package addressed in Sect. 6.1.1 are not changed. The same codes and standards apply. No change is employed in the methodology addressed in Sect. 6.1.2 for demonstrating maximum reactivity. The shipping limit for an ES-3100 package with HEU product oxide content having a bulk density $\geq$2.0 g/cm^3 is increased from 9,682 g ^{235}U to 12,323 g ^{235}U by specifying a CSI = 0.4. The CSI is assigned as described in Sect. 6.1.3. This administrative limit restricts the size of an array of packages, maintaining subcriticality for both the Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

6.9.9.2 HEU Oxide Content for the ES-3100 Package

The criticality safety evaluation documented in this appendix pertains to HEU product oxide as described in Sect. 6.2.1, and Appendices 6.9.1 and 6.9.3. The convenience cans described in Sect. 6.2.2 and the packing materials described in Sect. 6.2.3 are not affected by the new fissile loading limit. The packing content loading restrictions stated in Sect. 6.2.4 are unchanged.

6.9.9.3 General Considerations

General considerations expressed in Sect. 6.3 regarding both assumptions made about the ES-3100 packaging and the calculation methodology for the evaluation are maintained. No changes are required to the calculation models of the containment vessel, the single-unit packaging (Sect. 6.3.1.1), the infinite array and finite array packaging (Sect. 6.3.1.2), the damaged packaging (Sect. 6.3.1.3), or the catastrophically-damaged packaging (Sect. 6.3.1.4). The material properties specification for the HEU product oxide (Sect. 6.3.2) does not change.

6.9.9.4 Computer Codes and Cross-Section Libraries

Calculations presented in this appendix were performed using the Monte Carlo CSAS25 code and 238-group ENDFB-V cross section library of SCALE 5.0 (NUREG/CR-0200, rev. 7), executed on identical

Hewlett Packard (HP) Model zx6000 Itanium workstations (CMODC and CMODD) of the Y-12 Safety Analysis Engineering organization in Oak Ridge, Tennessee. Criticality calculations documented in Sects. 6.4–6.6 were performed using SCALE 4.4a (NUREG/CR-0200, rev. 6) executed on an HP Model J5600 RISC workstation (CMODB). The obsolete CMODB with HP-UX 10.20 operating system was recently retired from service. No longer supported by the code developer, SCALE 4.4a is not portable to the new computing platforms, thus necessitating the use of SCALE 5.0.

The SCALE 4.4a criticality codes and cross-section library are addressed in Sect. 6.3.3. The 238-group ENDF/B-V cross-section library used by SCALE 5.0 is unchanged from the previous version SCALE 4.4a. Also, most of the modular codes in CSAS25 control sequence of SCALE 5.0 are unchanged except for the cross-section processing functional module NITAWL-III.

NITAWL-III applies the Nordheim integral treatment to perform neutron cross-section processing in the resonance energy range for nuclides that have ENDF/B resonance parameter data. This technique involves the numerical integration of ENDF/B resonance parameters using a calculated flux distribution, which is based on the calculated collision density across each resonance and subsequent weighing of the reaction cross section to the desired broad group structure. In the CSAS code, NITAWL-III assembles the group-to-group transfer arrays from the elastic and inelastic scattering components and performs other tasks to produce a problem-dependent working cross-section library which can be used by KENO V.a.

As noted in the user manual, several extensions to the Nordheim calculation have been implemented into the algorithm contained in NITAWL-III:

- Elements containing more than one isotope can be treated.
- Self-shielding is applied to resonance scattering. Transfer matrices are adjusted.
- g-, f-, d-, and p-wave as well as s-wave levels can be treated.
- The asymptotic approximation for the flux in the thermal energy range is assumed to have a Maxwellian energy distribution.
- A refined procedure for generating the energy mesh over which reaction rates are integrated has been developed.

As with the SCALE 4.4a calculations, the k_{eff} values for each KENO V.a case are based on 500,000 neutron histories produced by running for 215 generations with 2,500 neutrons per generation and truncating the first 15 generations of data. The convergence of the KENO V.a calculation is related to trends in the average calculated k_{eff}. In general, the KENO V.a output table of k_{eff} by generation skipped is reviewed for trends. If no trends are observed, the calculation is accepted, and the reported value of k_{eff} is the one with the most neutron histories. There is usually no statistically significant difference between this result and the one with the smallest standard deviation.

No manual cross-section adjustment is performed for the criticality evaluation. Cross-section processing is performed automatically in the CSAS25 code. Modeling the contents as precisely as possible improves the accuracy of cross-section processing.

The CSAS25 control module, the associated functional modules, the cross section library, and databases used in this evaluation reside in the verified configuration control area designated **/vcc/scale5** on CMODC and CMODD. Also, the computer input and output files for the criticality safety evaluation of the ES-3100 shipping package with the additional/new content reside in a configuration control area **/archive/ylf717_Rev3PC1** on CMODC.

6.9.9.5 Single Package Evaluation (NCT and HAC)

The analysis presented in Sect. 6.4 demonstrates that $k_{eff} + 2\sigma$ increases with increasing MOIFR. Therefore, a model of a fully flooded, reflected package is used to calculate neutron multiplication factors for the single package analysis. The reference analysis reveals that a continuous decrease in $k_{eff} + 2\sigma$ occurs with decreasing fissile mass when density is held constant. Also, $k_{eff} + 2\sigma$ increases as the bulk density decreases for a fixed fissile mass, which is due to the increased moderation of the HEU oxide.

Cases **5ncsrpdoxt11_1_*n*_14** (Table 6.9.9.8-2) represents the NCT model of an ES-3100 package with 14 kg of HEU oxide (12,323 g ^{235}U). The parameter "***n***" ranging from 1 to 5, signifies oxide density values of 2.0, 3.0, 4.0, 5.0, and 6.54 g/cm^3, respectively. The $k_{eff} + 2\sigma$ values ranging from 0.810 to 0.752 are well below the USL value of 0.924.

Case **5cvcrpdoxt11_1_1_14_15)** (Table 6.9.9.8-1) models a reflected containment vessel with 14 kg of HEU oxide at 2.0 g/cm^3. The $k_{eff} + 2\sigma$ value is ~0.1 greater in the reflected containment vessel than in the corresponding reflected, flooded single package (Case **5cvcrpdoxt11_1_1_14_15)**. This result is consistent with the reference evaluation of Sect. 6.4.

Cases **5hcsrpdoxt12_1_*n*_14** (Table 6.9.9.8-2) represents the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly and the entire package is flooded except the neutron poison of the body weldment liner inner cavity. The $k_{eff} + 2\sigma$ values range from 0.811 to 0.757. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in a ≤0.004 change in the neutron multiplication factor, also consistent with the reference evaluation of Sect. 6.4.

6.9.9.6 Array Package Evaluation (NCT and HAC)

The infinite array analyses presented in Sects. 6.5 and 6.6 demonstrate that the CSI is 0.0 for ES-3100 packages having product oxide content with a bulk density ≥2.0 g/cm^3 and with a maximum of 9,682 g ^{235}U. Case result presented in Table 6.9.9.8-3 substantiate this conclusion.

The array analyses presented in Sects. 6.5 and 6.6 also demonstrate maximum reactivity occurs in an array of packages when both the containment vessel is flooded (MOCFR = 1.0) and the ES-3100 packaging is dry (MOIFR = 1e-04). A water fraction of MOIFR = 1e-04 pertains specifically to NCT or HAC packages where both the neutron poison of the body weldment liner inner cavity and the Kaolite are dry and both the recesses of the package external to the containment vessel and the interstitial space between drums of the array do no contain any residual moisture. Therefore, the ES-3100 package model consisting of dry packaging and flooded containment vessel is used for the finite array package analysis as required for establishing a non-zero CSI value.

Cases **5ncf1pdoxt11_1_*n*_15_3** through **5ncf1pdoxt11_1_*n*_11_3** (Table 6.9.9.8-4) represent a 13 × 13 × 6 array of NCT packages. The content mass ranges from 15 kg of HEU oxide (13,203 g ^{235}U) to 11 kg of HEU oxide (9,682 g ^{235}U). Case parameter "***n***" ranging from 1 to 5, signifies oxide density values of 2.0, 3.0, 4.0, 5.0, and 6.54 g/cm^3, respectively. Likewise, Cases **5hcf2pdoxt12_1_*n*_15_3** through **5hcf2pdoxt12_1_*n*_11_3** (Table 6.9.9.8-4) represent a 9 × 9 × 4 array of HAC packages. These finite array configurations support the assignment of a CSI = 0.4. (Cases **5ncf1pdoxt11_1_1_15_3** and **5hcf2pdoxt12_1_1_15_3** are not evaluated because the capacity of the convenience cans is exceeded for the 15 kg oxide loading at a density of 2.0 g/cm^3.)

As expected, the neutron multiplication factor for the finite array configurations of ES-3100 packages with HEU product oxide decreases as a function of decreasing ^{235}U mass. Also, calculation results for the parametric cases reveal the same continuous increase in the $k_{eff} + 2\sigma$ values with decreasing bulk density as observed in both the single package calculation results (Sect. 6.4.3) and infinite array

calculation results (Table 6.9.9.8-4). Given that the $k_{eff} + 2\sigma$ values are below the USL of 0.924, ES-3100 packages may be shipped under a CSI = 0.4 for ES-3100 packages having HEU product oxide content with a bulk density ≥2.0 g/cm^3 and with a maximum of 12,323 g ^{235}U.

6.9.9.7 Benchmark experiments and the criticality

The criticality validation for SCALE 5.0 is a repetition of the SCALE 4.4a validation based on benchmark experiments documented in the Organization for Economic Cooperation and Development (OECD) Handbook. [NEA/NSC/DOC(95)03] Validation cases for SCALE 4.4a were executed on an HP Model J5600 RISC workstation under the HP-UX 10.20 operating system. For SCALE 5.0, these same validation cases were executed on an HP Model zx6000 Itanium workstation (CMODC).

The validation of CSAS25 control module of SCALE 5.0 with the 238-group ENDF/B-V cross-section library is documented in Y/DD-1220 and Y/DD-1221. Like Y/DD-896/R1, Y/DD-1220 addresses the establishment of bias, bias trends, and uncertainty associated with the use of SCALE 5.0 for performance of criticality calculations. Like Y/DD-972R1, Y/DD-1221 addresses determining USL and for incorporating uncertainty and margin into this USL.

SCALE 5.0 incorporates minor improvements in the code modules for the Bondarenko and the Nordheim Integral Treatment processing of resonance cross sections and the KENO V.a module. Consequently, the USL used is validation dependent based on the SCALE-platform combination. The evaluation of additional/new contents based upon SCALE 5.0 calculations is documented in this appendix separate from the main body of Sect. 6 because this new work could not easily be folded into the existing SCALE 4.4a evaluation without inclusion of a patchwork of clarifications.

The USL is based on the non-parametric statistics-based lower tolerance limit (LTL) for greater than 0.99/99% where there is a probability of greater than 0.99 that 99% of the population is greater than a specified result, reduced by additional margin. From Table 1 of Y/DD-1221, the LTL combining bias and bias uncertainty is 0.974 for uranium systems, including HEU metal. Tables 4.2, 4.3, and 4.4 of Y/DD-1220 list the maximum (positive) and minimum (negative) biases for HEU (metal, compound, solution), IEU (metal, compound) and LEU (compound, solution) systems. Since the positive bias is conservatively treated as a "zero" bias in the validation analysis, the negative bias is applied to determine the USL for the systems. The minimum bias given for HEU, IEU, and LEU systems is −0.0230, −0.0055 and −0.0260, respectively.

The minimum bias given for HEU systems in Table 4.2 of Y/DD-1220 is -0.1423. However, this result is from one of the four k-infinite models which are somewhat different than the usual benchmark experiments. As discussed in Sect. 5.3 of Y/DD-1220, the four outlier results are for benchmark experiments that were modeled as infinite in extent, thereby amplifying the effects of imperfections in cross section data. The models also required additional interpretation and adjustment from the actual finite experimental configuration to create an infinite benchmark model. After eliminating outlier models from the bias determination, the minimum bias was determined to be -0.023 for HEU systems.

The global minimum bias results for these systems (−0.0260) is applied to all uranium enrichments. Ordinarily, the USL would be 0.954 where an additional margin of subcriticality of 0.02 is subtracted from the LTL of 0.974. However, NUREG/CR-5661 provides guidance that the USL should be established with a minimum margin of subcriticality of 0.05. Thus, the USL is equal to 0.95 plus the minimum bias (−0.026), giving a value of 0.924.

6.9.9.8 Calculation results tables for additional/new contents

Tables 6.9.9.8-1 through 6.9.9.8-4 contain a summary of the calculation results for the additional/new contents to be shipped in the ES-3100 shipping package.

Table 6.9.9.8-1. Results for HEU oxide content in the containment vessel calculation model

Case name 5cvcrpdoxt11	Oxide (g)	^{235}U (g)	Oxide density (g/cm^3)	Oxide volume (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2\sigma$
14,000 g UO_2 content, 500-g polyethylene, flooded containment vessel, reflected											
_1_1_14_15	14000	12323	2.00	7000	5712	2667	19.11	1.0E+00	0.91213	0.00154	0.91521

Table 6.9.9.8-2. Results for HEU oxide content in single-unit packaging calculation model

Case name 5ncsrpdoxt11	Oxide (g)	^{235}U (g)	Oxide density (g/cm^3)	Oxide vol. (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	k_{eff}	σ	$k_{eff}+2\sigma$	Case name 5hcsrpdoxt12	k_{eff}	σ	$k_{eff}+2\sigma$
UO2, content and 500-g polyethylene in flooded containment vessel, flooded package														
NCT											**HAC**			
_1_1_14	14000	12323	2.00	7000	5712	2667	19.11	0.80682	0.00154	0.80990	_1_1_14	0.80844	0.00132	0.81108
_1_2_14	14000	12323	3.00	4667	3383	4996	19.11	0.79264	0.00147	0.79557	_1_2_14	0.79564	0.00161	0.79887
_1_3_14	14000	12323	4.00	3500	2219	6161	19.11	0.78217	0.00138	0.78493	_1_3_14	0.78181	0.00127	0.78436
_1_4_14	14000	12323	5.00	2800	1520	6860	19.11	0.76784	0.00125	0.77035	_1_4_14	0.77058	0.00119	0.77296
_1_5_14	14000	12323	6.54	2141	862	7518	19.11	0.74948	0.00136	0.75219	_1_5_14	0.75379	0.00136	0.75651

Table 6.9.9.8-3. Results for HEU oxide content in array packaging calculation model

Case name 5nciapdoxt11	Oxide (g)	^{235}U (g)	Oxide density (g/cm^3)	Oxide volume (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	k_{eff}	σ	$k_{eff}+2\sigma$	Case name 5hciapdoxt12	k_{eff}	σ	$k_{eff}+2\sigma$
UO_2 content and 500 g polyethylene in flooded containment vessel, infinite array packaging model for CSI=0.0														
				NCT								**HAC**		
_1_2_15_3	15000	13203	3.00	5000	3625	4664	17.66	0.91962	0.00120	0.92202	_1_2_15_3	0.92011	0.00143	0.92298
_1_3_15_3	15000	13203	4.00	3750	2377	5911	17.66	0.88779	0.00122	0.89023	_1_3_15_3	0.88737	0.00177	0.89092
_1_4_15_3	15000	13203	5.00	3000	1628	6660	17.66	0.86134	0.00122	0.86377	_1_4_15_3	0.86151	0.00139	0.86429
_1_5_15_3	15000	13203	6.54	2294	923	7365	17.66	0.83226	0.00105	0.83436	_1_5_15_3	0.83147	0.00128	0.83404
_1_1_14_3	14000	12323	2.00	7000	5712	2667	19.11	0.96251	0.00139	0.96530	_1_1_14_3	0.96173	0.00120	0.96413
_1_2_14_3	14000	12323	3.00	4667	3383	4996	19.11	0.90999	0.00125	0.91250	_1_2_14_3	0.91039	0.00133	0.91306
_1_3_14_3	14000	12323	4.00	3500	2219	6161	19.11	0.87432	0.00136	0.87704	_1_3_14_3	0.87390	0.00123	0.87636
_1_4_14_3	14000	12323	5.00	2800	1520	6860	19.11	0.84766	0.00107	0.84981	_1_4_14_3	0.85075	0.00157	0.85390
_1_5_14_3	14000	12323	6.54	2141	862	7518	19.11	0.82262	0.00114	0.82489	_1_5_14_3	0.81885	0.00117	0.82120
_1_1_13_3	13000	11443	2.00	6500	5304	3166	20.79	0.95083	0.00137	0.95356	_1_1_13_3	0.94754	0.00124	0.95002
_1_2_13_3	13000	11443	3.00	4333	3142	5329	20.79	0.89635	0.00119	0.89874	_1_2_13_3	0.89884	0.00238	0.90360
_1_3_13_3	13000	11443	4.00	3250	2060	6410	20.79	0.86131	0.00115	0.86362	_1_3_13_3	0.86176	0.00134	0.86443
_1_4_13_3	13000	11443	5.00	2600	1411	7059	20.79	0.83841	0.00119	0.84080	_1_4_13_3	0.83735	0.00179	0.84093
_1_5_13_3	13000	11443	6.54	1988	800	7670	20.79	0.80709	0.00129	0.80967	_1_5_13_3	0.81006	0.00147	0.81301
_1_1_12_3	12000	10562	2.00	6000	4896	3665	22.74	0.93557	0.00146	0.93849	_1_1_12_3	0.93442	0.00130	0.93701
_1_2_12_3	12000	10562	3.00	4000	2900	5662	22.74	0.88421	0.00123	0.88667	_1_2_12_3	0.88382	0.00127	0.88637
_1_3_12_3	12000	10562	4.00	3000	1902	6660	22.74	0.84986	0.00136	0.85259	_1_3_12_3	0.84962	0.00123	0.85208
_1_4_12_3	12000	10562	5.00	2400	1303	7259	22.74	0.82606	0.00117	0.82839	_1_4_12_3	0.82224	0.00116	0.82456
_1_5_12_3	12000	10562	6.54	1835	739	7823	22.74	0.79269	0.00117	0.79503	_1_5_12_3	0.79562	0.00120	0.79802
_1_1_11_3	11000	9682	2.00	5500	4488	4164	25.06	0.91920	0.00170	0.92260	_1_1_11_3	0.91961	0.00132	0.92224
_1_2_11_3	11000	9682	3.00	3667	2658	5994	25.06	0.86941	0.00134	0.87208	_1_2_11_3	0.87089	0.00131	0.87352
_1_3_11_3	11000	9682	4.00	2750	1743	6909	25.06	0.83680	0.00152	0.83984	_1_3_11_3	0.83444	0.00132	0.83707
_1_4_11_3	11000	9682	5.00	2200	1194	7458	25.06	0.81122	0.00126	0.81373	_1_4_11_3	0.81127	0.00110	0.81346
_1_5_11_3	11000	9682	6.54	1682	677	7976	25.06	0.78014	0.00137	0.78288	_1_5_11_3	0.78034	0.00131	0.78296

Table 6.9.9.8-4. Results for finite array analysis of HEU oxide content in the array packaging calculation model

Case name 5ncf1pdoxt11	Oxide (g)	^{235}U (g)	Oxide density (g/cm^3)	Oxide volume (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	k_{eff}	σ	$k_{eff}+2\sigma$	Case name 5hcf2pdoxt12	k_{eff}	σ	$k_{eff}+2\sigma$
UO_2 content and 500 g polyethylene in flooded containment vessel, finite array packaging model for CSI=0.4														
				NCT									**HAC**	
_1_2_15_3	15000	13203	3.00	5000	3625	4664	17.66	0.86899	0.00119	0.87137	_1_2_15_3	0.85996	0.00128	0.86251
_1_3_15_3	15000	13203	4.00	3750	2377	5911	17.66	0.83024	0.00127	0.83278	_1_3_15_3	0.82926	0.00123	0.83173
_1_4_15_3	15000	13203	5.00	3000	1628	6660	17.66	0.80781	0.00148	0.81077	_1_4_15_3	0.80377	0.00145	0.80667
_1_5_15_3	15000	13203	6.54	2294	923	7365	17.66	0.78101	0.00137	0.78375	_1_5_15_3	0.77553	0.00145	0.77843
_1_1_14_3	14000	12323	2.00	7000	5712	2667	19.11	0.91235	0.00152	0.91539	_1_1_14_3	0.90222	0.00126	0.90473
_1_2_14_3	14000	12323	3.00	4667	3383	4996	19.11	0.85665	0.00130	0.85925	_1_2_14_3	0.85184	0.00187	0.85558
_1_3_14_3	14000	12323	4.00	3500	2219	6161	19.11	0.81979	0.00150	0.82279	_1_3_14_3	0.81814	0.00164	0.82143
_1_4_14_3	14000	12323	5.00	2800	1520	6860	19.11	0.79749	0.00139	0.80027	_1_4_14_3	0.79489	0.00132	0.79752
_1_5_14_3	14000	12323	6.54	2141	862	7518	19.11	0.76730	0.00112	0.76954	_1_5_14_3	0.76607	0.0012	0.76848
_1_1_13_3	13000	11443	2.00	6500	5304	3166	20.79	0.90096	0.00137	0.90369	_1_1_13_3	0.89146	0.00168	0.89482
_1_2_13_3	13000	11443	3.00	4333	3142	5329	20.79	0.84451	0.00150	0.84750	_1_2_13_3	0.83795	0.00125	0.84046
_1_3_13_3	13000	11443	4.00	3250	2060	6410	20.79	0.80806	0.00175	0.81156	_1_3_13_3	0.80364	0.0014	0.80643
_1_4_13_3	13000	11443	5.00	2600	1411	7059	20.79	0.78428	0.00120	0.78668	_1_4_13_3	0.78119	0.0013	0.78379
_1_5_13_3	13000	11443	6.54	1988	800	7670	20.79	0.75713	0.00132	0.75977	_1_5_13_3	0.75345	0.00134	0.75612
_1_1_12_3	12000	10562	2.00	6000	4896	3665	22.74	0.88673	0.00148	0.88969	_1_1_12_3	0.87895	0.00133	0.8816
_1_2_12_3	12000	10562	3.00	4000	2900	5662	22.74	0.83038	0.00129	0.83296	_1_2_12_3	0.82545	0.00137	0.82819
_1_3_12_3	12000	10562	4.00	3000	1902	6660	22.74	0.79879	0.00148	0.80175	_1_3_12_3	0.79221	0.00133	0.79487
_1_4_12_3	12000	10562	5.00	2400	1303	7259	22.74	0.77086	0.00131	0.77349	_1_4_12_3	0.77013	0.00151	0.77316
_1_5_12_3	12000	10562	6.54	1835	739	7823	22.74	0.74245	0.00181	0.74608	_1_5_12_3	0.74028	0.00127	0.74282
_1_1_11_3	11000	9682	2.00	5500	4488	4164	25.06	0.87072	0.00152	0.87376	_1_1_11_3	0.86583	0.00113	0.86809
_1_2_11_3	11000	9682	3.00	3667	2658	5994	25.06	0.81756	0.00176	0.82108	_1_2_11_3	0.81406	0.00155	0.81715
_1_3_11_3	11000	9682	4.00	2750	1743	6909	25.06	0.78439	0.00122	0.78682	_1_3_11_3	0.77978	0.0015	0.78279

Table 6.9.9.8-4. Results for finite array analysis of HEU oxide content in the array packaging calculation model

Case name 5ncf1pdoxt11	Oxide (g)	^{235}U (g)	Oxide density (g/cm^3)	Oxide volume (cm^3)	Sat. H_2O (g)	CV H_2O (g)	h/x	k_{eff}	σ	$k_{eff}+2\sigma$	Case name 5hcf2pdoxt12	k_{eff}	σ	$k_{eff}+2\sigma$
_1_4_11_3	11000	9682	5.00	2200	1194	7458	25.06	0.75752	0.00159	0.76070	_1_4_11_3	0.75642	0.00115	0.75872
_1_5_11_3	11000	9682	6.54	1682	677	7976	25.06	0.72893	0.00156	0.73205	_1_5_11_3	0.72536	0.00168	0.72871

6.9.9.9 Input Listing for Select SCALE 5.0 Cases

Select input files for calculations identified in Tables 6.9.9.8-1 through 6.9.9.8-4 are presented below.

6.9.9.9.1 Case 5cvcrpdoxt11_1_1_14_15

```
=csas25    parm=size=3000000
5cvcrpdoxt11,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gH2Ocv hx= 19.11 fr=1
238groupndf5 infhommedium
'HEU volume =7000.05000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 14000.1 g, sat.h2o in HEU oxide=5712.4 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.36, CV void volume 2671.83368'
arbmuox    1.85591   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  7.5725e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  6.6282e-02  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.31846e4 cm3 = (8.0457422e2 in3)(16.387064)'
'den.multiplier = 1.31846e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.518047 = (den.mult)(np277-4 min.den.) = 0.9935052*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.26267e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.06375e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
```

```
                              20000   11.8336
                              26000    0.5298   11  1.0000  293  end
arbmnph2o 3.81674e-1  2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                               8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
```

```
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
5cvcrpdoxt11,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gH2Ocv,hx= 19.11 fr=1
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                         end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  58.78051 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
```

```
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.2 Case 5ncsrpdoxt11_1_1_14

```
=csas25    parm=size=3000000
5ncsrpdoxt11,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gH2Ocv hx= 19.11 fr=1
238groupndf5 infhommedium
'HEU volume =7000.05000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 14000.1 g, sat.h2o in HEU oxide=5712.4 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.36, CV void volume 2671.83368'
arbmuox    1.85591   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  7.5725e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  6.6282e-02  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
```

```
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                                8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
arbmh2ok   0.52294  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.34864  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.34864  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.34864  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.34864  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.34864  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.34864  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.34864  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
```

```
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  1       293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
'ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
'ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
'arbmwed    1.16026  2 0 0 0    1001   11.1913
'                              8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   21  1.0     293  end
end comp
5ncsrpdoxt11,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gH2Ocv,hx= 19.11 fr=1
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                       end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   24.587200    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   23.329900    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p24.587200    0.26670   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
```

```
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   23.177500   11.59510   0.0     com='kaolite'
 cylinder  19 1   23.329900   11.59510   0.0     com='drum'
 cuboid    21 1 4p24.587200   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  58.78051 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   23.177500   77.72400   0.0     com='kaolite'
 cylinder  19 1   23.329900   77.72400   0.0     com='drum'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   23.177500    0.22860   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.22860   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.27000   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.27000   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   23.177500    2.92100   0.0     com='kaolite'
 cylinder  19 1   23.329900    2.92100   0.0     com='drum'
 cuboid    21 1 4p24.587200    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
```

```
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   23.177500    1.01600   0.0     com='kaolite'
 cylinder  19 1   23.329900    1.01600   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   23.177500    0.15240   0.0     com='kaolite'
 cylinder  19 1   23.329900    0.15240   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   23.177500    8.17880   0.0     com='kaolite'
 cylinder  19 1   23.329900    8.17880   0.0     com='drum'
 cuboid    21 1 4p24.587200    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   23.177500    4.44500   0.0     com='kaolite'
 cylinder  19 1   23.329900    4.44500   0.0     com='drum'
 cuboid    21 1 4p24.587200    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   23.177500    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   23.329900    0.63500   0.0     com='drum'
 cuboid    21 1 4p24.587200    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   22.961600    1.90500   0.15240 com='void above lid'
 cylinder  19 1   23.114000    1.90500   0.0     com='drum lid'
 cylinder  21 1   23.177500    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   23.329900    1.90500   0.0     com='drum'
 cuboid    21 1 4p24.587200    1.90500   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-24.587200     0.0
'cuboid     0  1 4p24.587200    110.4905  0.0    com='bare package'
 cuboid    21  1 4p55.067200   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
```

```
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.3 Case 5hcsrpdoxt12_1_1_14

```
=csas25    parm=size=3000000
5hcsrpdoxt12,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gH2Ocv hx= 19.11 fr=1
238groupndf5 infhommedium
'HEU volume =7000.05000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 14000.1 g, sat.h2o in HEU oxide=5712.4 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.36, CV void volume 2671.83368'
arbmuox    1.85591   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  7.5725e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  6.6282e-02  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
```

```
                                8016   43.4254
                               11023    0.1174
                               12000    0.3378
                               13027   39.0477
                               14000    2.4671
                               16000    0.3083
                               20000   11.8335
                               26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1       293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                8016   88.8087   13  1       293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                                1001    8.1573
                                8016   21.5782
                               14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
```

```
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  1       293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
'arbmwed    0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   20  1       293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
5hcsrpdoxt12,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gH2Ocv,hx= 19.11 fr=1
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vac                        end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    21 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    21 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  58.78051 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.838092   77.72400   0.0     com='drum'
 cuboid    21 1 4p21.838092   77.72400   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
```

```
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    21 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    21 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
```

```
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    21 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    21 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  21 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  21 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    21 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
'cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.4 Case 5nciapdoxt11_1_1_11_3

```
=csas25    parm=size=3000000
5nciapdoxt11,11000.1gUO2 ( 9682.3g235)4488.3gSH2O 4164.3gHcv hx= 25.06 fr=0.0001
238groupndf5 infhommedium
'HEU volume =5500.05000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 11000.1 g, sat.h2o in HEU oxide=4488.3 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.73, CV void volume 4171.83368'
arbmuox    1.82015   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  7.4266e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  8.2733e-02  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
```

```
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
```

```
arbmcao    0.42622  2 0 0 0   20000   71.4815
                              8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                              8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                              8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                              8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                              8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                              8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                              8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                              8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                              8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                              8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                              8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                         19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                         19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                              8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
5nciapdoxt11,11000.1gUO2 ( 9682.3g235)4488.3gSH2O 4164.3gHcv,hx= 25.06 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                  end boun
read geometry
```

```
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  47.21851 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
```

```
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
```

```
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.5 Case 5nciapdoxt11_1_1_12_3

```
=csas25    parm=size=3000000
5nciapdoxt11,12000.0gUO2 (10562.4g235)4896.3gSH2O 3665.3gHcv hx= 22.74 fr=0.0001
238groupndf5 infhommedium
'HEU volume =6000.00000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 12000.0 g, sat.h2o in HEU oxide=4896.3 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.59, CV void volume 3671.88368'
arbmuox    1.83389   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  7.4827e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  7.6412e-02  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                          8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                          9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
```

```
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
```

```
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                           16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                           17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                           18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                           18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                           19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                           19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
5nciapdoxt11,12000.0gUO2 (10562.4g235)4896.3gSH2O 3665.3gHcv,hx= 22.74 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  51.07212 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
```

```
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
```

```
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.6 Case 5nciapdoxt11_1_1_11_3

```
=csas25    parm=size=3000000
5nciapdoxt11,11000.1gUO2 ( 9682.3g235)4488.3gSH2O 4164.3gHcv hx= 25.06 fr=0.0001
238groupndf5 infhommedium
'HEU volume =5500.05000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 11000.1 g, sat.h2o in HEU oxide=4488.3 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.73, CV void volume 4171.83368'
arbmuox    1.82015   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  7.4266e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  8.2733e-02  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
```

```
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                         16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                         17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                         18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                         18  1.25705 293  end
'steel: drum steel for single units'
```

```
'ss304                                              19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                             19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
5nciapdoxt11,11000.1gUO2 ( 9682.3g235)4488.3gSH2O 4164.3gHcv,hx= 25.06 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                    end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  47.21851 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
```

```
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
```

```
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.7 Case 5nciapdoxt11_1_2_11_3

```
=csas25    parm=size=3000000
5nciapdoxt11,11000.1gUO2 ( 9682.3g235)2658.2gSH2O 5994.4gHcv hx= 25.06 fr=0.0001
238groupndf5 infhommedium
'HEU volume =3666.70000 HEU oxide, bulk density of oxide in cans=  3.00000 g/cm3'
'oxide= 11000.1 g, sat.h2o in HEU oxide=2658.2 g, oxide h/x= 7.17'
'poly (packed or wrapped) dry content h/x=1.73, CV void volume 6005.18368'
arbmuox    2.61274   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  6.3139e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  1.1876e-01  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
```

```
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                                8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                             8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                             9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                            10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
```

```
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                               8016   88.8087   21  1.0     293  end
end comp
5nciapdoxt11,11000.1gUO2 ( 9682.3g235)2658.2gSH2O 5994.4gHcv,hx= 25.06 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
```

```
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  33.08705 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
```

```
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5197  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
```

```
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.8 Case 5hciapdoxt12_1_1_11_3

```
=csas25    parm=size=3000000
5hciapdoxt12,11000.1gUO2 ( 9682.3g235)4488.3gSH2O 4164.3gHcv hx= 25.06 fr=0.0001
238groupndf5 infhommedium
'HEU volume =5500.05000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 11000.1 g, sat.h2o in HEU oxide=4488.3 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.73, CV void volume 4171.83368'
arbmuox    1.82015   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  7.4266e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  8.2733e-02  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                           8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                           9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                          10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
```

```
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                 8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                                 8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                                 8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                                 8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                                 8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                                 8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                                 8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                                 8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                                 8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                                 8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                                 8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                                 8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                                 8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                                 8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                                 8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                                 8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
```

```
                              1001    8.1573
                              8016   21.5782
                             14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                              8016   88.8087   20  0.0001  293  end
'reflective water'
'arbmh20r   0.9982   2 0 0 0    1001   11.1913
'                              8016   88.8087   21  1.0     293  end
end comp
5hciapdoxt12,11000.1gUO2 ( 9682.3g235)4488.3gSH2O 4164.3gHcv,hx= 25.06 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=specular                   end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  47.21851 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.838092   77.72400   0.0     com='drum'
 cuboid    20 1 4p21.838092   77.72400   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
```

```
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    20 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    20 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
```

```
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    20 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  20 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  20 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
'cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 4   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
'read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.9 Case 5ncf1pdoxt11_1_1_14_3

```
=csas25    parm=size=3000000
5ncf1pdoxt11,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gHcv hx= 19.11 fr=0.0001
238groupndf5 infhommedium
'HEU volume =7000.05000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 14000.1 g, sat.h2o in HEU oxide=5712.4 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.36, CV void volume 2671.83368'
arbmuox    1.85591   2 0 0 0  92235   88.0203
                              8016    11.9797    1  1.0000  293  end
arbmastm  7.5725e-01  2 0 0 0  1001   11.1913
                              8016    88.8087    1  1.0000  293  end
```

```
arbmpoly  6.6282e-02  2 0 0 0  1001   14.3798
                               6012   85.6202    1  1.0000  293  end
'np277-4: spacer (NCT_MD&H)'
'NCT min.den.(95.3886 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07070e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.84169e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
ss304                                            8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                            9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                           10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (NCT_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.527971 = (95.3886 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.477385 = (den.mult)(np277-4 min.den.) = 0.9668933*1.527971'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9189
                                 7014    0.0141
                                 8016   43.4251
                                11023    0.1174
                                12000    0.3378
                                13027   39.0479
                                14000    2.4672
                                16000    0.3083
                                20000   11.8336
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.71451e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 1.012373*0.51655,  for rest = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'nct array densities are s.u.dens. multiplied by volume ratio 1.34888/1.10336'
arbmh2ok   0.63931  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.42622  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.42622  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
```

```
arbmfe2o3  0.42622  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.42622  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.42622  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.42622  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.42622  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for single units'
'ss304                                          18  1.0     293  end
'steel: angle iron (ai) for arrays'
'array density is multiplied by a volume fraction 7.08030/5.63249'
ss304                                          18  1.25705 293  end
'steel: drum steel for single units'
'ss304                                          19  1.0     293  end
'steel: drum steel for arrays'
'array density is multiplied by a volume fraction 3.20482/3.20544'
ss304                                          19  0.99981 293  end
'void space external to drum'
'array density is multiplied by a volume ratio 8.11698/6.98323'
arbmwed    1.16026  2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
```

```
5ncf1pdoxt11,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gHcv,hx= 19.11 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vacuum                      end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.111 in. at top of unit]'
'cylinder  19 1   22.866096    0.28150   0.0     com='extended radius not used'
 cylinder  19 1   21.722275    0.28150   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p22.866096    0.28150   0.0     com='drum chine outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.676 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.555075   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.722275   11.59510   0.0     com='drum'
 cuboid    20 1 4p22.866096   11.59510   0.0     com='drum chine outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.276 in.]'
 cylinder  3  1    6.426200   77.72400  58.78051 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.722275   77.72400   0.0     com='drum'
 cuboid    20 1 4p22.866096   77.72400   0.0     com='drum chine outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.336 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.426 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.555075    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.22860   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.22860   0.0     com='drum chine outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.926 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.27000   0.0     com='kaolite'
```

```
 cylinder  19 1   21.722275    1.27000   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.27000   0.0     com='drum chine outer radius'
unit 1013
'cv flange above cv well [Elev=37.076 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.555075    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.92100   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.92100   0.0     com='drum chine outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.476 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.555075    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.722275    1.01600   0.0     com='drum'
 cuboid    20 1 4p22.866096    1.01600   0.0     com='drum chine outer radius'
unit 1015
'2nd step in liner [Elev=37.536 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.555075    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.722275    0.15240   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.15240   0.0     com='drum chine outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.756 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.555075    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.722275    8.17880   0.0     com='drum'
 cuboid    20 1 4p22.866096    8.17880   0.0     com='drum chine outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.506 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.555075    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.722275    4.44500   0.0     com='drum'
 cuboid    20 1 4p22.866096    4.44500   0.0     com='drum chine outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.756 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.555075    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.722275    0.63500   0.0     com='drum'
 cuboid    20 1 4p22.866096    0.63500   0.0     com='drum chine outer radius'
unit 1019
'drum lid and lip [Elev=43.512 in.]'
 cylinder  20 1   21.330090    1.91973   0.16720 com='void above lid'
 cylinder  19 1   21.497290    1.91973   0.0     com='drum lid'
 cylinder  20 1   21.555075    1.91973   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.722275    1.91973   0.0     com='drum'
```

```
 cuboid    20 1 4p22.866096    1.91973   0.0     com='drum chine outer radius'
'global
unit 1020
'es3100 drum [Elev=43.512 in.]'
array 3         2r-22.866096     0.0
'cuboid     0  1 4p24.587200    1120.337  0.0    com='bare package'
'cuboid    21  1 4p55.067200   1150.817 -30.48   com='reflected package'
 cuboid    20  1 4p22.866096    110.5198  0.0    com='interstital array space'
global
unit 1021
array 4   3r0.0
reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
ara=4 nux=13 nuy=13 nuz=06 fill f1020               end fill
end array
read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

6.9.9.9.10 Case 5hcf2pdoxt12_1_1_14_3

```
=csas25    parm=size=3000000
5hcf2pdoxt12,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gHcv hx= 19.11 fr=0.0001
238groupndf5 infhommedium
'HEU volume =7000.05000 HEU oxide, bulk density of oxide in cans=  2.00000 g/cm3'
'oxide= 14000.1 g, sat.h2o in HEU oxide=5712.4 g, oxide h/x=12.10'
'poly (packed or wrapped) dry content h/x=1.36, CV void volume 2671.83368'
arbmuox    1.85591   2 0 0 0  92235   88.0203
                              8016   11.9797    1  1.0000  293  end
arbmastm  7.5725e-01  2 0 0 0  1001   11.1913
                              8016   88.8087    1  1.0000  293  end
arbmpoly  6.6282e-02  2 0 0 0  1001   14.3798
                              6012   85.6202    1  1.0000  293  end
'np277-4: spacer (HAC_MD&H)'
'HAC min.den.(95.3157 lb/ft3) and hydrogen'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.31015e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520    2  0.7500  293  end
arbmnpmx  1.07071e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298    2  1.0000  293  end
arbmnph2o 3.82995e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.9820e-01  2 0 0 0   1001   11.1913
                               8016   88.8087    3  1       293  end
'steel: containment vessel body 16.60 lb but use 15.74 lb'
```

```
ss304                                              8  1.0     293  end
'steel: cv flange lower use 3.36 lb'
ss304                                              9  0.97267 293  end
'steel: cv flange upper use 13.75 lb'
ss304                                             10  0.94348 293  end
'np277-4: confinement -- neutron poison inner liner (HAC_MD&H)'
'actual vol.= 1.28314e4 cm3 = (7.83023e2 in3)(16.387064)'
'den.multiplier = 1.28314e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'np277-4 min.den.= 1.526803 = (95.3157 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
'density = 1.476265 = (den.mult)(np277-4 min.den.) = 0.9668933*1.526803'
'use 75% of boron in calculations per NUREG-1609 Section 6.5.3.2'
arbmboron 7.06813e-2  2 0 0 0    5010   18.1479
                                 5011   81.8520   11  0.7500  293  end
arbmnpmx  1.03525e+0 10 0 0 0    6012    1.9188
                                 7014    0.0141
                                 8016   43.4254
                                11023    0.1174
                                12000    0.3378
                                13027   39.0477
                                14000    2.4671
                                16000    0.3083
                                20000   11.8335
                                26000    0.5298   11  1.0000  293  end
arbmnph2o 3.70316e-1  2 0 0 0    1001   11.1913
                                 8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'nct.sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k 0.52294 = 1.012373*0.51655, for rest 0.34864 = 1.012373*0.34438'
'den.mult= 1.36557e5 cm3 (actual vol.) / 1.34888e5 cm3 (model vol.)'
'actual vol.= 1.36557e5 cm3 = (28316.84 cm3/ft3)(108.33188 lb)/(22.464 lb/ft3)'
'hac.s.u.dens= (hac.mult)(nct.s.u.dens)'
'hac.mult = 1.34888e5 cm3 (nct vol.)/ 1.12246e5 cm3 (model vol.)'
' for arbmh2ok 0.62843 = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac array densities are hac s.u.dens.'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                               8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41898  2 0 0 0   13027   52.9390
                               8016   47.0610   12  0.096   293  end
arbmsio2   0.41898  2 0 0 0   14000   46.7570
                               8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41898  2 0 0 0   26000   69.9540
                               8016   30.0460   12  0.067   293  end
arbmtio2   0.41898  2 0 0 0   22000   59.9535
                               8016   40.0465   12  0.012   293  end
arbmcao    0.41898  2 0 0 0   20000   71.4815
                               8016   28.5185   12  0.307   293  end
arbmmgo    0.41898  2 0 0 0   12000   60.3169
                               8016   39.6831   12  0.131   293  end
arbmna2o   0.41898  2 0 0 0   11023   74.1961
                               8016   25.8039   12  0.020   293  end
'kaolite 1600 top plug'
'sing.unit.density= (den.mult)(min.den.)'
' for arbmh20k = 0.965246*0.51655,  for rest = 0.965246*0.34438'
'den.mult= 1.21592e4 cm3 (actual vol.) / 1.25970e4 cm3 (model vol.)'
'actual vol.= 1.21592e4 cm3 = (28316.84 cm3/ft3)(9.646 lb)/(22.464 lb/ft3)'
arbmh2ok   0.49860  2 0 0 0    1001   11.1913
                               8016   88.8087   13  0.0287  293  end
arbmal2o3  0.33241  2 0 0 0   13027   52.9390
                               8016   47.0610   13  0.096   293  end
arbmsio2   0.33241  2 0 0 0   14000   46.7570
                               8016   53.2430   13  0.367   293  end
```

```
arbmfe2o3  0.33241  2 0 0 0   26000   69.9540
                               8016   30.0460   13  0.067   293  end
arbmtio2   0.33241  2 0 0 0   22000   59.9535
                               8016   40.0465   13  0.012   293  end
arbmcao    0.33241  2 0 0 0   20000   71.4815
                               8016   28.5185   13  0.307   293  end
arbmmgo    0.33241  2 0 0 0   12000   60.3169
                               8016   39.6831   13  0.131   293  end
arbmna2o   0.33241  2 0 0 0   11023   74.1961
                               8016   25.8039   13  0.020   293  end
'silicone rubber pads'
arbmsiru   1.21791  4 0 0 0    6012   32.3767
                               1001    8.1573
                               8016   21.5782
                              14000   37.8878   14  1.0     293  end
'void space external to containment vessel'
arbmwecv   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   15  0.0001  293  end
'steel: liner'
ss304                                          16  1.0     293  end
'steel: plug cover (pc) use 9.907 lb'
ss304                                          17  1.06388 293  end
'steel: angle iron (ai) for HAC'
'nct density is multiplied by volume fraction 7.08030/5.74516'
ss304                                          18  1.23239 293  end
'steel: drum steel for HAC'
'nct density is multiplied by volume fraction 3.20482/2.95645'
ss304                                          19  1.08401 293  end
'void space external to drum'
'array density is assumed not reduced by hac'
arbmwed    0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   20  0.0001  293  end
'reflective water'
arbmh20r   0.9982   2 0 0 0    1001   11.1913
                               8016   88.8087   21  1.0     293  end
end comp
5hcf2pdoxt12,14000.1gUO2 (12322.9g235)5712.4gSH2O 2667.0gHcv,hx= 19.11 fr=0.0001
read parameters nub=yes npg=2500 gen=215 nsk=15 tme=100 end parameters
read boun       all=vacuum                     end boun
read geometry
unit 1001
'drum bottom flat cover [Elev= 0.105 in. at top of unit]'
'cylinder  19 1   21.838092    0.26670   0.0     com='extended radius not used'
 cylinder  19 1   21.838092    0.26670   0.0     com='drum bottom flat cover'
 cuboid    20 1 4p21.838092    0.26670   0.0     com='drum(chine)outer radius'
unit 1002
'above drum bottom flat cover and below containment vessel [Elev= 4.670 in.]'
 cylinder  15 1    3.175000   11.59510  11.16330 com='void in pad-1'
 cylinder  14 1    7.924800   11.59510  11.16330 com='pad-1'
 cylinder  16 1    8.077200   11.59510  11.16330 com='np277_4 liner'
 cylinder  11 1   10.922000   11.59510  11.16330 com='np277_4'
 cylinder  16 1   11.074400   11.59510  10.85850 com='kaolite liner bottom'
 cylinder  12 1   21.685692   11.59510   0.0     com='kaolite'
 cylinder  19 1   21.838092   11.59510   0.0     com='drum'
 cuboid    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'cv bottom to bottom of 1st step [Elev=35.270 in.]'
 cylinder  3  1    6.426200   77.72400  58.78051 com='cavity abv HEU'
 cylinder  1  1    6.426200   77.72400   0.63500 com='HEU content'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv bottom'
 cylinder  15 1    7.924800   77.72400   0.0     com='void btw cv-np liner'
```

```
 cylinder  16 1    8.077200   77.72400   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   77.72400   0.0     com='np277_4'
 cylinder  16 1   11.074400   77.72400   0.0     com='kaolite liner'
 cylinder  12 1   21.685692   77.72400   0.0     com='kaolite'
 cylinder  19 1   21.838092   77.72400   0.0     com='drum'
 cuboid    20 1 4p21.838092   77.72400   0.0     com='drum(chine)outer radius'
unit 1010
'cv at 1st step in liner [Elev=35.330 in.]'
 cylinder  3  1    6.426200    0.15240   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.15240   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.15240   0.0     com='cv at 1st step'
 cylinder  15 1    7.924800    0.15240   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.15240   0.0     com='liner 1st step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1011
'vertical gap between 1st step in liner and cv flange [Elev=35.420 in.]'
 cylinder  3  1    6.426200    0.22860   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    0.22860   0.0     com='HEU content'
 cylinder  8  1    6.680200    0.22860   0.0     com='cv at gap btwn step-flng'
 cylinder  15 1   10.922000    0.22860   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    0.22860   0.0     com='liner wall'
 cylinder  12 1   21.685692    0.22860   0.0     com='kaolite'
 cylinder  19 1   21.838092    0.22860   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.22860   0.0     com='drum(chine)outer radius'
unit 1012
'cv flange to top of cv well [Elev=35.920 in.]'
 cylinder  3  1    6.426200    1.27000   0.00000 com='cavity abv HEU'
 cylinder  1  1    6.426200    1.27000   0.0     com='HEU content'
 cylinder  9  1    9.525000    1.27000   0.0     com='flange to top of well'
 cylinder  15 1    9.525000    1.27000   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    1.27000   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.27000   0.0     com='void btw cv and liner'
 cylinder  16 1   11.074400    1.27000   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.27000   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.27000   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.27000   0.0     com='drum(chine)outer radius'
unit 1013
'cv flange above cv well [Elev=37.070 in.]'
 cylinder  10 1    9.525000    2.92100   0.0     com='flange above cv well'
 cylinder  15 1    9.525000    2.92100   0.0     com='void btw cv and pad-2'
 cylinder  14 1   10.033000    2.92100   0.0     com='pad-2'
 cylinder  15 1   10.922000    2.92100   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    2.92100   0.0     com='liner wall'
 cylinder  12 1   21.685692    2.92100   0.0     com='kaolite'
 cylinder  19 1   21.838092    2.92100   0.0     com='drum'
 cuboid    20 1 4p21.838092    2.92100   0.0     com='drum(chine)outer radius'
unit 1014
'plugpad2 below liner 2nd step [Elev=37.470 in.]'
 cylinder  14 1   10.033000    0.76200   0.0     com='pad-2'
 cylinder  15 1   10.922000    1.01600   0.0     com='void btw pad2 and liner'
 cylinder  16 1   11.074400    1.01600   0.0     com='liner wall'
 cylinder  12 1   21.685692    1.01600   0.0     com='kaolite'
 cylinder  19 1   21.838092    1.01600   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.01600   0.0     com='drum(chine)outer radius'
unit 1015
'2nd step in liner [Elev=37.530 in.]'
 cylinder  15 1   10.922000    0.15240   0.0     com='void abv pad2'
 cylinder  16 1   18.757900    0.15240   0.0     com='liner 2nd step'
 cylinder  12 1   21.685692    0.15240   0.0     com='kaolite'
```

```
 cylinder  19 1   21.838092    0.15240   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.15240   0.0     com='drum(chine)outer radius'
unit 1016
'abv 2nd step in liner to bottom of angle iron [Elev=40.750 in.]'
 cylinder  13 1   18.097500    8.17880   0.49276 com='plug kaolite'
 cylinder  17 1   18.249900    8.17880   0.34036 com='sides of plug case'
 cylinder  15 1   18.605500    8.17880   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    8.17880   0.0     com='liner wall'
 cylinder  12 1   21.685692    8.17880   0.0     com='kaolite'
 cylinder  19 1   21.838092    8.17880   0.0     com='drum'
 cuboid    20 1 4p21.838092    8.17880   0.0     com='drum(chine)outer radius'
unit 1017
'bottom of angle iron to bend in angle iron [Elev=42.500 in.]'
 cylinder  13 1   18.097500    4.44500   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    4.44500   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    4.44500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    4.44500   0.0     com='liner wall'
 cylinder  18 1   19.392900    4.44500   0.0     com='lower angle iron'
 cylinder  12 1   21.685692    4.44500   0.0     com='kaolite'
 cylinder  19 1   21.838092    4.44500   0.0     com='drum'
 cuboid    20 1 4p21.838092    4.44500   0.0     com='drum(chine)outer radius'
unit 1018
'bend in angle iron to top of angle iron [Elev=42.750 in.]'
 cylinder  13 1   18.097500    0.11176   0.0     com='plug kaolite'
 cylinder  17 1   18.249900    0.26416   0.0     com='sides of plug case'
 cylinder  15 1   18.605500    0.63500   0.0     com='void: plug to liner'
 cylinder  16 1   18.757900    0.63500   0.0     com='liner wall'
 cylinder  18 1   21.685692    0.63500   0.0     com='bend section of ai'
 cylinder  19 1   21.838092    0.63500   0.0     com='drum'
 cuboid    20 1 4p21.838092    0.63500   0.0     com='drum(chine)outer radius'
unit 1019
'drum lid and lip [Elev=43.500 in.]'
 cylinder  20 1   21.469792    1.90500   0.15240 com='void above lid'
 cylinder  19 1   21.622192    1.90500   0.0     com='drum lid'
 cylinder  20 1   21.685692    1.90500   0.0     com='void btw lid - drum wall'
 cylinder  19 1   21.838092    1.90500   0.0     com='drum'
 cuboid    20 1 4p21.838092    1.90500   0.0     com='drum(chine)outer radius'
'global
unit 1020
'es3100 drum [Elev=43.500 in.]'
array 3         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4905  0.0    com='bare package'
'cuboid    21  1 4p52.318092   140.9700 -30.48   com='reflected package'
 cuboid    20  1 4p21.838092    110.4901  0.0    com='interstital array space'
global
unit 1021
array 4   3r0.0
reflector  21 2  6r3.0  10
end geometry
read array
ara=3 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
ara=4 nux=09 nuy=09 nuz=06 fill f1020               end fill
end array
ead bias id=500 2  11  end bias
read start nst=0
```

```
end start
end data
end
```

Appendix 6.9.10

Criticality Evaluation of HEU Oxide Product Content for Air Transportation

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Appendix 6.9.10

Criticality Evaluation of HEU Oxide Product Content for Air Transportation

Highly enriched uranium (HEU) product oxides (UO_2, UO_3, and U_3O_8) are evaluated as ES-3100 package contents for ground transport in Sects. 6.4–6.6. The criticality safety evaluation presented in this appendix is required for the approval of these oxides as a package content under the air transport mode. This analysis is simply an extension of the analysis presented in Sect. 6.7 for HEU metal. The catastrophically damaged package calculation models for HEU described in Sect. 6.3.1.4 for metal content were modified to address HEU product oxide under the air transport mode. Calculations presented in this appendix were performed using the Monte Carlo CSAS25 criticality code sequence and 238-group ENDFB-V cross-section library of SCALE 5.0 discussed in Sect. 6.9.8.4 (Appendix 6.9.8). Related discussion of the benchmark experiments and criticality evaluation is contained in Sect. 6.9.8.7 (Appendix 6.9.8).

6.9.10.1 Description of the Criticality Design

Changes to the design features of the ES-3100 package addressed in Sect. 6.1.1 are not required for air transport. However, the total free water permitted in the Kaolite is limited to 12 lb (5,443.1 g) as in the case of HEU metal content assuming the containment vessel well and other void spaces external to the containment vessel are dry. The codes and standards addressed in Sect. 6.1.2 apply to HEU product oxide as a package content for air transport. Moreover, the methodology for demonstrating maximum reactivity is not changed. The fissile mass loading limits for these contents listed in Table 6.9.10.1 are presented in Tables 6.9.10.2 and 6.2b for the air mode of transportation. Finally, the assignment of the criticality safety index (CSI) as to the ES-3100 package as described in Sect. 6.1.4 is unchanged.

6.9.10.2 The HEU Product Oxide Contents for the ES-3100 Package for Air Transport

HEU product oxide content for shipment by air in the ES-3100 is identified in Table 6.9.10.1. Physically, these uranium oxides (UO_2, UO_3, and U_3O_8) are non-rigid, bulk material in loose, granular, or powdered form. Both content moisture and content uniformity are undefined. The convenience cans, Teflon and polyethylene bottles, 277-4 canned spacers described in Sect. 6.2.2, and the packing materials described in Sect. 6.2.3 are not affected by inclusion of HEU product oxide as a package content for air transport. The Packing Content Loading Restrictions stated in Sect. 6.2.4 are unchanged.

Table 6.9.10.1. HEU product oxide contents

Name	Detailed description	Assay (wt % ^{235}U)	Net wt [a] (g)	U wt (g)	^{235}U wt (g)
UO_2, UO_3, U_3O_8	2.0 g/cm^3 ≤ density ≤ 6.54 g/cm^3	≤100	6,000	5,281	5,281

[a] 5,281-g ^{235}U corresponds to 6-kg U(100)O_2. The net weight of UO_3 and U_3O_8 are 6,359.4 and 6,239.6 g, respectively for 5,281-g ^{235}U at 100% enrichment. A lower enrichment level will result in a larger net weight of the particular oxide form at the 5,281-g ^{235}U limit. Thus, "g ^{235}U" not the net weight, is a limit.

Table 6.9.10.2. Fissile mass loading limits [a] for air transport of HEU product oxide

Content [b] description	Enrichment	No can spacers, [c] ^{235}U (g)	Basis for limit
HEU oxide (UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, UO_2-ZrO_2)	≤ 100%	5,281 [d]	Table 6.9.10.9-1, HEU product oxides

[a] The mass loading limit cannot be rounded up.
[b] Content in solution form is not permitted for shipment in the ES-3100. Content may be a combination of these oxides.
[c] 277-4 can spacers as described on Drawing M2E801580A043 (Appendix 1.3.7) are not required but are optional as dunnage.
[d] Non-uranium metallic constituents (e.g., aluminum , zirconium, or magnesium) are evaluated further in Appendix 6.9.11.

6.9.10.3 General Considerations

The general considerations expressed in Sect. 6.3 regarding both the calculation methodology for the ground and air transport modes, and the assumptions made about the ES-3100 packaging regarding geometry and material composition are unchanged. Only modifications to the calculation models for the catastrophically damaged package (Sect. 6.3.1.4) were required for evaluating HEU product oxide as a package content in the air transport mode.

6.9.10.3.1 Model configuration

The general modeling technique for the ES-3100 package described in Sect. 6.3.1, the single-unit packaging calculation models (Sect. 6.3.1.1), the infinite array and finite array packaging calculation models (Sect. 6.3.1.2), and the calculation models for damaged packages (Sect. 6.3.1.3) are specific to the ground transport. Only the content portion of the six calculation models for the catastrophically damaged package specific to HEU metal as a package content under the air transport (Sect. 6.3.1.4) were appropriately modified for evaluating HEU product oxide as a package content in the air transport mode. This was accomplished by replacing the homogeneous mixture of HEU metal and 500 g of polyethylene in the original models with a homogeneous mixture of water-saturated HEU oxide and 500 g of polyethylene. The 500-g polyethylene represents a limit on Teflon or polyethylene bottles as well as hydrogenous packing material. Given the requirement that containment vessels be flooded in the ground transport analysis; credit for product oxide quality (dryness) is not taken in the air transport analysis either. The HEU product oxide is assumed water-saturated in the air transport analysis.

The general arrangements of materials depicted in Figs. 6.11–6.16 (Sect. 6.1.3.4) remains the same for the HEU metal and HEU product oxide content configurations. Note that model dimensions are presented in the calculation results summary tables rather than depicted in these figures. Changes in dimensions of each model resulting from switching content from HEU metal to HEU product oxide content are slight and not visible in the figures. Consequently, revised figures were not drawn for HEU product oxide; instead, Figs. 6.11–6.16 are referenced accordingly in this appendix.

The content description for the HEU product oxide given in Table 6.9.10.1 provides the basis for the calculation model. The 6-kg UO_2 will be shown to be the largest amount allowable for air transport in Table 6.9.10.9-1). The uranium oxide mass is 6 kg, the uranium mass is 5,281 g, and the ^{235}U mass is 5,281 g at 100% enrichment for UO_2. There are three major oxides of uranium—UO_2, UO_3 , and U_3O_8. UO_3 and U_3O_8 are bounded by calculations using UO_2 for two reasons: (1) for the same net weight (6-kg oxide), there is more ^{235}U in UO_2 than in UO_3 or U_3O_8 and (2) for the same ^{235}U content (5,281 g), the UO_3 and U_3O_8 have more oxygen atoms per uranium atom and, therefore, have lower uranium densities. However, the neutron scattering and absorption in the additional oxygen is a minor

effect compared to reactivity changes due to the uranium mass/density differences. For this reason, Table 6.9.10.9-1 contains only a few calculations of UO_3 and U_3O_8 at the 6-kg oxide net weight amount included to demonstrate that the UO_2 is obviously bounding for the other two oxides.

HEU product oxide evaluated for ground transport in Sects. 6.4.3, 6.5.3, and 6.6.3 is characterized as non-hydroscopic or mildly hydroscopic, non-rigid, bulk material in clumped, loose, granular, or powdered form having a bulk density ranging from 2.0 to 6.54 g/cm^3. Oxide impurity (unidentified constituents) is treated as ^{235}U [Sect. 6.2.4(8)]. This same criteria is applied in the criticality evaluation for the air transport mode. Given the requirement that containment vessels be flooded in the ground transport analysis, credit for product quality (dryness) is not taken in the air transport analysis either. The HEU product oxide is assumed water-saturated.

As explained in Sect. 6.3.1.4, the air-transport calculation models incorporate features exhibiting the worst-case assumptions made regarding the geometric arrangement of the packaging and package contents. No credit is taken for the geometric form of the package content. Spherical geometry is used to represent the ultimate configuration of the ES-3100 package which undergoes catastrophic destruction.

The criticality analysis for air transport does not credit the ES-3100 for maintaining the geometrical configuration of the packaged content. Fissile material is configured spherical in shape for optimization of neutron multiplication. Also, the criticality analysis does not credit the ES-3100 packaging for structural integrity of the containment and the confinement. Therefore, the reactivity "enhancing" materials of the packaging may be interspersed with the fissile material content. A calculation model in which the fissile material is homogenized with moderating material is an appropriate representation because the form of HEU product uranium oxide being shipped consists of a bulk material in clumped, loose, granular, or powdered form. However, homogenization of fissile material with moderating material is not performed with exclusive preference given to specific constituents of the moderating material. Selective removal of the neutron-absorbing materials of the package (i.e., Kaolite and stainless steel) accompanied by retention of the moderating constituents of the neutron-absorbing material (i.e., bound water in the Kaolite) for enhancing content reactivity is not a credible condition.

Concerning the "no water inleakage" condition of 10 CFR 71.55(f)(1) and (f)(2), the focus is on the Kaolite region of the ES-3100 package. The 53,419 g of dry-baked Kaolite in the drum body weldment and drum top plug consists of 51,214.9 g of vermiculite-cement constituents and 2,204.7 g of bound water. For establishing the loading limits for air transport, the total **free** water permitted in wet Kaolite was conservatively evaluated up to 15 lb (6,803.8 g). As in the case of HEU metal content, this limit assumes that the containment vessel well and other void spaces external to the containment vessel are dry.

A set of six calculation models are constructed in order to determine the worst case or most reactive configuration with consideration given to the efficiency of moderators, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes, and temperature effects. In each case, fissile material content in the core consists of HEU product oxide saturated with water (e.g., 2,448.1-g H_2O for UO_2 at 2 g/cm^3) and homogenized with 500-g polyethylene which models the allowed hydrogenous packing material.

Model 1 (Fig. 6.11, Sect. 6.3.1.4) represents the fissile material content configured into a spherical core with a 20.0-cm thick water reflector. All ES-3100 packaging material (Kaolite, stainless steel, 277-4 neutron poison, etc.) is excluded from Model 1. The fissile material content considered in the calculation model consists of a specific material form: HEU product oxide (6- to 14-kg UO_2 containing 5,281- to 12,323-g ^{235}U). The presence of hydrogenous packing material inside the containment vessel is also addressed in this calculation model where 500 g of polyethylene is used to represent a maximum amount of hydrogenous packing material allowed in the ES-3100. For 6-kg HEU product oxide

(5,281-g ^{235}U) homogenized with 500 g of polyethylene, the radius of the core is 6.3861 cm. HEU product oxide is assumed to be saturated with water that is 2,448.1-g H_2O for UO_2 at 2.0 g/cm^3. The parametric variation of both the ^{235}U mass and the density of the water-saturated oxide in Model 1 is used to establish a reference point for the evaluation neutron reflection and absorption effects on k_{eff} provided by the stainless steel and Kaolite packaging materials, which are addressed separately in Models 2 and 3. Case names for Model 1 are designated with the prefix "5atdor." The leading "5" in alphanumeric prefix indicates calculations were run with SCALE5 rather than with the SCALE4.4a. UO_2 is shown to be the most reactive uranium oxide; therefore, the oxide content is modeled as UO_2 at various densities ranging from 2.0 to 6.54 g/cm^3. The amount of saturation water varies from a low of 369.3 g for an oxide density of 6.54 g/cm^3 to the high of 2,448.1 g for a lower oxide density of 2 g/cm^3. Details are provided in Table 6.9.10.9-1 for each density evaluated.

Model 2 (Fig. 6.12, Sect. 6.3.1.4) represents a spherical core of Model 1 blanketed by a variable-thickness shell of stainless steel and a 20.0-cm-thick water reflector external to the shell. The shell at maximum thickness corresponds to the 66,133-g stainless steel of the containment vessel and the liner and drum assembly. For a homogeneous mixture of 6-kg HEU product oxide (5,281-g ^{235}U), 2,448.1 g of saturation water (consistent with an oxide density of 2 g/cm^3) and 500 g of polyethylene, the radius of the core is 9.4576 cm while the outer radius of the stainless steel shell is 14.1521 cm. Case names in Table 6.9.10.9-1 for Model 2 are designated with the prefix "5atdosr."

Model 3 (Fig. 6.13, Sect. 6.3.1.4) is configured the same as Model 2 with the exception that instead of stainless steel, the variable-thickness shell is composed of dry Kaolite in one set of cases and wet Kaolite in the other set. Dry Kaolite from inside the body weldment outer liner and the drum top plug consists of 51,214.3-g vermiculite-cement and 2,204.8-g bound water. Wet Kaolite to a maximum of 60,223 g consists of the dry Kaolite and up to 6,803.9-g free water—moisture which dampens the Kaolite and may also be present in the containment vessel well. Because the Kaolite is constrained within the liners of the ES-3100 packaging, the Kaolite density rather than its volume changes when water is added to the material. Therefore, at maximum shell thickness, the outer radius of the Kaolite shell, wet or dry, is 31.2952 cm. Like Model 2, the radius of the core is 9.4576 cm for a homogeneous mixture of 6-kg HEU product oxide (5,281-g ^{235}U), 2,448.1 g of saturation water, and 500 g of polyethylene. Case names for Model 3 designated with the prefix "5atdodkr" are for HEU product oxide content with a dry Kaolite shell (Kaolite only contains bound water) while case names designated with the prefix "5atdo15kr" are for HEU product oxide content with a wet Kaolite having 15-lb free water. The parametric variation of shell thickness/composition in Models 2 and 3 is performed for the purpose of evaluating the effect on k_{eff} of neutron reflection and absorption provided by each packaging material.

Models 1–3 for water-saturated HEU product oxide evaluate scenarios where containment and confinement of the content are assumed but the physical shape of the packaging is destroyed. Models 4–6 evaluate scenarios where the package content blends with the other materials of the packaging in the air transport accident given the physical form of the HEU product oxide is bulk material in clumped, loose, granular, or powdered form.

Model 4 (Fig. 6.14, Sect. 6.3.1.4) depicts a spherical core of HEU product oxide and 2,448.1 g of saturation water homogenized with wet Kaolite (variable amount) and hydrogenous packing materials from inside the containment vessel represented by 500 g of polyethylene. A 20-cm-thick water reflector blankets the spherical core. All other ES-3100 packaging material (stainless steel, 277-4 neutron poison, etc.) is excluded from Model 4. For the homogenized core containing 6 kg of HEU product oxide (5,281 g of ^{235}U), 2,448.1 g of saturation water for the oxide at 2 g/cm^3, 500 g of polyethylene and wet Kaolite, the radius of the core is 31.2953 cm. The amount of water in wet Kaolite ranges from 2,204.7-g bound water in baked-dry Kaolite to 9,008.6 g (2,204.7-g bound plus 15-lb free water). Case names in Table 6.9.10.9-1 for Model 4 are designated with the prefix "5athop15kr" for the HEU product oxide.

Model 5 (Fig. 6.15, Sect. 6.3.1.4) is an extension of Model 3 applied to HEU product oxide contents. Excess water from wet Kaolite is homogenized with the fissile material in the core along with the water of saturation and the hydrogenous packing materials (modeled as polyethylene). For a homogeneous mixture of 6-kg HEU product oxide (5,281-g ^{235}U), 2,448.1 g of saturation water, 500 g of polyethylene, and 0.0 g of free water from wet Kaolite, the radius of the spherical core is 9.4576 cm. The corresponding exterior Kaolite shell, containing 9,008.5 g (2,204.7-g bound plus 15-lb free water) of water homogenized with the 51,214.9 g of vermiculite-cement constituents, has an outer radius of 31.2952 cm. For the extreme condition where the entire 6,803.8 g of water from wet Kaolite is homogenized with the core, the radius of the spherical core is 13.5234 cm. The corresponding exterior shell of dry Kaolite, containing 2,204.7 g of bound water and 51,214.9 g of vermiculite-cement constituents, has an outer radius of 31.8395 cm. Case names in Table 6.9.10.9-1 for Model 5 are designated with the prefix "5athopw15kr" for 15-lb free water in the Kaolite and "5athopw13kr" for 13-lb free water in the Kaolite.

Model 6 (Fig. 6.16, Sect. 6.3.1.4) is configured similar to Model 4 with the exception that only a partial amount of HEU product oxide resides in the homogenized core. The remainder of the fissile material is modeled as a shell external to the spherical core and internal to the 20.0-cm-thick water reflector. A series cases is run with suffixes "**_f_a_b**" is run where the first number "**f**"designates variable water mass in the fissile core region, the second number "**a**" designates oxide mass in the fissile core, and the third number "**b**"designates oxide mass in shell around the core. For Cases **5athop15kor_f_a_b**, the amount of water-saturated HEU oxide in the homogenized core is varied in 1-kg increments from 5 kg for **"a"**=5 (the full 6-kg amount in Model 5 minus 1 kg) to 1 kg for "**a**"=1. The unsaturated HEU product oxide removed from the core to form the shell adjacent to the core correspondingly increases from 1 to 5 kg for "**b**"=1 to 5 where "**b=6-a**." For maximization of reactivity, it is assumed that all the saturation water present in the 6-kg oxide remains in the core. The effect of varying the free water in the core is evaluated in cases designated by the suffix "**f**." In Cases **5athop15kor_1_a_b**, the 11,456.8-g water represents the saturated water in the oxide plus both the free water and bound water in Kaolite. In Cases **5athop15kor_5_a_b**, the 4,653.0-g water represents the saturated water in the oxide plus the bound water in Kaolite. Case names in Table 6.9.10.9-2 for Model 6 are designated with the prefix "5athop15kor" for the HEU product oxide contents. Model 6 addresses potential redistribution of fissile material consisting of HEU product oxide content. The parametric variation of shell thickness in Model 6 is performed for the purpose of evaluating the effect on k_{eff} of moderation efficiency of the core and enhanced neutron multiplication of the shell.

Models 1–6 are applicable to air transport of the ES-3100 package given that the physical integrity of the fissile content following the air-transport accident cannot be established and that the physical form of fissile material content is oxide.

6.9.10.3.2 Content model material specifications for HEU product oxide

The material properties for the ES-3100 package addressed in Sect. 6.3.2 remain unchanged for the air transport analysis. However, additional specification data is provided in Table 6.9.10.3 for addressing the HEU product oxide content modeled in the air-transport analysis.

Table 6.9.10.3. Material compositions for HEU product oxide content calculation models for air transport

Material	Mix. No.	Theoretical density input parameter (g/cm^3) [a]	Volume fraction	Constituent	Atomic weight	Weight fraction	Atomic density (atoms/b-cm) [b]
Fissile material contents							
Uranium oxide (UO_2)	1	10.96000	1.0	O	15.9954	11.9827	4.46663E-02
				^{235}U	235.0441	88.0173	2.47161E-02
HEU product oxide (UO_2) at 2 g/cm^3, 2,448.1-g saturation water, and 500-g poly	1	1.69325	1.0	O	15.9954	88.0203	3.07374E-02
				^{235}U	235.0441	11.9797	3.81861E-03
	1	0.69089	1.0	H	1.0078	11.1913	5.83269E-02
				O	15.9954	88.8087	
	1	0.14110	1.0	C	12.0111	14.3798	6.06280E-03
				H	1.0078	85.6202	
HEU product oxide (UO_2) at 3 g/cm^3, 1,449.9-g saturation water, and 500-g poly	1	2.35897	1.0	O	15.9954	88.0203	2.97000E-02
				^{235}U	235.0441	11.9797	5.31994E-03
	1	0.57006	1.0	H	1.0078	11.1913	5.50137E-02
				O	15.9954	88.8087	
	1	0.19658	1.0	C	12.0111	14.3798	8.44667E-03
				H	1.0078	85.6202	
HEU product oxide (UO_2) at 4 g/cm^3, 950.8-g saturation water, and 500-g poly	1	2.93617	1.0	O	15.9954	88.0203	2.88006E-02
				^{235}U	235.0441	11.9797	6.62164E-03
	1	0.46530	1.0	H	1.0078	11.1913	5.21411E-02
				O	15.9954	88.8087	
	1	0.24468	1.0	C	12.0111	14.3798	1.05134E-02
				H	1.0078	85.6202	
HEU product oxide (UO_2) at 5 g/cm^3, 651.4-g saturation water, and 500-g poly	1	3.44140	1.0	O	15.9954	88.0203	2.80136E-02
				^{235}U	235.0441	11.9797	7.76104E-03
	1	0.37361	1.0	H	1.0078	11.1913	4.96269E-02
				O	15.9954	88.8087	
	1	0.28678	1.0	C	12.0111	14.3798	1.23224E-02
				H	1.0078	85.6202	
HEU product oxide (UO_2) at 6.54 g/cm^3, 369.3-g saturation water, and 500-g poly	1	4.10703	1.0	O	15.9954	88.0203	2.69763E-02
				^{235}U	235.0441	11.9797	9.26216E-03
	1	0.25280	1.0	H	1.0078	11.1913	4.63142E-02
				O	15.9954	88.8087	
	1	0.34225	1.0	C	12.0111	14.3798	1.47058E-02
				H	1.0078	85.6202	

[a] The theoretical density input parameter is specified for each material such that the required (or desired) mass of material is represented in the KENO V.a calculation model. The mass of material is computed by KENO V.a as the product of the theoretical density input parameter times the volume fraction times the volume of the geometry region in which the material resides in the calculation model.

[b] Atomic densities are specified for the total isotope in a homogenized material as Mix No. 1.

6.9.10.4 Computer Codes and Cross-Section Libraries

This information is discussed in Section 6.9.8.4.

6.9.10.5 Single Package Evaluation (NCT and HAC)

The evaluation of a single ES-3100 package with HEU product oxide content for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) in the ground mode of transportation is presented in Sect. 6.4.3 while the evaluation of a catastrophically damaged package in air transport mode is addressed in Appendix 6.9.10.7.

6.9.10.6 Array Package Evaluation (NCT and HAC)

The evaluation of arrays of packages in NCT and in HAC for the ground transport mode are presented in Sects. 6.5.3 and 6.6.3, respectively. The array evaluations are not required by 10 CFR 71.55(f) for the air mode of transportation. However, the CSI established for the ground transport mode establishes the maximum number of packages which can be loaded onto an aircraft for criticality safety purposes.

6.9.10.7 Fissile Material Packages with HEU Product Oxide for Air Transport

As discussed in Sect. 6.7, a series of calculations are performed for determining the most reactive configuration of the content and surrounding packaging material in an ES-3100 package that undergoes catastrophic destruction. Subcriticality is demonstrated after due consideration of such aspects as the efficiency of moderator, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes and temperature effects. Details of the six calculation models used in this evaluation are described in Sect. 6.9.10.3.1. Key model dimensions and parameters are provided in Tables 6.9.10.9-1 and 6.9.10.9-2.

Model 1 (Fig. 6.11, Sect. 6.3.1.4) represents fissile material content configured into a spherical core with a 20.0-cm-thick water reflector taking no credit for the geometry or structure of the container. In addition, all ES-3100 packaging material (Kaolite, stainless steel, 277-4 neutron poison, etc.) is excluded from Model 1. The parametric variation of both the ^{235}U mass and the density of the oxide along with its corresponding saturation water in Model 1 is used to establish a reference point for the evaluation of neutron reflection and absorption effects on k_{eff} provided by the stainless steel and Kaolite packaging materials, which are addressed separately in Models 2 and 3. The purpose of the variations in Model 1 is to identify the most reactive oxide type (UO_2, UO_3, or U_3O_8) and density (from 2 to 6.54 g/cm^3) for water-saturated HEU product oxide (saturation water ranging from 369.3 to 2,448.1 g for corresponding oxide densities from 6.54 to 2 g/cm^3). In Cases **5atdor_1_5_6** through **5atdor_1_5_14** (Table 6.9.10.9-1), the $k_{eff} + 2\sigma$ values increase from 0.751 to 0.871 as the mass of saturated HEU product oxide increases from 6-kg UO_2 (5,281-g ^{235}U) to 14-kg UO_2 (12,323-g ^{235}U) at 6.54 g/cm^3. In Cases **5atdor_1_1_6** through **5atdor_1_5_6** for UO_2, Cases **5atdor_2_1_6** through **5atdor_2_5_6** for U_3O_8, and Cases **5atdor_3_1_6** through **5atdor_3_5_6** for UO_3, the densities of the three oxides are varied from 2 to 6.54 g/cm^3. These contents are most reactive at minimum density where the $k_{eff} + 2\sigma$ values range from 0.671 for UO_3 (**Case 5atdor_3_5_6**) to 0.917 for UO_2 (**Case 5atdor_1_1_6**). UO_2 is the most reactive of the product oxides evaluated. In Cases **5atdor_1_1_6** through **5atdor_1_1_14** (Table 6.9.10.9-1), the $k_{eff} + 2\sigma$ values range from 0.917 to 1.073 as the mass of saturated HEU product oxide is varied from 6- to 14-kg UO_2 for oxide at minimum density (2 g/cm^3). Only the result for Case **5atdor_1_1_6** is adequately below the USL of 0.924; therefore, 6-kg (5,281-g ^{235}U) HEU product oxide is the limiting mass and 2 g/cm^3 is the optimum density for consideration of this material for air transport in the ES-3100.

Model 2 (Fig. 6.12, Sect. 6.3.1.4) represents a spherical core of water-saturated HEU product oxide and polyethylene (Model 1) blanketed by a variable thickness shell of stainless steel, with a 20.0-cm-thick water reflector external to the shell. The shell at maximum thickness corresponds to the 66,133-g stainless steel of the containment vessel and the liner and drum assembly. The thickness of the stainless steel shell is varied from zero to 4.6944 cm in Cases **5atdosr_1** through **5atdosr_11** (Table 6.9.10.9-1). The maximum $k_{eff} + 2\sigma$ is 0.915 for 6 kg of HEU product oxide and zero stainless-steel thickness. The $k_{eff} + 2\sigma$ values decrease to a minimum of 0.863 at 1.84-cm stainless-steel shell thickness (Case **5atdosr_4**). The $k_{eff} + 2\sigma$ values increase to within 0.02 of the maximum at the maximum stainless steel thickness (Case **5atdosr_11**). The overall effect of adding the stainless steel of the ES-3100 packaging to the configuration is the reduction in the neutron multiplication factor for the system. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.924.

Model 3 (Fig. 6.13, Sect. 6.3.1.4) is configured the same as Model 2 with the exception that instead of stainless steel, the variable-thickness shell is composed of dry Kaolite (Cases **5atdodrk_1** through **5atdodkr_6**) or wet Kaolite (Cases **5atdo15rk_1** through **5atdo15kr_6**). Dry Kaolite from inside the body weldment outer liner and the drum top plug consists of 51,214.9-g vermiculite-cement and 2,204.7-g bound water. Wet Kaolite to a maximum of 60,223 g consists of the dry Kaolite and up to 6,803.8-g free water—moisture which dampens the Kaolite and may also be present in the containment vessel well. Because the Kaolite is constrained within the liners of the packaging, the Kaolite density rather than its volume changes when water is added to the material. Consequently, the shell thickness in Model 3 does not change as free water is added. The $k_{eff} + 2\sigma$ decreases from 0.915 to 0.719 for dry Kaolite (Cases **5atdodkr_1** through **5atdodkr_6**) and decreases from 0.916 to 0.729 for wet Kaolite (Cases **5atdo15kr_1** − **5atdo15kr_6**). NCT Kaolite of the ES-3100 packaging or wet Kaolite is not as effective a reflector as 20 cm water surrounding the core.

Model 4 (Fig. 6.14, Sect. 6.3.1.4) represents a spherical core of water-saturated HEU product oxide and polyethylene (Model 1) homogenized with wet Kaolite. A 20-cm-thick water reflector blankets the spherical core. All other ES-3100 packaging material (stainless steel, 277-4 neutron poison, etc.) is excluded from Model 4. In Cases **5athop15kr_1** through **5athop15kr_5** (Table 6.9.10.9-1), $k_{eff} + 2\sigma$ increases from 0.484 to 0.574 as free water is added to the 15-lb limit. Again, the core radius is constant with changing moisture conditions because the volume of the porous Kaolite constrained within the liners of the packaging does not change appreciably as the material is dried out or absorbs water. Small amounts of free water in the Kaolite can have a significant moderating effect if introduced to the fissile core.

Model 5 (Fig. 6.15, Sect. 6.3.1.4) is an extension of Model 3 applied to HEU product oxide contents. Excess water from wet Kaolite is homogenized with the spherical core of water-saturated HEU product oxide and polyethylene (Model 3). Two variations are evaluated: a maximum 13-lb free water from the Kaolite for Cases **5athopw13kr_1** through **5athopw13kr_5** with the $k_{eff} + 2\sigma$ varying from 0.286 to 0.782 and a maximum 15-lb free water for Cases **5athopw15kr_1** through **5athopw15kr_5** with the $k_{eff} + 2\sigma$ varying from 0.292 to 0.830. The homogenized core is under moderated because sufficient water is not present in the wet Kaolite and containment vessel well to reach the point of optimum moderation. While 15-lb water appears an acceptable amount of free water in Kaolite for HEU product oxide content, the 12-lb limit on free water established in Sect. 6.7.3 for the more reactive HEU metal content applies to HEU product oxide in order for it to be shipped by air transport.

Model 6 (Fig. 6.16, Sect. 6.3.1.4) is configured similar to Model 4 with the exception that only a partial amount of HEU product oxide resides in the homogenized core; the remainder of the unsaturated HEU product oxide is modeled as a shell external to the spherical core and internal to the 20.0 cm thick water reflector. As discussed in Sect. 6.9.10.3.1, the amount of HEU product oxide in the homogenized core is varied in 1-kg increments from the full 6-kg amount of Model 5 minus 1 kg (Cases **5athop15kor_1_5_1** to **5athop15kor_5_5_1** with the $k_{eff} + 2\sigma$ ranging varying from 0.483 to

0.572) to an amount of 1-kg HEU product oxide (Cases **5athop15kor_1_1_5** to **5athop15kor_5_1_5** with the $k_{eff} + 2\sigma$ varying from 0.496 to 0.579). The most reactive variation of Model 6 occurs for Case **5athop15kor_5_2_4** ($k_{eff} + 2\sigma = 0.584$) where 2-kg HEU product oxide (1,761-g ^{235}U) is homogenized in the core with 11,456.8-g water and 500-g polyethylene, and the remaining 4-kg HEU product oxide (3,521-g ^{235}U) forms a shell between the core and the 20-cm-thick water reflector.

The most reactive case from all six models is Cases **5atdor_1_1_6** (Table 6.9.10.9-1) which has a $k_{eff} + 2\sigma = 0.917$ and represents a single UO_2 sphere of 6-kg HEU product oxide (5,281-g ^{235}U) at a minimum oxide density of 2-g/cm^3 homogenized with 2,448.1-g water and 500-g polyethylene.

6.9.10.8 Benchmark Experiments and the Criticality Validation

This information is discussed in Sect. 6.9.8.7. The USL is 0.924 for calculations run using SCALE 5.

6.9.10.9 Calculation Results Tables for HEU Product Oxide Contents for Air Transport

Tables 6.9.10.9-1 and 6.9.10.9-2 contain a summary of the calculation results for the HEU product oxide contents to be shipped by air transport as contents in the ES-3100 shipping package.

Table 6.9.10.9-1. Results for HEU oxide content for air transportation (Models 1–5)

Case name	Core							Shell				nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	Oxide (g)	^{235}U (g)	H_2O (g)	CH_2 (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)				
Compromised package, HEU-poly core in spherical configuration, 20.0-cm water reflector (Model 1)															
UO_2 saturated oxide at 6.54 g/cm^3															
5atdor_1_5_14	14,000	12,323	861.8	500	na	3.19	8.6213	na	na	na	na	0.0633	0.86843	0.00141	0.87125
5atdor_1_5_13	13,000	11,443	800.2	500	na	3.29	8.4544	na	na	na	na	0.0637	0.85690	0.00144	0.85978
5atdor_1_5_12	12,000	10,562	738.6	500	na	3.41	8.2806	na	na	na	na	0.0645	0.84384	0.00137	0.84658
5atdor_1_5_11	11,000	9,682	677.1	500	na	3.56	8.0992	na	na	na	na	0.0651	0.83277	0.00119	0.83515
5atdor_1_5_10	10,000	8,802	615.5	500	na	3.73	7.9093	na	na	na	na	0.0660	0.81625	0.00152	0.81929
5atdor_1_5_9	9,000	7,922	554.0	500	na	3.94	7.7098	na	na	na	na	0.0677	0.80044	0.00135	0.80314
5atdor_1_5_8	8,000	7,042	492.4	500	na	4.21	7.4994	na	na	na	na	0.0690	0.78520	0.00157	0.78834
5atdor_1_5_7	7,000	6,162	430.9	500	na	4.55	7.2765	na	na	na	na	0.0702	0.76642	0.00132	0.76906
5atdor_1_5_6	6,000	5,281	369.3	500	na	5.00	7.0390	na	na	na	na	0.0715	0.74917	0.00114	0.75145
UO_2 saturated oxide, density increasing from 2.0 to 6.54 g/cm^3 in 1-g/cm^3 increments															
5atdor_1_1_6	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	na	na	0.0557	0.91417	0.00131	0.91679
5atdor_1_2_6	6,000	5,281	1,449.9	500	na	10.34	8.4680	na	na	na	na	0.0616	0.84504	0.00131	0.84766
5atdor_1_3_6	6,000	5,281	950.8	500	na	7.87	7.8722	na	na	na	na	0.0655	0.80424	0.00143	0.80710
5atdor_1_4_6	6,000	5,281	651.4	500	na	6.39	7.4664	na	na	na	na	0.0684	0.77776	0.00140	0.78056
5atdor_1_5_6	6,000	5,281	369.3	500	na	5.00	7.0390	na	na	na	na	0.0715	0.74917	0.00114	0.75145
U_3O_8 saturated oxide, density increasing from 2.0 to 6.54 g/cm^3 in 1-g/cm^3 increments															
5atdor_2_1_6	6,000	5,078	2,273.0	500	na	14.98	9.4576	na	na	na	na	0.0579	0.88563	0.00150	0.88863
5atdor_2_2_6	6,000	5,078	1,274.8	500	na	9.85	8.4680	na	na	na	na	0.0637	0.81028	0.00142	0.81312
5atdor_2_3_6	6,000	5,078	775.7	500	na	7.29	7.8722	na	na	na	na	0.0689	0.76364	0.00147	0.76658
5atdor_2_4_6	6,000	5,078	476.2	500	na	5.75	7.4664	na	na	na	na	0.0714	0.73359	0.00133	0.73625
5atdor_2_5_6	6,000	5,078	194.2	500	na	4.30	7.0390	na	na	na	na	0.0751	0.69773	0.00112	0.69997

Table 6.9.10.9-1. Results for HEU oxide content for air transportation (Models 1–5)

Case name	Core							Shell				nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	Oxide (g)	^{235}U (g)	H_2O (g)	CH_2 (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)				
UO_3 saturated oxide, density increasing from 2.0 to 6.54 g/cm^3 in 1-g/cm^3 increments															
5atdor_3_1_6	6,000	4,983	2,173.0	500	na	14.75	9.4576	na	na	na	na	0.0582	0.87189	0.00138	0.87465
5atdor_3_2_6	6,000	4,983	1,174.8	500	na	9.52	8.4680	na	na	na	na	0.0647	0.79330	0.00132	0.79594
5atdor_3_3_6	6,000	4,983	675.7	500	na	6.91	7.8722	na	na	na	na	0.0695	0.74451	0.00130	0.74711
5atdor_3_4_6	6,000	4,983	376.3	500	na	5.34	7.4664	na	na	na	na	0.0735	0.70743	0.00127	0.70997
5atdor_3_5_6	6,000	4,983	94.2	500	na	3.86	7.0390	na	na	na	na	0.0774	0.66826	0.00120	0.67066
UO_2 saturated oxide at 2.0 g/cm^3															
5atdor_1_1_14	14,000	12,323	5,712.4	500	na	13.46	12.1664	na	na	na	na	0.0449	1.06986	0.00138	1.07262
5atdor_1_1_13	13,000	11,443	5,304.4	500	na	13.56	11.8915	na	na	na	na	0.0462	1.05375	0.00152	1.05679
5atdor_1_1_12	12,000	10,562	4,896.3	500	na	13.69	11.6031	na	na	na	na	0.0470	1.04068	0.00156	1.04380
5atdor_1_1_11	11,000	9,682	4,488.3	500	na	13.83	11.2997	na	na	na	na	0.0478	1.02468	0.00141	1.02750
5atdor_1_1_10	10,000	8,802	4,080.3	500	na	14.00	10.9791	na	na	na	na	0.0493	1.00466	0.00125	1.00716
5atdor_1_1_9	9,000	7,922	3,672.2	500	na	14.22	10.6385	na	na	na	na	0.0507	0.98663	0.00148	0.98959
5atdor_1_1_8	8,000	7,042	3,264.2	500	na	14.48	10.2740	na	na	na	na	0.0527	0.96167	0.00137	0.96441
5atdor_1_1_7	7,000	6,162	2,856.2	500	na	14.82	9.8831	na	na	na	na	0.0542	0.93946	0.00158	0.94262
5atdor_1_1_6	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	na	na	0.0557	0.91417	0.00131	0.91679
Compromised package, HEU-poly core in spherical configuration, stainless-steel shell, 20.0-cm water reflector (Model 2)															
UO_2 saturated oxide at 2.0 g/cm^3, steel from full amount in the packaging (66,113 g) to none															
5atdosr_11	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	66,133	14.1521	0.0292	0.89162	0.00136	0.89434
5atdosr_10	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	59,520	13.8131	0.0301	0.88373	0.00183	0.88739
5atdosr_9	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	52,907	13.4566	0.0313	0.88073	0.00128	0.88329
5atdosr_8	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	46,293	13.0802	0.0330	0.87977	0.00157	0.88291
5atdosr_7	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	39,680	12.6807	0.0347	0.87051	0.00153	0.87357
5atdosr_6	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	33,067	12.2543	0.0367	0.86825	0.00149	0.87123
5atdosr_5	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	26,453	11.7960	0.0393	0.86201	0.00170	0.86541

Table 6.9.10.9-1. Results for HEU oxide content for air transportation (Models 1–5)

Case name	Core							Shell				nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	Oxide (g)	^{235}U (g)	H_2O (g)	CH_2 (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)				
5atdosr_4	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	19,840	11.2990	0.0420	0.85884	0.00223	0.86330
5atdosr_3	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	13,227	10.7539	0.0461	0.86209	0.00210	0.86629
5atdosr_2	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	6,613	10.1472	0.0499	0.87559	0.00144	0.87847
5atdosr_1	6,000	5,281	2,448.1	500	na	15.27	9.4576	na	na	0	9.4577	0.0557	0.91194	0.00135	0.91464
Compromised package, HEU-poly core in spherical configuration, dry (bound water) Kaolite shell, 20.0-cm water reflector (Model 3) UO_2 saturated oxide at 2.0 g/cm^3, Kaolite from full amount in the packaging (53,419.1 g) to none															
5atdodkr_6	6,000	5,281	2,448.1	500	na	15.27	9.4576	51,214.3	2,204.8	53,419.1	31.2952	0.0420	0.71552	0.00154	0.71860
5atdodkr_5	6,000	5,281	2,448.1	500	na	15.27	9.4576	40,971.5	1,763.8	42,735.3	29.1186	0.0435	0.72104	0.00132	0.72368
5atdodkr_4	6,000	5,281	2,448.1	500	na	15.27	9.4576	30,728.6	1,322.9	32,051.5	26.5564	0.0451	0.72819	0.00126	0.73071
5atdodkr_3	6,000	5,281	2,448.1	500	na	15.27	9.4576	20,485.7	881.9	21,367.6	23.3725	0.0476	0.74581	0.00142	0.74865
5atdodkr_2	6,000	5,281	2,448.1	500	na	15.27	9.4576	10,242.9	440.9	10,683.8	18.9517	0.0514	0.77362	0.00188	0.77738
5atdodkr_1	6,000	5,281	2,448.1	500	na	15.27	9.4576	0.0	0.0	0.0	9.4577	0.0556	0.91160	0.00180	0.91520
Compromised package, HEU-poly core in sph. config., wet (bound plus 15-lb free water) Kaolite shell, 20.0-cm water reflector (Model 3) UO_2 saturated oxide at 2.0 g/cm^3, Kaolite from full amount in the packaging (53,419.1 g plus 6803.9 g water) to none															
5atdo15kr_6	6,000	5,281	2,448.1	500	na	15.27	9.4576	51,214.3	9,008.7	60,223.0	31.2952	0.0352	0.72501	0.00179	0.72859
5atdo15kr_5	6,000	5,281	2,448.1	500	na	15.27	9.4576	40,971.5	7,206.9	48,178.4	29.1186	0.0371	0.73185	0.00123	0.73431
5atdo15kr_4	6,000	5,281	2,448.1	500	na	15.27	9.4576	30,728.6	5,405.2	36,133.8	26.5564	0.0394	0.73706	0.00135	0.73976
5atdo15kr_3	6,000	5,281	2,448.1	500	na	15.27	9.4576	20,485.7	3,603.5	24,089.2	23.3725	0.0424	0.74768	0.00162	0.75092
5atdo15kr_2	6,000	5,281	2,448.1	500	na	15.27	9.4576	10,242.9	1,801.7	12,044.6	18.9517	0.0474	0.77452	0.00119	0.77690
5atdo15kr_1	6,000	5,281	2,448.1	500	na	15.27	9.4576	0.0	0.0	0.0	9.45770	0.0561	0.91134	0.00212	0.91558

Table 6.9.10.9-1. Results for HEU oxide content for air transportation (Models 1–5)

Case name	Core							Shell				nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	Oxide (g)	^{235}U (g)	H_2O (g)	CH_2 (g)	Kaolite (g)	h/x	Rc (cm)	Kaolite (g)	H_2O (g)	Shell (g)	Rs (cm)				
Compromised package, homogeneous fixed-radius core [HEU, poly, wet Kaolite], 20.0-cm water reflector (Model 4)															
UO_2 saturated oxide at 2.0 g/cm^3															
5athop15kr_5	6,000	5,281	11,456.8	500	51,214.9	59.80	31.2953	na	na	na	na	0.0581	0.57123	0.00147	0.57417
5athop15kr_4	6,000	5,281	9,755.7	500	51,214.9	51.39	31.2953	na	na	na	na	0.0601	0.54795	0.00112	0.55019
5athop15kr_3	6,000	5,281	8,054.8	500	51,214.9	42.98	31.2953	na	na	na	na	0.0615	0.52486	0.00109	0.52704
5athop15kr_2	6,000	5,281	6,353.8	500	51,214.9	34.58	31.2953	na	na	na	na	0.0639	0.50302	0.00102	0.50506
5athop15kr_1	6,000	5,281	4,652.9	500	51,214.9	26.17	31.2953	na	na	na	na	0.0666	0.48198	0.00105	0.48408
Compromised package, homogeneous core [HEU, poly, free water from wet Kaolite], wet Kaolite shell, 20.0-cm water reflector (Model 5)															
UO_2 saturated oxide at 2.0 g/cm^3, maximum free water in wet Kaolite limited to 15 lb															
5athopw15kr_5	6,000	5,281	9252.0	500	na	48.90	13.5234	51214.9	2204.7	53419.6	31.8395	0.0392	0.82713	0.00145	0.83003
5athopw15kr_4	6,000	5,281	7551.0	500	na	40.49	12.7371	51214.9	3905.7	55120.6	31.7052	0.0408	0.74649	0.00140	0.74929
5athopw15kr_3	6,000	5,281	5850.1	500	na	32.09	11.8394	51214.9	5606.6	56821.5	31.5697	0.0428	0.63699	0.00131	0.63961
5athopw15kr_2	6,000	5,281	4149.1	500	na	23.68	10.7801	51214.9	7307.6	58522.5	31.4331	0.0465	0.48742	0.00132	0.49006
5athopw15kr_1	6,000	5,281	2448.1	500	na	15.27	9.4576	51214.9	9008.5	60223.4	31.2952	0.0557	0.29031	0.00072	0.29175
UO_2 saturated oxide at 2.0 g/cm^3, maximum free water in wet Kaolite limited to 13 lb															
5athopw13kr_5	6,000	5,281	8344.7	500	na	44.42	13.1157	51214.9	2204.7	53419.6	31.7680	0.0416	0.77874	0.00159	0.78192
5athopw13kr_4	6,000	5,281	6870.6	500	na	37.13	12.3935	51214.9	3678.9	54893.8	31.6512	0.0428	0.70043	0.00128	0.70299
5athopw13kr_3	6,000	5,281	5396.5	500	na	29.85	11.5756	51214.9	5153.0	56367.9	31.5334	0.0453	0.59483	0.00127	0.59737
5athopw13kr_2	6,000	5,281	3922.3	500	na	22.56	10.6222	51214.9	6627.2	57842.1	31.4148	0.0496	0.45474	0.00112	0.45698
5athopw13kr_1	6,000	5,281	2448.1	500	na	15.27	9.4576	51214.9	8101.3	59316.2	31.2952	0.0578	0.28459	0.00072	0.28603

Table 6.9.10.9-2. Results for HEU oxide content for air transportation (Model 6)

Case name	Core							Shell				nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	Oxide (g)	^{235}U (g)	H_2O (g)	CH_2 (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Oxide (g)	^{235}U (g)	Rs (cm)				
Compromised package, homogeneous core [HEU, poly, wet Kaolite, sat moisture from oxide], dry oxide shell, 20.0-cm water reflector UO_2 saturated oxide at 2.0 g/cm^3, maximum free water in wet Kaolite limited to 15 lb															
5athop15kor															
_5_5_1	5,000	4,401	11,456.8	500	51,214.9	71.76	31.9731	na	1000	880	32.0075	0.0579	0.56957	0.00117	0.57191
_4_5_1	5,000	4,401	9,755.9	500	51,214.9	61.67	31.8399	na	1000	880	31.8745	0.0598	0.54395	0.00114	0.54623
_3_5_1	5,000	4,401	8,054.9	500	51,214.9	51.58	31.7056	na	1000	880	31.7405	0.0618	0.52367	0.00103	0.52573
_2_5_1	5,000	4,401	6,353.9	500	51,214.9	41.49	31.5701	na	1000	880	31.6053	0.0634	0.50176	0.00107	0.50390
_1_5_1	5,000	4,401	4,653.0	500	51,214.9	31.41	31.4335	na	1000	880	31.4690	0.0665	0.48060	0.00100	0.48260
5athop15kor															
_5_4_2	4,000	3,521	11,456.8	500	51,214.9	89.69	31.9342	na	2000	1,761	32.0028	0.0572	0.57314	0.00130	0.57574
_4_4_2	4,000	3,521	9,755.9	500	51,214.9	77.08	31.8006	na	2000	1,761	31.8698	0.0587	0.55395	0.00110	0.55615
_3_4_2	4,000	3,521	8,054.9	500	51,214.9	64.47	31.6660	na	2000	1,761	31.7358	0.0604	0.53308	0.00132	0.53572
_2_4_2	4,000	3,521	6,353.9	500	51,214.9	51.86	31.5302	na	2000	1,761	31.6006	0.0621	0.50942	0.00125	0.51192
_1_4_2	4,000	3,521	4,653.0	500	51,214.9	39.26	31.3932	na	2000	1,761	31.4642	0.0642	0.48878	0.00120	0.49118
5athop15kor															
_5_3_3	3,000	2,641	11,456.7	500	51,214.9	119.59	31.8951	na	3000	2,641	31.9981	0.0559	0.57798	0.00103	0.58004
_4_3_3	3,000	2,641	9,755.7	500	51,214.9	102.78	31.7612	na	3000	2,641	31.8651	0.0574	0.55885	0.00120	0.56125
_3_3_3	3,000	2,641	8,054.8	500	51,214.9	85.97	31.6262	na	3000	2,641	31.7310	0.0594	0.53632	0.00102	0.53836
_2_3_3	3,000	2,641	6,353.8	500	51,214.9	69.15	31.4901	na	3000	2,641	31.5958	0.0614	0.51426	0.00104	0.51634
_1_3_3	3,000	2,641	4,652.9	500	51,214.9	52.34	31.3527	na	3000	2,641	31.4594	0.0632	0.49194	0.00108	0.49410
5athop15kor															
_5_2_4	2,000	1,761	11,456.8	500	51,214.9	179.38	31.8559	na	4000	3,521	31.9935	0.0552	0.58113	0.00119	0.58351
_4_2_4	2,000	1,761	9,755.9	500	51,214.9	154.17	31.7217	na	4000	3,521	31.8605	0.0566	0.55859	0.00114	0.56087
_3_2_4	2,000	1,761	8,054.9	500	51,214.9	128.95	31.5864	na	4000	3,521	31.7263	0.0586	0.53825	0.00116	0.54057

Table 6.9.10.9-2. Results for HEU oxide content for air transportation (Model 6)

Case name	Core							Shell				nlf	k_{eff}	σ	$k_{eff} + 2\sigma$
	Oxide (g)	^{235}U (g)	H_2O (g)	CH_2 (g)	Kaolite (g)	h/x	Rc (cm)	H_2O (g)	Oxide (g)	^{235}U (g)	Rs (cm)				
_2_2_4	2,000	1,761	6,353.9	500	51,214.9	103.73	31.4499	na	4000	3,521	31.5910	0.0604	0.51481	0.00120	0.51721
_1_2_4	2,000	1,761	4,653.0	500	51,214.9	78.51	31.3122	na	4000	3,521	31.4545	0.0617	0.49484	0.00121	0.49726
5athop15kor															
_5_1_5	1,000	880	11,456.8	500	51,214.9	358.71	31.8167	na	5000	4,401	31.9888	0.0546	0.57631	0.00127	0.57885
_4_1_5	1,000	880	9,755.9	500	51,214.9	308.28	31.6822	na	5000	4,401	31.8558	0.0555	0.55694	0.00118	0.55930
_3_1_5	1,000	880	8,054.9	500	51,214.9	257.85	31.5465	na	5000	4,401	31.7216	0.0569	0.53685	0.00094	0.53873
_2_1_5	1,000	880	6,353.9	500	51,214.9	207.43	31.4096	na	5000	4,401	31.5862	0.0586	0.51698	0.00112	0.51922
_1_1_5	1,000	880	4,653.0	500	51,214.9	157.00	31.2716	na	5000	4,401	31.4497	0.0604	0.49388	0.00101	0.49590

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Appendix 6.9.11

Criticality Evaluation of HEU Metal Turnings, Fines, or Powders (>80% enriched); Removal of Carbon Limits for Oxides; Low Density Oxides; Removal of Cladding Limits; and Uranium Tetrafluoride at a Criticality Safety Index of 2.0

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Appendix 6.9.11

Criticality Evaluation of HEU Metal Turnings, Fines, or Powders (>80% enriched); Removal of Carbon Limits for Oxides; Low Density Oxides; Removal of Cladding Limits; and Uranium Tetrafluoride at a Criticality Safety Index of 2.0

This appendix presents the criticality safety evaluation of several modifications to the limits for the ES-3100 package. First, highly enriched uranium (HEU) metal turnings, fines, or powders at enrichments of 90%, 95%, and 100% for criticality safety index (CSI) values of 0.0, 0.4, 0.8, 2.0, and 3.2 are evaluated. Previous analyses in Sects. 6.4 and 6.5 only evaluated the HEU metal turnings, fines, or powders for enrichments up to 80%. This appendix also evaluates the removal of the carbon restriction for all HEU oxides (i.e., eliminating the 921-g carbon limit). Furthermore, HEU oxides with a bulk density from 0.5 to 2.0 g/cm^3 at a CSI of 0.0 are evaluated. Based on evaluations in this appendix, HEU broken metal cladding restrictions are not required for ground and air transport. Cladding is also not controlled for research reactor fuel elements and components that are shown to be bounded by HEU bulk oxide (U_3O_8-Al, oxides of U-Zr, and UO_2-Mg). Studies on the effect of cladding on fuel pellets are also examined. Lastly, this appendix evaluates uranium tetrafluoride (UF_4) at CSI of 2.0.

Calculations presented in this appendix are performed using the Monte Carlo Criticality Safety Analysis Sequence (CSAS), CSAS5 code module (KENO V.a), and the 238-group ENDF/B-VII cross-section library of the Standardized Computer Analysis for Licensing Evaluation (SCALE) 6.1.1 (ORNL/TM-2005/39). Criticality calculations documented in Sects. 6.4–6.6 were performed using SCALE 4.4a (NUREG/CR-200, Rev. 6) executed on an Hewlett Packard (HP) Model J5600 RISC Workstation (CMODB). This system has been retired from service, and the SCALE 4.4a version of the code is no longer supported by the Radiation Safety Information Computational Center at the Oak Ridge National Laboratory.

6.9.11.1 Description of the Criticality Design

The design features of the ES-3100 package addressed in Sect. 6.1.1 are not changed. The same codes and standards addressed in Sect. 6.1.2 apply.

6.9.11.2 Additional or Revised Content Description for the ES-3100 Package

The materials identified in Table 6.4 are used in this analysis. The only changes from Table 6.4 would be higher enriched uranium for metal turnings, fines, or powders and the addition of carbon to UO_2 calculations. The amount of carbon modeled in these calculations is varied from 0 to 5000 g in 1000-g increments. The amount of UO_2 modeled in these calculations is also varied in increments of 1000 g except for the HEU oxide CSI 0.4 calculations in which UO_2 is varied in increments of 250 g. The theoretical density of carbon (2.27 g/cm^3) is used in these calculations. Low bulk density oxides ranging from 0.5 to 2.0 g/cm^3 are also evaluated. The various amounts of cladding for broken metal is analyzed for both ground and air transport. Cladding is also evaluated for research reactor fuel elements and components that are shown to be bounded by HEU bulk oxide (U_3O_8-Al, oxides of U-Zr, and UO_2-Mg) in Table 6.9.8.2.

6.9.11.3 General Considerations

General considerations expressed in Sect. 6.3 regarding assumptions made about the ES-3100 packaging and the calculation methodology for the evaluation is maintained. No changes are required to the calculation models of the containment vessel (CV), the single-unit packaging (Sect. 6.3.1.1), the damaged packaging (Sect. 6.3.1.3), or the material properties specifications (Sect. 6.3.2) except for the analysis of carbon in HEU oxides.

6.9.11.3.1 Model configuration for supplemental contents

Unless stated otherwise, the materials and models used in this analysis are the same as described in Sect. 6.3. The only difference is using higher uranium enrichments for the metal turnings, fines, or powders; adding carbon in UO_2; and evaluating lower bulk density HEU oxides, HEU oxides at a CSI of 0.4 (not including bulk densities below 2.0 g/cm^3), and UF_4 at a CSI of 2.0.

In this analysis, UO_2 is evaluated with varying amount of carbon. Only UO_2 is evaluated because this is shown as the most reactive oxide in Sect. 6.4.3. Calculations are performed substituting various amounts of carbon for equal amounts oxide as well as adding carbon to a fixed amount of oxide. These calculations are performed using the same input decks used in the HEU UO_2 evaluation in this safety analysis report for packaging (SARP). The methodologies used for the calculations in this appendix are also used for the rest of the analyses in this SARP. In this SARP—no changes are made in the ES-3100 material content models except for carbon, and no changes are made to the ES-3100 container model. Oxide cases are run with 500 g of polyethylene mixed with the oxide.

6.9.11.3.2 Content model material specification

Material property specifications for this material are presented in Table 6.4.

6.9.11.4 Computer Codes and Cross-Section Libraries

KENO V.a calculations are performed using CSAS5 in SCALE 6.1.1 on the Microway Parallel Linux Cluster ENGHPC01 in the Y-12 Engineering organization in Oak Ridge, Tennessee. The upper subcritical limit (USL) without any safety margin for running SCALE 6.1.1 on this workstation is 0.985 (which covers all HEU systems with enrichments > 60%) as documented in RP YAREA-F-0455. NUREG/CR-5661 provides guidance that the USL should be established with a minimum margin of subcriticality of 0.05. Using this safety margin, the USL for the calculations performed in this appendix would be 0.935.

Several CSAS control modules are contained in SCALE6.1. The CSAS control modules are designed to analyze systems containing fissile material and calculate the neutron multiplication factor (k_{eff}) of the system. This validation is only applicable to the CSAS5 control module that uses the KENO V.a functional module. Prior to entering the KENO V.a functional module, the CSAS5 control module calls a series of utility modules and other functional modules to process the cross-section data. This validation used the 238-group ENDF/B-VII cross-section library. This is a multigroup library containing 238 distinct neutron energy groups based on the ENDF/B-VII library. The CSAS5 control module executes several functional modules to process the cross-section data used in KENO V.a. These programs are:

- WORKER: This functional module interfaces between the AMPX master library contained in the SCALE code package and the AMPX working library used in KENO V.a.
- BONAMI: This functional module processes the unresolved resonance data contained in the master library and places it in the working library.
- PMC: This functional module uses point-wise continuous cross-section data to solve a one dimensional equivalent problem producing a flux profile used for processing cross-section data.
- CENTRM: This functional module uses the flux profile calculated in PMC to collapse point-wise continuous cross-section data into the appropriate group structure producing a working library used in KENO V.a.
- KENO V.a: This functional module performs the three dimensional Monte Carlo calculation using the cross-section library provided by the WORKER module.

This validation covers the execution of the CSAS5 control module and the functional modules that are executed by it.

6.9.11.5 CV and Single Package Evaluation

Calculations are performed for the fully reflected CV and fully reflected single unit [for both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC)] with the specific gravity of water inside the CV varied from dry to fully flooded for the CV cases and evaluated as fully flooded for the single-unit cases. The CV is analyzed only for fully flooded because full flooding of the CV is shown to be the most reactive configuration.

6.9.11.5.1 HEU metal turnings, fines, or powders

In the reflected CV cases, calculations are performed examining the HEU metal turnings, fines, or powders at enrichments of 100%, 95%, and 90%. Table 6.9.11.1 examined the CV flooded while Table 6.9.11.2 examined with CV with varying amounts of water, which are shown as varying amount of moisture fraction inside the containment vessel (MOCFR). For the single package cases, Table 6.9.11.3 examined the CV flooded for the NCT cases, and Table 6.9.11.4 examined the CV flooded for the HAC cases.

Table 6.9.11.1. Results for HEU turnings, fines, and powders, reflected CV, flooded CV

Case cvr3cha_	100% ^{235}U (ω = 8)		95% ^{235}U (ω = 7)		90% ^{235}U (ω = 6)	
	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$
11_ω_15	10,172	0.9305	9,670	0.9178	9,166	0.9132
12_ω_15	**11,097**	**0.9319**	10,549	0.9215	10,000	0.9131
13_ω_15	12,946	0.9380	12,307	0.9236	11,666	0.9157
16_ω_15	15,721	0.9381	14,944	0.9301	14,166	0.9221
18_ω_15	17,570	0.9443	16,702	0.9302	15,833	0.9243
19_ω_15	18,495	0.9484	**17,581**	**0.9344**	16,667	0.9260
20_ω_15	19,420	0.9496	18,460	0.9394	17,500	0.9297
22_ω_15	21,269	0.9555	20,219	0.9401	19,167	0.9332
24_ω_15	23,119	0.9564	21,977	0.9428	20,833	0.9331
25_ω_15	24,968	0.9603	23,735	0.9437	**21,667**	**0.9340**
26_ω_15	25,893	0.9622	24,613	0.9451	23,333	0.9365

Table 6.9.11.2. Results for HEU turnings, fines, and powders, reflected CV, varying water in the CV

Case cvr3cha_	MOCFR	k_{eff}	σ	k_{eff} + 2σ
	100% ^{235}U, 11,097-g ^{235}U (ω = 8)			
12_ω_15	1.0	0.9293	0.0013	**0.9319**
12_ω_14	0.9	0.8814	0.0012	0.8838
12_ω_12	0.7	0.7813	0.0013	0.7839
12_ω_8	0.3	0.5792	0.0011	0.5814
12_ω_1	1.0E-20	0.4446	0.0011	0.4468
	95% ^{235}U, 17,581-g ^{235}U (ω = 7)			
19_ω_15	1.0	0.9314	0.0015	**0.9344**
19_ω_14	0.9	0.8914	0.0013	0.8940
19_ω_12	0.7	0.8006	0.0011	0.8028
19_ω_8	0.3	0.6207	0.0010	0.9227
19_ω_1	1.0E-20	0.4976	0.0011	0.4998
	90% ^{235}U, 21,667-g ^{235}U (ω = 6)			
25_ω_15	1.0	0.9316	0.0012	**0.9340**
25_ω_14	0.9	0.8928	0.0011	0.8950
25_ω_12	0.7	0.8123	0.0012	0.8147
25_ω_8	0.3	0.6459	0.0011	0.6481
25_ω_1	1.0E-20	0.5272	0.0012	0.5296

From the results found in Tables 6.9.11.1 and 6.9.11.2 for a fully flooded CV, the highest amount of ^{235}U that is shown to be below the USL is ~11 kg for 100% enriched (Case **cvr3cha_12_8_15** with k_{eff} + 2σ of 0.932), ~17.5 kg for 95% enriched (Case **cvr3cha_19_7_15** with k_{eff} + 2σ of 0.934), and ~21.6 kg for 90% enriched (Case **cvr3cha_25_6_15** with k_{eff} + 2σ of 0.934).

In the reflected single-unit cases for both NCT and HAC, calculations are performed examining the HEU metal turnings, fines, or powders at enrichments of 100%, 95%, and 90%. Only the fully flooded CV cases are examined, and the results are found in Tables 6.9.11.3 and 6.9.11.4.

Table 6.9.11.3. Results for HEU turnings, fines, and powders, reflected single package, flooded CV, NCT

Case ncsrbmt11_	100% ^{235}U (ω = 8)		95% ^{235}U (ω = 7)		90% ^{235}U (ω = 6)	
	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$
1_ω_15	924	0.6554	879	0.6462	833	0.6338
10_ω_15	9,247	0.8247	8,790	0.8100	8,333	0.8048
20_ω_15	19,420	0.8480	18,460	0.8350	17,500	0.8262
25_ω_15	24,968	0.8612	23,735	0.8451	21,667	0.8306
30_ω_15	29,952	0.8713	28,130	0.8574	26,667	0.8429
35_ω_15	34,216	0.8828	32,526	0.8667	30,833	0.8515
36_ω_15	**35,141**	**0.88440**	**33,405**	**0.8693**	**31,667**	**0.8562**

Table 6.9.11.4. Results for HEU turnings, fines, and powders, reflected single package, flooded CV, HAC

Case hcsrbmt12_	100% ^{235}U (ω = 8)		95% ^{235}U (ω = 7)		90% ^{235}U (ω = 6)	
	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$
1_ω	924	0.6535	879	0.6455	833	0.6381
10_ω	9,247	0.8214	8,790	0.8137	8,333	0.8048
20_ω	19,420	0.8796	18,460	0.8354	17,500	0.8253
25_ω	24,968	0.8612	23,735	0.8491	21,667	0.8333
30_ω	29,952	0.8732	28,130	0.8581	26,667	0.8457
35_ω	34,216	0.8831	32,526	0.8690	30,833	0.8601
36_ω	**35,141**	**0.8887**	**33,405**	**0.8710**	**31,667**	**0.8581**

From the results found in the Tables 6.9.11.3 and 6.9.11.4, all of the cases are shown to below the USL. All cases are well below the comparative fully flooded and reflected CV cases presented in Tables 6.9.11.1 and 6.9.11.2. The comparison of the single package case results with corresponding case results for the reflected CV reveals that flooded ES-3100 packaging is not as good a reflector as 30.48-cm water surrounding the CV.

6.9.11.5.2 UO_2 and carbon

In the reflected CV cases, calculations are performed examining various amounts of oxide mixed with 500 g of polyethylene and carbon ranging from 0 to 5000 g in 1000-g increments. In Tables 6.9.11.5–6.9.11.7, the fully reflected CV is modeled fully flooded and dry at various uranium and carbon masses. The single package cases are examined in Tables 6.9.11.8–6.9.11.10. Note that the shaded sections of these tables (and those that follow) are masses that would not fit inside the CV at that density, while "N/A" entries in the tables denote where additional calculations are not necessary.

Table 6.9.11.5. ES-3100 results for UO_2 at a bulk density of 2 g/cm^3, reflected CV, varying amounts of carbon, CV fully flooded and dry

MOCFR	Oxide mass (kg)	Case cvcrpdoxt11a_	$k_{eff} + 2\sigma$ [a]					
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	4 kg carbon (ω = 5)	5 kg carbon (ω = 6)
1.0	19	1_19_ω_15	0.9168					
1.0	18	1_18_ω_15	0.9186	0.9038				
1.0	17	1_17_ω_15	0.9163	0.9010	0.8871			
1.0	16	1_16_ω_15	0.9148	0.9027	0.8851	0.8707		
1.0	15	1_15_ω_15	0.9120	0.8959	0.8817	0.8679	0.8560	
1.0	14	1_14_ω_15	0.9095	0.8932	0.8785	0.8621	0.8489	0.8350
1.0	13	1_13_ω_15	0.9042	0.8863	0.8726	0.8563	0.8232	0.8299
1.0	12	1_12_ω_15	0.9031	0.8846	0.8654	0.8479	0.8360	0.8207
1.0E-20	19	1_19_ω_1	0.9225					
1.0E-20	18	1_18_ω_1	0.9171	0.9065				
1.0E-20	17	1_17_ω_1	0.9137	0.9017	0.8911			
1.0E-20	16	1_16_ω_1	0.9136	0.8978	0.8878	0.8707		
1.0E-20	15	1_15_ω_1	0.9103	0.8938	0.8811	0.8684	0.8552	
1.0E-20	14	1_14_ω_1	0.9075	0.8888	0.8754	0.8620	0.8460	0.8325
1.0E-20	13	1_13_ω_1	0.9012	0.8866	0.8722	0.8563	0.8405	0.8256
1.0E-20	12	1_12_ω_1	0.9012	0.8811	0.8634	0.8502	0.8360	0.8190

[a] The shaded sections are masses that would not fit inside the CV at that density.

From Table 6.9.11.5 for 2-g/cm^3 bulk density oxide, the volume of oxides with masses >19 kg would not fit inside the CV. Oxide masses of 15 kg and higher with a significant amount of carbon added would also not fit inside the CV. The same volumetric limitation is found for oxide masses of 23 kg and higher for 3-g/cm^3 bulk density oxide.

Table 6.9.11.6. ES-3100 results for UO_2 at a density of 3 g/cm^3, reflected CV, varying amounts of carbon, CV fully flooded and dry

MOCFR	Oxide mass (kg)	Case cvcrpdoxt11a_	$k_{eff} + 2\sigma$ [a]					
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	4 kg carbon (ω = 5)	5 kg carbon (ω = 6)
1.0	24	2_24_ω_15	0.9172	0.9045	0.8876	0.8799		
1.0	23	2_23_ω_15	0.9158	0.9012	0.8893	0.8729	0.8594	
1.0	22	2_22_ω_15	0.9133	0.8991	0.8849	0.9012	0.8581	0.8447
1.0	21	2_21_ω_15	0.9113	0.8953	0.8818	0.8691	0.8514	0.8396
1.0	20	2_20_ω_15	0.9113	0.8931	0.8803	0.8640	0.8496	0.8344
1.0	19	2_19_ω_15	0.9091	0.8901	0.8754	0.8580	0.8465	0.8308
1.0E-20	24	2_24_ω_1	0.9185	0.8995	0.8881	0.8754		
1.0E-20	23	2_23_ω_1	0.9140	0.9031	0.8873	0.8723	0.8600	
1.0E-20	22	2_22_ω_1	0.8116	0.8986	0.8826	0.8706	0.8572	0.8449
1.0E-20	21	2_21_ω_1	0.9119	0.8967	0.8790	0.8655	0.8517	0.8419
1.0E-20	20	2_20_ω_1	0.9079	0.8938	0.8785	0.8609	0.8480	0.8377
1.0E-20	19	2_19_ω_1	0.9050	0.8875	0.8739	0.8573	0.8448	0.8300

[a] The shaded sections are masses that would not fit inside the CV at that density.

Table 6.9.11.7. ES-3100 results for UO_2 at a density of 4 g/cm^3, reflected CV, varying amounts of carbon, CV fully flooded and dry

MOCFR	Oxide mass (kg)	Case cvcrpdoxt11a_	$k_{eff} + 2\sigma$					
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	4 kg carbon (ω = 5)	5 kg carbon (ω = 6)
1.0	24	3_24_ω_15	0.9085	0.8907	0.8761	0.8590	0.8450	0.8331
1.0	23	3_23_ω_15	0.9095	0.8899	0.8740	0.8579	0.8440	0.8273
1.0	22	3_22_ω_15	0.9035	0.8858	0.8727	0.8530	0.8380	0.8230
1.0	21	3_21_ω_15	0.9037	0.8842	0.8650	0.8494	0.8353	0.8192
1.0	20	3_20_ω_15	0.9005	0.8814	0.8625	0.8441	0.8286	0.8173
1.0	19	3_19_ω_15	0.8980	0.8759	0.8559	0.8386	0.8261	0.8096
1.0E-20	24	3_24_ω_1	0.9089	0.8914	0.8757	0.8580	0.8441	0.8320
1.0E-20	23	3_23_ω_1	0.9059	0.8878	0.8712	0.8558	0.8399	0.8262
1.0E-20	22	3_22_ω_1	0.9022	0.8843	0.8683	0.8517	0.8353	0.8217
1.0E-20	21	3_21_ω_1	0.8964	0.8815	0.8623	0.8462	0.8309	0.8196
1.0E-20	20	3_20_ω_1	0.8935	0.8771	0.8554	0.8454	0.8272	0.8156
1.0E-20	19	3_19_ω_1	0.8924	0.8730	0.8577	0.8385	0.8209	0.8095

From the results found in Tables 6.9.11.5–6.9.11.7 for a fully flooded and dry reflected CV, the most reactive cases are those with no carbon mixed with the oxide. In both scenarios, substituting carbon for oxide and adding carbon to a fixed amount of oxide resulted in a decrease of reactivity. For example, when substituting 1000 g of carbon for 1000 g of oxide at 4-g/cm^3 bulk density for a total mass (oxide and carbon) of 24 kg in a flooded CV (Cases **cvcrpdoxt11a_3_24_1_15**, **cvcrpdoxt11a_3_23_2_15**, **cvcrpdoxt11a_3_22_3_15**, **cvcrpdoxt11a_3_21_4_15**, **cvcrpdoxt11a_3_20_5_15**, and **cvcrpdoxt11a_3_19_6_15** from Table 6.9.11.7), the reactivity decreases from k_{eff} + 2σ of 0.909 to 0.810. When adding carbon to 24 kg of oxide (Cases **cvcrpdoxt11a_3_24_1_15**, **cvcrpdoxt11a_3_24_2_15**, **cvcrpdoxt11a_3_24_3_15**, **cvcrpdoxt11a_3_24_4_15**, **cvcrpdoxt11a_3_24_5_15**, and **cvcrpdoxt11a_3_24_6_15**), the reactivity decreases from k_{eff} + 2σ of 0.909 to 0.832. In both scenarios, the reactivity of this system decreases. Substitution of carbon for oxide has the highest decrease in reactivity as opposed to just adding carbon to a fixed amount of oxide.

In the reflected single-unit cases for both NCT and HAC, calculations are performed examining uranium oxide with varying amounts of carbon ranging from 0 to 5000 g in 1000-g increments. The ES-3100 package is fully reflected with the specific gravity of water in the CV (MOCFR) modeled as fully flooded because this is shown in Tables 6.9.11.5–6.9.11.7 as the most reactive configuration. The results are shown in Tables 6.9.11.8–6.9.11.10.

Table 6.9.11.8. ES-3100 results for UO_2 at a bulk density of 2 g/cm^3, reflected package, varying amounts of carbon, CV fully flooded

Oxide mass (kg)	Case	k_{eff} + 2σ [a]					
		No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	4 kg carbon (ω = 5)	5 kg carbon (ω = 6)
NCT (Case ncsrptoxt11a_)							
19	1_19_ω	0.8143					
18	1_18_ω	0.8104	0.7946				
17	1_17_ω	0.8081	0.7923	0.7757			
16	1_16_ω	0.8071	0.7903	0.7724	0.7568		
15	1_15_ω	0.8083	0.7884	0.7689	0.7470	0.7361	
14	1_14_ω	0.8024	0.7870	0.7631	0.7465	0.7296	0.7142
13	1_13_ω	0.8011	0.7803	0.7602	0.7397	0.7231	0.7048
HAC (Case hcsrpdoxt12a_)							
19	1_19_ω	0.8126					
18	1_18_ω	0.8123	0.7979				
17	1_17_ω	0.8107	0.7946	0.7784			
16	1_16_ω	0.8092	0.7917	0.7742	0.7573		
15	1_15_ω	0.8092	0.7911	07692	0.7519	0.7364	
14	1_14_ω	0.8082	0.7843	0.7662	0.7477	0.7324	0.7119
13	1_13_ω	0.8048	0.7815	0.7623	0.7432	0.7239	0.7066

[a] The shaded sections are masses that would not fit inside the CV at that density.

Table 6.9.11.9. ES-3100 results for UO_2 at a bulk density of 3 g/cm^3, reflected package, varying amounts of carbon, CV fully flooded

Oxide mass (kg)	Case	$k_{eff} + 2\sigma$ [a]					
		No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	4 kg carbon (ω = 5)	5 kg carbon (ω = 6)
NCT (Case ncsrptoxt11a_)							
24	2_24_ω	0.8154	0.7943	0.7791	0.7629		
23	2_23_ω	0.8104	0.7950	0.7786	0.7607	0.7430	
22	2_22_ω	0.8125	0.7900	0.7730	0.7564	0.7395	0.7247
21	2_21_ω	0.8090	0.7896	0.7709	0.7534	0.7366	0.7221
20	2_20_ω	0.8050	0.7871	0.7670	0.7460	0.7328	0.7163
HAC (Case hcsrpdoxt12a_)							
24	2_24_ω	0.8128	0.7984	0.7793	0.7656		
23	2_23_ω	08127	0.7966	0.7760	0.7627	0.7435	
22	2_22_ω	0.8133	0.7948	0.7768	0.7594	0.7399	0.7275
21	2_21_ω	0.8122	0.7890	0.7737	0.7563	0.7366	0.7197
20	2_20_ω	0.8121	0.7914	0.7677	0.7509	0.7356	0.7172

[a] The shaded sections are masses that would not fit inside the CV at that density.

Table 6.9.11.10. ES-3100 results for UO_2 at a bulk density of 4 g/cm^3, reflected package, varying amounts of carbon, CV fully flooded

Oxide mass (kg)	Case	$k_{eff} + 2\sigma$					
		No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	4 kg carbon (ω = 5)	5 kg carbon (ω = 6)
NCT (Case ncsrptoxt11a_)							
24	3_24_ω	0.8107	0.7865	0.7678	0.7468	0.7313	0.7129
23	3_23_ω	0.8084	0.7864	0.7638	0.7444	0.7276	0.7078
22	3_22_ω	0.8057	0.7827	0.7627	0.7417	0.7216	0.7038
21	3_21_ω	0.8042	0.7796	0.7589	0.7358	0.7162	0.6986
20	3_20_ω	0.8026	0.7768	0.7541	0.7318	0.7104	0.6920
HAC (Case hcsrpdoxt12a_)							
24	3_24_ω	0.8115	0.7893	0.7673	0.7507	0.7345	0.7160
23	3_23_ω	0.8090	0.7888	0.7648	0.7465	0.7275	0.7107
22	3_22_ω	0.8092	0.7857	0.7684	0.7430	0.7239	0.7034
21	3_21_ω	0.8057	0.7828	0.7597	0.7379	0.7199	0.6997
20	3_20_ω	0.8018	0.7797	0.7564	0.7333	0.7124	0.6957

From the results found in the Tables 6.9.11.8–6.9.11.10 as in the CV cases shown in Tables 6.9.11.5–6.9.11.7, substituting carbon for oxide and adding carbon to a fixed amount of oxide resulted in a decrease of reactivity. The substitution of carbon for oxide results in the highest decrease in reactivity as opposed to adding carbon to a fixed amount of oxide. All cases are well below the comparative fully flooded and reflected CV cases shown in Tables 6.9.11.5–6.9.11.7. The comparison of the single package case results with corresponding case results for the reflected CV reveals that flooded ES-3100 packaging is not as good a reflector as 30.48-cm water surrounding the CV.

6.9.11.5.3 HEU low bulk density oxide

In the reflected CV cases, calculations are performed examining uranium oxide at bulk densities of 1.75, 1.5, 1.25, 1.0, 0.75, and 0.5 g/cm^3 at 100% enrichment. Tables 6.9.11.11 and 6.9.11.13 examined the CV dry (MOCFR of 1.0E-20) while Tables 6.9.11.12 and 6.9.11.14 examined with the CV fully flooded (MOCFR of 1.0). The single package cases are examined in Tables 6.9.11.15–6.9.11.18.

Table 6.9.11.11. Reflected CV model, oxide mixed with 500-g polyethylene, MOCFR of 1.0E−20

UO_2 mass (kg)	Case cvrcldoxt11_	1.75 g/cm^3 (ω = 1) [a]			1.50 g/cm^3 (ω = 2) [a]			1.25 g/cm^3 (ω = 3) [a]		
		k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$
16	ω_20_1	0.9158	0.0012	0.9182						
15	ω_19_1	0.9119	0.0013	0.9145						
14	ω_18_1	0.9111	0.0012	0.9135	0.9140	0.0019	0.9178			
13	ω_17_1	0.9041	0.0011	0.9063	0.9109	0.0014	0.9137			
12	ω_16_1	0.9018	0.0010	0.9038	0.9091	0.0014	0.9119	0.9130	0.0013	0.9156
11	ω_15_1	N/A	N/A	N/A	0.9044	0.0016	0.9076	0.9104	0.0017	0.9138
10	ω_14_1	N/A	N/A	N/A	0.9043	0.0016	0.9075	0.9098	0.0013	0.9124
9	ω_13_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9037	0.0017	0.9071
8	ω_12_1	N/A	N/A	N/A	N/A	N/A	N/A	0.8972	0.0014	0.9000

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

Table 6.9.11.12. Reflected CV model, oxide mixed with 500-g polyethylene, MOCFR of 1.0

UO_2 mass (kg)	Case cvrcldoxt11_	1.75 g/cm³ (ω = 1) [a]			1.50 g/cm³ (ω = 2) [a]			1.25 g/cm³ (ω = 3) [a]		
		k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ
16	ω_20_15	0.9172	0.0012	0.9196						
15	ω_19_15	0.9141	0.0015	0.9171						
14	ω_18_15	0.9126	0.0013	0.9152	0.9128	0.0013	0.9154			
13	ω_17_15	0.9102	0.0013	0.9128	0.9158	0.0018	0.9194			
12	ω_16_15	0.9063	0.0013	0.9089	0.9105	0.0014	0.9133	0.9173	0.0016	0.9205
11	ω_15_15	N/A	N/A	N/A	0.9060	0.0019	0.9098	0.9120	0.0012	0.9144
10	ω_14_15	N/A	N/A	N/A	0.9038	0.0014	0.9066	0.9083	0.0013	0.9109
9	ω_13_15	N/A	N/A	N/A	N/A	N/A	N/A	0.9056	0.0012	0.9080
8	ω_12_15	N/A	N/A	N/A	N/A	N/A	N/A	0.8992	0.0013	0.9018

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

Table 6.9.11.13. Reflected CV model, oxide mixed with 500-g polyethylene, MOCFR of 1.0E−20

UO_2 mass (kg)	Case cvrcldoxt11_	1.00 g/cm³ (ω = 4) [a]			0.75 g/cm³ (ω = 5) [a]			0.50 g/cm³ (ω = 6) [a]		
		k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ
9	ω_13_1	0.9081	0.0015	0.9111						
8	ω_12_1	0.9038	0.0013	0.9064						
7	ω_11_1	0.8989	0.0014	0.9017	0.9040	0.0010	0.9060			
6	ω_10_1	0.8912	0.0012	0.8936	0.9013	0.0013	0.9039			
5	ω_9_1	0.8780	0.0013	0.8806	0.8880	0.0015	0.8910			
4.5	ω_8_1	N/A	N/A	N/A	0.8816	0.0012	0.8840	0.8915	0.0014	0.8943
4	ω_7_1	N/A	N/A	N/A	0.8756	0.0015	0.8786	0.8848	0.0015	0.8878
3.5	ω_6_1	N/A	N/A	N/A	N/A	N/A	N/A	0.8783	0.0012	0.8807
3	ω_5_1	N/A	N/A	N/A	N/A	N/A	N/A	0.8703	0.0017	0.8737

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

Table 6.9.11.14. Reflected CV model, oxide mixed with 500-g polyethylene, MOCFR of 1.0

UO_2 mass (kg)	Case cvrcldoxt11_	1.00 g/cm³ (ω = 4) [a]			0.75 g/cm³ (ω = 5) [a]			0.50 g/cm³ (ω = 6) [a]		
		k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ
9	ω_13_15	0.9098	0.0013	0.9124						
8	ω_12_15	0.9066	0.0015	0.9096						
7	ω_11_15	0.9031	0.0013	0.9057	0.9069	0.0016	0.9101			
6	ω_10_15	0.8933	0.0013	0.8959	0.8996	0.0013	0.9022			
5	ω_9_15	0.8820	0.0013	0.8846	0.8952	0.0013	0.8978			
4.5	ω_8_15	N/A	N/A	N/A	0.8871	0.0014	0.8899	0.8880	0.0016	0.8912
4	ω_7_15	N/A	N/A	N/A	0.8794	0.0015	0.8824	0.8871	0.0017	0.8905
3.5	ω_6_15	N/A	N/A	N/A	N/A	N/A	N/A	0.8813	0.0014	0.8841
3	ω_5_15	N/A	N/A	N/A	N/A	N/A	N/A	0.8729	0.0015	0.8759

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

From the results found in Tables 6.9.11.11–6.9.11.14 for any oxide bulk density evaluated (down to 0.5 g/cm^3) with dry and flooded CV, the system is shown to be below the USL. Note that higher amounts of oxide are not evaluated for (e.g., > 16 kg at 1.75 g/cm^3, > 14 kg at 1.5 g/cm^3) because this quantity of material at these bulk densities would not fit inside the CV along with 500 g of polyethylene.

In the reflected single-unit cases for both NCT and HAC, calculations are performed examining the oxide bulk densities of 1.75, 1.5, 1.25, 1.0, 0.75, and 0.5 g/cm^3 at enrichments of 100%. Only the fully flooded CV cases are examined because these are the most reactive. The results are found in Tables 6.9.11.15–6.9.11.18.

Table 6.9.11.15. Reflected single package model, oxide mixed with 500-g polyethylene, NCT, MOCFR of 1.0

UO_2 mass (kg)	Case ncsrltoxt11_	1.75 g/cm³ (ω = 1) [a]			1.50 g/cm³ (ω = 2) [a]			1.25 g/cm³ (ω = 3) [a]		
		k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ
16	ω_20	0.8095	0.0014	0.8123						
15	ω_19	0.8081	0.0012	0.8105						
14	ω_18	0.8047	0.0018	0.8083	0.8080	0.0015	0.8110			
13	ω_17	0.8050	0.0014	0.8078	0.8039	0.0014	0.8067			
12	ω_16	0.7988	0.0014	0.8016	0.8025	0.0014	0.8053	0.8064	0.0014	0.8092
11	ω_15	N/A	N/A	N/A	0.8019	0.0013	0.8045	0.8067	0.0015	0.8097
10	ω_14	N/A	N/A	N/A	0.7969	0.0013	0.7995	0.8049	0.0014	0.8077
9	ω_13	N/A	N/A	N/A	N/A	N/A	N/A	0.7983	0.0013	0.8009
8	ω_12	N/A	N/A	N/A	N/A	N/A	N/A	0.7930	0.0014	0.7958

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

Table 6.9.11.16. Reflected single package model, oxide mixed with 500-g polyethylene, NCT, MOCFR of 1.0

UO_2 mass (kg)	Case ncsrltoxt11_	1.00 g/cm^3 (ω = 4) [a]			0.75 g/cm^3 (ω = 5) [a]			0.50 g/cm^3 (ω = 6) [a]		
		k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$
9	ω_13	0.8024	0.0014	0.8052						
8	ω_12	0.7990	0.0015	0.8020						
7	ω_11	0.7950	0.0013	0.7976	0.7962	0.0011	0.7984			
6	ω_10	0.7886	0.0012	0.7910	0.7960	0.0016	0.7992			
5	ω_9	0.7810	0.0014	0.7838	0.7866	0.0013	0.7892			
4.5	ω_8	N/A	N/A	N/A	0.7827	0.0014	0.7855	0.7845	0.0013	0.7871
4	ω_7	N/A	N/A	N/A	0.7782	0.0014	0.7810	0.7804	0.0017	0.7838
3.5	ω_6	N/A	N/A	N/A	N/A	N/A	N/A	0.7762	0.0012	0.7786
3	ω_5	N/A	N/A	N/A	N/A	N/A	N/A	0.7653	0.0016	0.7685

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

Table 6.9.11.17. Reflected single package model, oxide mixed with 500-g polyethylene, HAC, MOCFR of 1.0

UO_2 mass (kg)	Case hcsrldoxt12_	1.75 g/cm^3 (ω = 1) [a]			1.50 g/cm^3 (ω = 2) [a]			1.25 g/cm^3 (ω = 3) [a]		
		k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$
16	ω_20	0.8108	0.0012	0.8132						
15	ω_19	0.8074	0.0014	0.8102						
14	ω_18	0.8045	0.0011	0.8067	0.8070	0.0014	0.8098			
13	ω_17	0.8048	0.0014	0.8076	0.8098	0.0015	0.8128			
12	ω_16	0.8020	0.0016	0.8032	0.8063	0.0014	0.8091	0.8093	0.0012	0.8117
11	ω_15	N/A	N/A	N/A	0.8025	0.0012	0.8049	0.8055	0.0011	0.8077
10	ω_14	N/A	N/A	N/A	0.7978	0.0013	0.8004	0.8038	0.0012	0.8062
9	ω_13	N/A	N/A	N/A	N/A	N/A	N/A	0.8025	0.0012	0.8049
8	ω_12	N/A	N/A	N/A	N/A	N/A	N/A	0.7937	0.0012	0.7961

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

Table 6.9.11.18. Reflected single package model, oxide mixed with 500-g polyethylene, HAC, MOCFR of 1.0

UO_2 mass (kg)	Case hcsrldoxt12_	1.00 g/cm^3 (ω = 4) [a]			0.75 g/cm^3 (ω = 5) [a]			0.50 g/cm^3 (ω = 6) [a]		
		k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$
9	ω_13	0.8029	0.0017	0.8063						
8	ω_12	0.8000	0.0013	0.8026						
7	ω_11	0.7952	0.0013	0.7978	0.7967	0.0015	0.7997			
6	ω_10	0.7890	0.0014	0.7918	0.7938	0.0012	0.7962			
5	ω_9	0.7791	0.0016	0.7823	0.7882	0.0013	0.7908			
4.5	ω_8	N/A	N/A	N/A	0.7836	0.0014	0.7864	0.7856	0.0017	0.7890
4	ω_7	N/A	N/A	N/A	0.7789	0.0017	0.7823	0.7811	0.0014	0.7839
3.5	ω_6	N/A	N/A	N/A	N/A	N/A	N/A	0.7771	0.0014	0.7799
3	ω_5	N/A	N/A	N/A	N/A	N/A	N/A	0.7702	0.0013	0.7728

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

From the results found in the Tables 6.9.11.15–6.9.11.18, all cases are below the USL and are well below the comparative fully flooded and reflected CV cases in Tables 6.9.11.11–6.9.11.14. The comparison of the single package case results with corresponding case results for the reflected CV reveals that flooded ES-3100 packaging is not as good a reflector as 30.48-cm water surrounding the CV.

6.9.11.5.4 Cladding for broken metal

In the broken metal reflected CV cases, calculations are performed examining various amounts of cladding materials (stainless steel, aluminum, zirconium, and nickel). Two reflected CV calculation models are re-run using cladding. The first model is "**cvr3sqa**," which evaluated the broken metal explicitly as small cubes. The second model, "**cvr3lhac**," evaluated the broken metal homogeneously mixed within the rectangular lattices formed by the unit cells of the small cubes. This "**cvr3lhac**" model is the basis for the limits found in Table 6.1.c. The maximum amount of cladding is evaluated for both models that would fit around the small cube without intersection the adjacent cubes. The single package cases are not examined because the CV cases are shown to be the most reactive. The results are found in Tables 6.9.11.19 and 6.9.11.20.

Table 6.9.11.19. ES-3100 results for broken metal cubes with various amounts of cladding CV fully reflected and flooded 27,743.2-g ^{235}U

Clad thickness (cm)	Case cvr3sqac_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	28_1_ω	**0.81945**	N/A	N/A	N/A
0.0506	28_2_ω	0.80551	0.80715	0.80854	0.80144
0.1016	28_3_ω	0.78845	0.79439	0.79857	0.78129
0.1508	28_4_ω	0.77341	0.78234	0.78429	0.75999
0.2032	28_5_ω	0.75227	0.76879	0.77016	0.73555
0.2446	28_6_ω	0.73709	0.75773	0.76040	0.71594

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

Table 6.9.11.20. ES-3100 results for broken metal mixed with various amounts of cladding CV fully reflected and flooded 27,743.2-g ^{235}U

Clad thickness (cm)	Case cvr3lhac_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	28_1_ω	**0.84431**	N/A	N/A	N/A
0.0506	28_2_ω	0.83882	0.83728	0.83899	0.83823
0.1016	28_3_ω	0.83123	0.82932	0.82994	0.83228
0.1508	28_4_ω	0.82467	0.82152	0.82317	0.82490
0.2032	28_5_ω	0.81595	0.81376	0.81514	0.81585
0.2446	28_6_ω	0.80975	0.80727	0.80756	0.80975

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

From the results found in Tables 6.9.11.19 and 6.9.11.20 for a fully flooded and reflected CV, the most reactive cases are those with no cladding material either surrounding the broken metal or intermixed with the broken metal. The more cladding material is added to the broken metal, the more the reactivity of this system is decreased. The single-unit package is not evaluated because it has been shown that the reflected and flooded CV model is bounding.

6.9.11.5.5 Cladding for U_3O_8-AI, oxides of U-Zr, and UO_2-Mg reactor fuel elements and components

For the research reactor fuel elements and components (U_3O_8-Al, oxides of U-Zr, and UO_2-Mg), the bulk oxide cases are re-run modeling varying amounts of cladding material (stainless steel, aluminum, zirconium, and nickel) in a reflected CV with the CV fully flooded. Only the 24-kg bulk oxide cases are re-run for these calculations. The amount of cladding material is varied from none up to 1.5 L for 3.0 g/cm^3 and up to 2.5 L for 4 g/cm^3 calculations. The 2.0-g/cm^3 cases are not run because 24 kg of UO_2 at this density will not fit inside the CV. The results are found in Table 6.9.11.21.

Table 6.9.11.21. ES-3100 results for bulk oxide with various amounts of cladding CV fully reflected and flooded 24 kg UO_2 (21,1242-g ^{235}U)

Clad volume (L)	Case cvcrpdoxt11c_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
Bulk density 3.0 g/cm^3					
0.0	2_1_ω	**0.91714**	N/A	N/A	N/A
0.5	2_2_ω	0.89736	0.89736	0.89736	0.89753
1.0	2_3_ω	0.88099	0.87694	0.87975	0.87955
1.5	2_4_ω	0.86201	0.85852	0.86214	0.85886
Bulk density 4.0 g/cm^3					
0.0	3_1_ω	**0.90905**	N/A	N/A	N/A
0.5	3_2_ω	0.88574	0.88348	0.88574	0.88574
1.0	3_3_ω	0.86509	0.86178	0.86250	0.86423
1.5	3_4_ω	0.84416	0.84001	0.84511	0.84274
2.0	3_5_ω	0.82535	0.82009	0.82563	0.82460
2.5	3_6_ω	0.80823	0.80209	0.80762	0.80513

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

From the results found in Table 6.9.11.21 for a fully flooded and reflected CV, the most reactive case is with no cladding material intermixed with the bulk oxide. The more cladding material is added to the bulk oxide, the more the reactivity of this system is decreased. The single-unit package is not evaluated because it has been shown that the reflected and flooded CV model is bounding.

6.9.11.5.6 Cladding for fuel pellets

The evaluation involving HEU fuel pellets in rods is performed using the analysis found in Sect. 6.9.8.3.1 as the basis for the next set of calculations. In this section, 12 fuel pellet rods are evaluated inside the CV. These fuel pellets in the shape of rods are modeled as UO_2 at a density of 10.96 g/cm^3 with a diameter of 1.8288 cm and length of 63.5 cm. The SARP evaluated the fuel pellet rods with 0.005-cm-thick aluminum, stainless steel, and zirconium cladding surrounding the fuel pellet rod as well as no cladding. The "UO2_D" model (Fig. 6.9.8.3.1-1d) is shown to be the most reactive configuration for the fuel rods (Table 6.9.8.8-2). The analysis in this appendix modified the "UO2_D" model by varying the cladding thickness up to 0.45-cm thick and adding nickel as cladding material. The results are found in Table 6.9.11.22. These calculations examine the effect of cladding on high density HEU oxide fuel.

Table 6.9.11.22. ES-3100 results for fuel pellet rods with various amounts of cladding CV fully reflected and flooded 27,743.2-g ^{235}U

Clad thickness (cm)	Case 5cvsroxt11c_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	1_ω	**0.80118**			
0.05	2_ω	0.78499	0.79184	0.79419	0.77725
0.10	3_ω	0.76727	0.78347	0.78415	0.75428
0.15	4_ω	0.75077	0.77116	0.77298	0.73055
0.20	5_ω	0.75004	0.75941	0.76237	0.70619
0.25	6_ω	0.70952	0.74496	0.74696	0.68138
0.30	7_ω	0.68972	0.72921	0.73497	0.65613
0.35	8_ω	0.66924	0.71227	0.71956	0.63118
0.40	9_ω	0.64547	0.69589	0.70424	0.60577
0.45	10_ω	0.62212	0.67797	0.68446	0.58020

[a] The shaded sections are masses that would not fit inside the CV at that density.
SS304 = Type 304 stainless steel.

From the results found in Table 6.9.11.22 for a fully flooded and reflected CV, the most reactive case is with no cladding material surrounding each fuel pellet rod. The more cladding material is added to each fuel pellet rod, the more the reactivity of this system is decreased. The single-unit package is not evaluated because it has been shown that the reflected and flooded CV model is bounding.

6.9.11.6 Array Package Evaluation (NCT and HAC)

The analyses presented in Sects. 6.5 and 6.6 demonstrate that maximum reactivity occurs in an array of packages when the CV is flooded (MOCFR of 1.0). Calculations are performed for various size arrays (for both NCT and HAC) with the CV modelled as fully flooded because full flooding of the CV is shown to be the most reactive configuration in Sects. 6.5 and 6.9.11.5.

6.9.11.6.1 HEU metal turnings, fines, or powders

The next set of calculations evaluated the ES-3100 package loaded with HEU metal turnings, fines, or powders in various size arrays with a CSI of 0.0, 0.4, 0.8, 2.0, and 3.2. The discussion on how the CSI is calculated is found in Sect. 6.1.4. In the array cases, the CV is modeled flooded because this is shown to be the most reactive from Tables 6.9.11.1 and 6.9.11.2 and is also shown to be the most reactive model in this SARP. No changes were made in the original HEU metal turnings, fines, or powders calculation models except for evaluating higher enrichments in this appendix. Calculations for both NCT and HAC are performed for 90%, 95% and 100% enrichments and varying the specific gravity outside the CV [moisture fraction of the package external to the containment vessel (MOIFR)] from dry to fully flooded. The results of the calculations are found in Tables 6.9.11.23–6.9.11.32 for NCT and HAC cases.

6.9.11.6.1.1 Infinite array calculations (CSI of 0.0)

This section discusses the calculations for the infinite array calculations for HEU metal turnings, fines, or powders at a CSI of 0.0. The results of these calculations are found in Tables 6.9.11.23 and 6.9.11.24.

Table 6.9.11.23. Results for HEU turnings, fines, and powders, infinite array, NCT

Case nciabmt11_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ
1_ω_1	1.0E-20	924	0.7777	879	0.7671	833	0.7528
2_ω_1	1.0E-20	**1849**	**0.8898**	1758	0.8768	1851	0.8685
2_ω_2	1.0E-5	1849	0.8909	N/A	N/A	N/A	N/A
2_ω_3	1.0E-4	1849	0.8866	N/A	N/A	N/A	N/A
2_ω_6	0.1	1849	0.7797	N/A	N/A	N/A	N/A
2_ω_15	1.0	1849	0.7509	N/A	N/A	N/A	N/A
3_ω_1	1.0E-20	2774	0.9390	**2637**	**0.9283**	2500	0.9277
3_ω_2	1.0E-5	2774	N/A	2637	0.9250	2500	0.9162
3_ω_3	1.0E-4	2774	N/A	2637	0.9270	2500	0.9160
3_ω_6	0.1	2774	N/A	2637	0.8097	2500	0.8015
3_ω_15	1.0	2774	N/A	2637	0.7762	2500	0.7735
4_ω_1	1.0E-20	3699	0.9659	3516	0.9546	3333	0.9439

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.23 for an infinite array (CSI of 0.0) with NCT, the highest amount of ^{235}U below the USL is ~1849 g for an enrichment of 100% (Case **nciabmt11_2_8_1** with k_{eff} + 2σ of 0.890), and ~2637 g for an enrichment of 95% (Case **nciabmt11_3_7_1** with k_{eff} + 2σ of 0.928). The 90% enriched cases are not cited because the 95% enriched cases are bounding.

Table 6.9.11.24. Results for HEU turnings, fines, and powders, infinite array, HAC

Case hciabmt12_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ
1_ω_1	1.0E-20	924	0.7769	879	0.7665	833	0.7566
2_ω_1	1.0E-20	**1849**	**0.8897**	1758	0.8772	1851	0.8682
2_ω_2	1.0E-5	1849	0.8866	N/A	N/A	N/A	N/A
2_ω_3	1.0E-4	1849	0.8914	N/A	N/A	N/A	N/A
2_ω_6	0.1	1849	0.8113	N/A	N/A	N/A	N/A
2_ω_15	1.0	1849	0.7745	N/A	N/A	N/A	N/A
3_ω_1	1.0E-20	2774	0.9368	**2637**	**0.9287**	2500	0.9183
3_ω_2	1.0E-5	N/A	N/A	2637	0.9255	2500	0.9139
3_ω_3	1.0E-4	N/A	N/A	2637	0.9267	2500	0.9179
3_ω_6	0.1	N/A	N/A	2637	0.8449	2500	0.8363
3_ω_15	1.0	N/A	N/A	2637	0.8010	2500	0.7961
4_ω_1	1.0E-20	3699	0.9663	3516	0.9543	3333	0.9435

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.24 for an infinite array (CSI of 0.0) with HAC, the highest amount of ^{235}U below the USL is ~1848 g for an enrichment of 100% (Case **hciabmt12_2_8_1** with $k_{eff} + 2\sigma$ of 0.890) and ~2637 g for enrichment of 95% (Case **nciabmt11_3_7_1** with $k_{eff} + 2\sigma$ of 0.929). The 90% enriched cases are not cited because the 95% enriched cases are bounding. The HAC cases are as reactive as the NCT cases.

6.9.11.6.1.2 CSI 0.4 calculations

This section discusses the calculations for the array calculations for HEU metal turnings, fines, or powders at a CSI of 0.4. For a CSI of 0.4, the array size for NCT is 13 × 13 × 6 while the array size for HAC is 9 × 9 × 4. The results of these calculations are found in Tables 6.9.11.25 and 6.9.11.26.

Table 6.9.11.25. Results for HEU turnings, fines, and powders, CSI=0.4 array, NCT

Case ncf1bmt11_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$
3_ω_1	1.0E-20	2774	0.8970	2637	0.8860	2500	0.8780
4_ω_1	1.0E-20	**3699**	**0.9251**	3516	0.9156	3333	0.9026
4_ω_2	1.0E-5	3699	0.9246	N/A	N/A	N/A	N/A
4_ω_3	1.0E-4	3699	0.9235	N/A	N/A	N/A	N/A
4_ω_6	0.1	3699	0.8306	N/A	N/A	N/A	N/A
4_ω_15	1.0	3699	0.8025	N/A	N/A	N/A	N/A
5_ω_1	1.0E-20	4623	0.9413	**4395**	**0.9317**	4166	0.9211
5_ω_2	1.0E-5	N/A	N/A	4395	0.9285	N/A	N/A
5_ω_3	1.0E-4	N/A	N/A	4395	0.9317	N/A	N/A
5_ω_6	0.1	N/A	N/A	4395	0.8340	N/A	N/A
5_ω_15	1.0	N/A	N/A	4395	0.8074	N/A	N/A
6_ω_1	1.0E-20	5548	0.9541	5274	0.9441	5000	0.9326
6_ω_2	1.0E-5	N/A	N/A	N/A	N/A	**5000**	**0.9330**
6_ω_3	1.0E-4	N/A	N/A	N/A	N/A	5000	0.9329
6_ω_6	0.1	N/A	N/A	N/A	N/A	5000	0.8334
6_ω_15	1.0	N/A	N/A	N/A	N/A	5000	0.8045
7_ω_1	1.0E-20	6473	0.9645	6153	0.9506	5833	0.9410

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.25 for a 13 × 13 × 6 array (CSI of 0.4) with NCT, the highest amount of ^{235}U below the USL is ~3699 g for an enrichment of 100% (Case **ncf1bmt11_4_8_1** with $k_{eff} + 2\sigma$ of 0.925), ~4395 g for an enrichment of 95% (Case **ncf1bmt11_5_7_1** with $k_{eff} + 2\sigma$ of 0.932), and ~5000 g for an enrichment of 90% (Case **ncf1bmt11_6_6_2** with $k_{eff} + 2\sigma$ of 0.933).

Table 6.9.11.26. Results for HEU turnings, fines, and powders CSI=0.4 array, HAC

Case hcf2bmt12_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$
3_ω_1	1.0E-20	2774	0.8719	2637	0.8659	2500	0.8579
4_ω_1	1.0E-20	3699	0.9012	3516	0.8912	3333	0.8847
4_ω_2	1.0E-5	3699	0.8995	N/A	N/A	N/A	N/A
4_ω_3	1.0E-4	**3699**	**0.9021**	N/A	N/A	N/A	N/A
4_ω_4	1.0E-3	3699	0.8969	N/A	N/A	N/A	N/A
4_ω_15	1.0	3699	0.8248	N/A	N/A	N/A	N/A
5_ω_1	1.0E-20	4623	0.9151	**4395**	**0.9076**	4166	0.8976
5_ω_2	1.0E-5	N/A	N/A	4395	0.9069	N/A	N/A
5_ω_3	1.0E-4	N/A	N/A	4395	0.9093	N/A	N/A
5_ω_4	1.0E-3	N/A	N/A	4395	0.9074	N/A	N/A
5_ω_15	1.0	N/A	N/A	4395	0.8291	N/A	N/A
6_ω_1	1.0E-20	5548	0.9327	5274	0.9189	5000	0.9083
6_ω_2	1.0E-5	N/A	N/A	N/A	N/A	**5000**	**0.9114**
6_ω_3	1.0E-4	N/A	N/A	N/A	N/A	5000	0.9096
6_ω_4	1.0E-3	N/A	N/A	N/A	N/A	5000	0.9095
6_ω_15	1.0	N/A	N/A	N/A	N/A	5000	0.8291
7_ω_1	1.0E-20	6473	0.9377	6153	0.9241	5833	0.9209

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.26 for a 9 × 9 × 4 array (CSI of 0.4) for the comparable HAC cases, the highest amount of ^{235}U below the USL is ~3699 g for an enrichment of 100% (Case **hcf2bmt12_4_8_3** with $k_{eff} + 2\sigma$ of 0.902), ~4395 g for an enrichment of 95% (Case **hcf2bmt12_5_7_1** with $k_{eff} + 2\sigma$ of 0.908), and ~5000 g for an enrichment of 90% (Case **hcf2bmt12_6_6_2** with $k_{eff} + 2\sigma$ of 0.911). For comparable masses, the HAC cases are less reactive than the NCT cases.

6.9.11.6.1.3 CSI 0.8 calculations

This section discusses the calculations for the array calculations for HEU metal turnings, fines, or powders at a CSI of 0.8. For a CSI of 0.8, the array size for NCT is 9 × 9 × 4 while the array size for HAC is 7 × 7 × 3. The results of these calculations are found in Tables 6.9.11.27 and 6.9.11.28.

Table 6.9.11.27. Results for HEU turnings, fines, and powders, CSI=0.8 array, NCT

Case ncf2bmt11_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ
6_ω_1	1.0E-20	5,548	0.9133	5,274	0.9114	5,000	0.9030
7_ω_1	1.0E-20	6,473	0.9327	6,153	0.9219	5,833	0.9088
7_ω_2	1.0E-5	6,473	0.9310	N/A	N/A	N/A	N/A
7_ω_3	1.0E-4	**6,473**	**0.9350**	N/A	N/A	N/A	N/A
7_ω_4	1.0E-3	6,473	0.9345	N/A	N/A	N/A	N/A
7_ω_6	0.1	6,473	0.8535	N/A	N/A	N/A	N/A
7_ω_15	1.0	6,473	0.8283	N/A	N/A	N/A	N/A
8_ω_1	1.0E-20	7,398	0.9383	7,032	0.9276	6,666	0.9177
8_ω_2	1.0E-5	N/A	N/A	**7,032**	**0.9291**	N/A	N/A
8_ω_3	1.0E-4	N/A	N/A	7,032	0.9250	N/A	N/A
8_ω_6	0.1	N/A	N/A	7,032	0.8486	N/A	N/A
8_ω_15	1.0	N/A	N/A	7,032	0.8217	N/A	N/A
9_ω_1	1.0E-20	8,323	0.9476	7,911	0.9363	7,500	0.9219
10_ω_1	1.0E-20	9,247	0.9540	8,790	0.9422	8,333	0.9261
11_ω_1	1.0E-20	10,172	0.9550	9,670	0.9425	9,166	0.9328
11_ω_2	1.0E-5	N/A	N/A	N/A	N/A	**9,166**	**0.9330**
11_ω_3	1.0E-4	N/A	N/A	N/A	N/A	9,166	0.9325
11_ω_6	0.1	N/A	N/A	N/A	N/A	9,166	0.8521
11_ω_15	1.0	N/A	N/A	N/A	N/A	9,166	0.8250
12_ω_1	1.0E-20	11,097	0.9631	10,549	0.9480	10,000	0.9345

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.27 for a 9 × 9 × 4 array (CSI of 0.8) with NCT, the highest amount of ^{235}U below the USL is ~6473 g for an enrichment of 100% (Case **ncf2bmt11_7_8_3** with k_{eff} + 2σ of 0.935), ~7032 g for an enrichment of 95% (Case **ncf2bmt11_8_7_2** with k_{eff} + 2σ of 0.929), and ~9166 g for enrichment of 90% (Case **ncf2bmt11_11_6_2** with k_{eff} + 2σ of 0.933).

Table 6.9.11.28. Results for HEU turnings, fines, and powders CSI=0.8 array, HAC

Case hcf3bmt12_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ
6_ω_1	1.0E-20	5,548	0.9030	5,274	0.8951	5,000	0.8810
7_ω_1	1.0E-20	6,473	0.9129	N/A	0.9036	N/A	0.8941
7_ω_3	1.0E-4	6,473	0.9123	N/A	N/A	N/A	N/A
7_ω_4	1.0E-3	**6,473**	**0.9134**	N/A	N/A	N/A	N/A
7_ω_6	0.1	6,473	0.8683	N/A	N/A	N/A	N/A
7_ω_15	1.0	6,473	0.8477	N/A	N/A	N/A	N/A
8_ω_1	1.0E-20	7,398	0.9216	7,032	0.9078	6,666	0.9008
8_ω_2	1.0E-5	N/A	N/A	7,032	0.9090	N/A	N/A
8_ω_3	1.0E-4	N/A	N/A	**7,032**	**0.9092**	N/A	N/A
8_ω_4	1.0E-3	N/A	N/A	7,032	0.9074	N/A	N/A
8_ω_6	0.1	N/A	N/A	7,032	0.8622	N/A	N/A
8_ω_15	1.0	N/A	N/A	7,032	0.8436	N/A	N/A
9_ω_1	1.0E-20	8,323	0.9256	7,911	0.9157	7,500	0.9028
10_ω_1	1.0E-20	9,247	0.9353	8,790	0.9180	8,333	0.9096
11_ω_1	1.0E-20	10,172	0.9382	9,670	0.9218	**9,166**	**0.9141**
11_ω_2	1.0E-5	N/A	N/A	N/A	N/A	9,166	0.9122
11_ω_3	1.0E-4	N/A	N/A	N/A	N/A	9,166	0.9109
11_ω_6	0.1	N/A	N/A	N/A	N/A	9166	0.8686
11_ω_15	1.0	N/A	N/A	N/A	N/A	9,166	0.8496
12_ω_1	1.0E-20	11,097	0.9402	10,549	0.9278	10,000	0.9170

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.28 for a 7 × 7 × 3 array (CSI of 0.8) for the comparable HAC cases, the highest amount of ^{235}U below the USL is ~6473 g for an enrichment of 100% (Case **hcf3bmt12_7_8_4** with k_{eff} + 2σ of 0.913), ~7032 g for an enrichment of 95% (Case **hcf3bmt12_8_7_3** with k_{eff} + 2σ of 0.909), and ~9166 g for an enrichment of 90% (Case **hcf3bmt12_11_6_1** with k_{eff} + 2σ of 0.914). For comparable masses, the HAC cases are less reactive than the NCT cases.

6.9.11.6.1.4 CSI 2.0 calculations

This section discusses the calculations for the array calculations for HEU metal turnings, fines, or powders at a CSI of 2.0. For a CSI of 2.0, the array size for NCT is 7 × 7 × 3 while the array size for HAC is 5 × 5 × 2. The results of these calculations are found in Tables 6.9.11.29 and 6.9.11.30.

Table 6.9.11.29. Results for HEU turnings, fines, and powders CSI=2.0 array, NCT

Case ncf3bmt11_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$
10_ω_1	1.0E-20	9,247	0.9229	8,790	0.9092	8,333	0.9009
11_ω_1	1.0E-20	10,172	0.9283	9,670	0.9165	9,166	0.9026
12_ω_1	1.0E-20	11,097	0.9317	10,549	0.9175	10,000	0.9067
12_ω_2	1.0E-5	11,097	0.9283	N/A	N/A	N/A	N/A
12_ω_3	1.0E-4	11,097	0.9324	N/A	N/A	N/A	N/A
12_ω_4	1.0E-3	**11,097**	**0.9332**	N/A	N/A	N/A	N/A
12_ω_6	0.1	11,097	0.8689	N/A	N/A	N/A	N/A
12_ω_15	1.0	11,097	0.8468	N/A	N/A	N/A	N/A
13_ω_1	1.0E-20	12,946	0.9378	12,307	0.9246	11,666	0.9123
15_ω_1	1.0E-20	14,796	0.9454	14,065	0.9331	13,333	0.9216
16_ω_1	1.0E-20	15,721	0.9529	14,944	0.9342	14,166	0.9250
16_ω_2	1.0E-5	N/A	N/A	**14,944**	**0.9346**	N/A	N/A
16_ω_3	1.0E-4	N/A	N/A	14,944	0.9336	N/A	N/A
16_ω_6	0.1	N/A	N/A	14,944	0.8693	N/A	N/A
16_ω_15	1.0	N/A	N/A	14,944	0.8432	N/A	N/A
17_ω_1	1.0E-20	16,645	0.9566	15,823	0.9393	15,000	0.9257
18_ω_1	1.0E-20	17,570	0.9596	16,702	0.9405	15,833	0.9273
19_ω_1	1.0E-20	18,495	0.9610	17,581	0.9446	16,667	0.9320
19_ω_2	1.0E-5	N/A	N/A	N/A	N/A	16,667	0.9321
19_ω_3	1.0E-4	N/A	N/A	N/A	N/A	**16,667**	**0.9334**
19_ω_4	1.0E-3	N/A	N/A	N/A	N/A	16,667	0.9322
19_ω_6	0.1	N/A	N/A	N/A	N/A	16,667	0.8687
19_ω_15	1.0	N/A	N/A	N/A	N/A	16,667	0.8406
20_ω_1	1.0E-20	19,420	0.9641	18,460	0.9459	17,500	0.9338

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.29 for a 7 × 7 × 3 array (CSI of 2.0) with NCT, the highest amount of ^{235}U below the USL is ~11,097 g for an enrichment of 100% (Case **ncf3bmt11_12_8_4** with $k_{eff} + 2\sigma$ of 0.933), ~14,944 g for an enrichment of 95% (Case **ncf3bmt11_16_7_2** with $k_{eff} + 2\sigma$ of 0.935), and ~16,667 g for an enrichment of 90% (Case **ncf3bmt11_19_6_3** with $k_{eff} + 2\sigma$ of 0.933).

Table 6.9.11.30. Results for HEU turnings, fines, and powders CSI=2.0 array, HAC

Case hcf4bmt12_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ
10_ω_1	1.0E-20	9,247	0.8861	8,790	0.8715	8,333	0.8620
11_ω_1	1.0E-20	10,172	0.8874	9,670	0.8782	9,166	0.8676
12_ω_1	1.0E-20	**11,097**	**0.8948**	10,549	0.8794	10,000	0.8716
12_ω_2	1.0E-5	11,097	0.8929	N/A	N/A	N/A	N/A
12_ω_3	1.0E-4	11,097	0.8930	N/A	N/A	N/A	N/A
12_ω_6	0.1	11,097	0.8704	N/A	N/A	N/A	N/A
12_ω_15	1.0	11,097	0.8626	N/A	N/A	N/A	N/A
13_ω_1	1.0E-20	12,946	0.9030	12,307	0.8856	11,666	0.8801
15_ω_1	1.0E-20	14,796	0.9090	14,065	0.8942	13,333	0.8862
16_ω_1	1.0E-20	15,721	0.9135	14,944	0.8964	14,166	0.8866
16_ω_2	1.0E-5	N/A	N/A	14,944	0.8956	N/A	N/A
16_ω_3	1.0E-4	N/A	N/A	14,944	0.8984	N/A	N/A
16_ω_4	1.0E-3	N/A	N/A	**14,944**	**0.8990**	N/A	N/A
16_ω_6	0.1	N/A	N/A	14,944	0.8694	N/A	N/A
16_ω_15	1.0	N/A	N/A	14,944	0.8641	N/A	N/A
17_ω_1	1.0E-20	16,645	0.9163	15,823	0.8989	15,000	0.8866
18_ω_1	1.0E-20	17,570	0.9210	16,702	0.9037	15,833	0.8895
19_ω_1	1.0E-20	18,495	0.9212	17,581	0.9103	16,667	0.8950
19_ω_2	1.0E-5	N/A	N/A	N/A	N/A	**16,667**	**0.8953**
19_ω_3	1.0E-4	N/A	N/A	N/A	N/A	16,667	0.8941
19_ω_6	0.1	N/A	N/A	N/A	N/A	16,667	0.8683
19_ω_15	1.0	N/A	N/A	N/A	N/A	16,667	0.8605
20_ω_1	1.0E-20	19,420	0.9255	18,460	0.9072	17,500	0.8970

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.30 for a 5 × 5 × 2 array (CSI of 2.0) for the comparable HAC cases, the highest amount of ^{235}U below the USL is ~11,097 g for an enrichment of 100% (Case **hcf4bmt12_12_8_1** with k_{eff} + 2σ of 0.895), ~14,944 g for an enrichment of 95% (Case **hcf4bmt12_16_7_4** with k_{eff} + 2σ of 0.899), and ~16,667 g for an enrichment of 90% (Case **hcf4bmt12_19_6_2** with k_{eff} + 2σ of 0.895). For comparable masses, the HAC cases are less reactive than the NCT cases.

6.9.11.6.1.5 CSI 3.2 calculations

This section discusses the array calculations for HEU metal turnings, fines, or powders at a CSI of 3.2. For a CSI of 3.2, the array size for NCT is 27 × 3 while the array size for HAC is 16 × 3. The results of these calculations are found in Tables 6.9.11.31 and 6.9.11.32.

Table 6.9.11.31. Results for HEU turnings, fines, and powders CSI=3.2 array, NCT

Case nctf5bmt11_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ	^{235}U mass (g)	k_{eff} + 2σ
20_ω_1	1.0E-20	19,420	0.93076	18,460	0.91400	17,500	0.90362
21_ω_1	1.0E-20	20,345	0.93210	19,340	0.91680	18,333	0.90560
21_ω_2	1.0E-5	**20,345**	**0.93489**	N/A	N/A	N/A	N/A
21_ω_3	1.0E-4	20,345	0.93314	N/A	N/A	N/A	N/A
21_ω_6	0.1	20,345	0.90318	N/A	N/A	N/A	N/A
21_ω_15	1.0	20,345	0.87391	N/A	N/A	N/A	N/A
22_ω_1	1.0E-20	21,269	0.93730	20,219	0.92002	19,167	0.90580
24_ω_1	1.0E-20	23,119	0.94061	21,977	0.92759	20,833	0.91336
26_ω_1	1.0E-20	25,893	0.95262	**24,614**	**0.93500**	23,333	0.91925
26_ω_2	1.0E-5	N/A	N/A	24,614	0.93440	N/A	N/A
26_ω_3	1.0E-4	N/A	N/A	24,614	0.93490	N/A	N/A
26_ω_6	0.1	N/A	N/A	24,614	0.90280	N/A	N/A
26_ω_15	1.0	N/A	N/A	24,614	0.87151	N/A	N/A
27_ω_1	1.0E-20	26,818	0.95373	25,493	0.93641	24,167	0.92364
29_ω_1	1.0E-20	28,668	0.95330	27,251	0.94340	25,833	0.93022
31_ω_1	1.0E-20	30,517	0.96621	29,010	0.94767	**27,500**	**0.93414**
31_ω_2	1.0E-5	N/A	N/A	N/A	N/A	27,500	0.93381
31_ω_3	1.0E-4	N/A	N/A	N/A	N/A	27,500	0.93340
31_ω_4	1.0E-4	N/A	N/A	N/A	N/A	27,500	0.93410
31_ω_6	0.1	N/A	N/A	N/A	N/A	27,500	0.90321
31_ω_15	1.0	N/A	N/A	N/A	N/A	2,7500	0.87000
32_ω_1	1.0E-20	31,442	0.96885	29,889	0.94919	28,333	0.93800

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.31 for a 27 × 3 array (CSI of 3.2) with NCT, the highest amount of ^{235}U below the USL is ~20,345 g for an enrichment of 100% (Case **ncf5bmt11_21_8_2** with k_{eff} + 2σ of 0.935), ~24,614 g for an enrichment of 95% (Case **ncf5bmt11_26_7_1** with k_{eff} + 2σ of 0.935), and ~27,500 g for an enrichment of 90% (Case **ncf5bmt11_31_6_1** with k_{eff} + 2σ of 0.934). These masses are higher than the most reactive single reflected CV calculations that are below the USL.

Because of this, the maximum amount of ^{235}U that is allowed would be reduced to those levels (11,097 g, 17,581 g, and 21,667 g for 100%, 95%, and 90% enriched, respectively, from Table 6.9.11.1).

Table 6.9.11.32. Results for HEU turnings, fines, and powders CSI=3.2 array, HAC

Case hctf5mt12_	MOIFR	100% ^{235}U (ω = 8) [a]		95% ^{235}U (ω = 7) [a]		90% ^{235}U (ω = 6) [a]	
		^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$	^{235}U mass (g)	$k_{eff} + 2\sigma$
20_ω_1	1.0E-20	19,420	0.90981	18,460	0.89505	17,500	0.88250
21_ω_1	1.0E-20	20,345	0.91200	19,340	0.89765	18,333	0.88475
21_ω_3	1.0E-4	20,345	0.91080	N/A	N/A	N/A	N/A
21_ω_4	1.0E-3	**20,345**	**0.91526**	N/A	N/A	N/A	N/A
21_ω_6	0.1	20,345	0.90476	N/A	N/A	N/A	N/A
21_ω_15	1.0	20,345	0.90204	N/A	N/A	N/A	N/A
22_ω_1	1.0E-20	21,269	0.91567	20,219	0.90080	19,167	0.88829
24_ω_1	1.0E-20	23,119	0.91952	21,977	0.90490	20,833	0.89260
26_ω_1	1.0E-20	25,893	0.89119	24,614	0.91320	23,333	0.90119
26_ω_3	1.0E-4	N/A	N/A	24,614	0.91181	N/A	N/A
26_ω_4	1.0E-3	N/A	N/A	**24,614**	**0.91640**	N/A	N/A
26_ω_6	0.1	N/A	N/A	24,614	0.90510	N/A	N/A
26_ω_15	1.0	N/A	N/A	24,614	0.90075	N/A	N/A
27_ω_1	1.0E-20	26,818	0.93452	25,493	0.91601	24,167	0.90403
29_ω_1	1.0E-20	28,668	0.94000	27,251	0.92140	25,833	0.90870
31_ω_1	1.0E-20	30,517	0.94562	29,010	0.92668	27,500	0.91370
31_ω_2	1.0E-5	N/A	N/A	N/A	N/A	27,500	0.91348
31_ω_3	1.0E-4	N/A	N/A	N/A	N/A	**27,500**	**0.91382**
31_ω_4	1.0E-4	N/A	N/A	N/A	N/A	27,500	0.91330
31_ω_6	0.1	N/A	N/A	N/A	N/A	27,500	0.90488
31_ω_15	1.0	N/A	N/A	N/A	N/A	27,500	0.89923
32_ω_1	1.0E-20	31,442	0.94637	29,889	0.92996	28,333	0.91800

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.32 for a 16 × 3 array (CSI of 3.2) for the comparable HAC cases, the highest amount of ^{235}U below the USL is ~20,345 g for an enrichment of 100% (Case **hcf5bmt12_21_8_4** with $k_{eff} + 2\sigma$ of 0.915), ~24,614 g for an enrichment of 95% (Case **hcf5bmt12_26_7_4** with $k_{eff} + 2\sigma$ of 0.916), and ~27,500 g for an enrichment of 90% (Case **hcf5bmt12_31_6_3** with $k_{eff} + 2\sigma$ of 0.914). For comparable masses, the HAC cases are less reactive than the NCT cases. These masses are higher than the most reactive single reflected CV calculations that are below the USL. Because of this, the maximum amount of ^{235}U that is allowed would be reduced to those levels (11,097 g, 17,581 g, and 21,667 g for 100%, 95%, and 90% enriched, respectively, from Table 6.9.11.1).

6.9.11.6.2 UO_2 and carbon

The next set of calculations evaluated the ES-3100 package loaded with oxide with varying amounts of carbon in an infinite array with the CV fully flooded. Calculations for both NCT and HAC are performed varying the amount of carbon from 0 to 5000 g in 1000-g increments at various UO_2 masses. Only calculations with a specific gravity of 1.0E-20 outside the CV (MOIFR) are shown because this specific gravity is shown to be the most reactive. The results of the calculations are found in Tables 6.9.11.33–6.9.11.38 for NCT and HAC cases. The results show that the carbon mixed with oxide does not require any control.

Table 6.9.11.33. ES-3100 results for UO_2 at a density of 2 g/cm^3, infinite array, varying amounts of carbon, CV fully flooded, NCT

MOIFR	Oxide mass (kg)	Case nciapdoxt11a_	$k_{eff} + 2\sigma$					
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	4 kg carbon (ω = 5)	5 kg carbon (ω = 6)
1.0E-20	14	1_14_ω_1	**0.9594**	0.9478	0.9375	0.9303	0.9235	0.9213
1.0E-20	13	1_13_ω_1	0.9458	0.9328	0.9202	0.9109	0.9008	0.8946
1.0E-20	12	1_12_ω_1	0.9346	0.9199	0.9254	0.8908	0.8811	0.8717
1.0E-20	11	1_11_ω_1	0.9182	0.9033	0.8868	0.8724	0.8613	0.8499
1.0E-20	10	1_10_ω_1	0.9031	0.8848	0.8680	0.8534	0.8398	0.8274
1.0E-20	9	1_9_ω_1	0.8887	0.8661	0.8486	0.8318	0.8158	0.8006
1.0E-20	8	1_8_ω_1	0.8685	0.8432	0.8249	0.8054	0.7863	0.7205

Table 6.9.11.34. ES-3100 results for UO_2 at a density of 3 g/cm^3, infinite array, varying amounts of carbon, CV fully flooded, NCT

MOIFR	Oxide mass (kg)	Case nciapdoxt11a_	$k_{eff} + 2\sigma$				
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	5 kg carbon (ω = 6)
1.0E-20	17	2_17_ω_1	**0.9378**	0.9245	0.9096	0.9027	0.8726
1.0E-20	16	2_16_ω_1	0.9284	0.9110	0.8972	0.8878	0.8649
1.0E-20	15	2_15_ω_1	0.9198	0.9018	0.8879	0.8717	0.8489
1.0E-20	14	2_14_ω_1	0.9070	0.8919	0.8715	0.8577	0.8311
1.0E-20	13	2_13_ω_1	0.8938	0.8736	0.8578	0.8420	0.8145
1.0E-20	12	2_12_ω_1	0.8839	0.8593	0.8448	0.8252	0.7939
1.0E-20	11	2_11_ω_1	0.8679	0.8467	0.8230	0.8075	0.7759

Table 6.9.11.35. ES-3100 results for UO_2 at a density of 4 g/cm^3, infinite array, varying amounts of carbon, CV fully flooded, NCT

MOIFR	Oxide mass (kg)	Case nciapdoxt11a_	$k_{eff} + 2\sigma$				
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	5 kg carbon (ω = 6)
1.0E-20	21	3_21_ω_1	**0.9392**	0.9291	0.9142	0.9015	0.8795
1.0E-20	20	3_20_ω_1	0.9312	0.9161	0.9030	0.8897	0.8384
1.0E-20	19	3_19_ω_1	0.9236	0.9065	0.8914	0.8803	0.8572
1.0E-20	18	3_18_ω_1	0.9144	0.8982	0.8811	0.8665	0.8422
1.0E-20	17	3_17_ω_1	0.9065	0.8855	0.8702	0.8562	0.8278
1.0E-20	16	3_16_ω_1	0.8956	0.8761	0.8574	0.8400	0.8153
1.0E-20	15	3_15_ω_1	0.8846	0.8642	0.8453	0.8252	0.7985

Table 6.9.11.36. ES-3100 results for UO_2 at a density of 2 g/cm^3, infinite array, varying amounts of carbon, CV fully flooded, HAC

MOIFR	Oxide mass (kg)	Case hciapdoxt12a_	$k_{eff} + 2\sigma$				
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	5 kg carbon (ω = 6)
1.0E-20	14	1_14_ω_1	**0.9606**	0.9520	0.9394	0.9312	0.9190
1.0E-20	13	1_13_ω_1	0.9490	0.9329	0.9224	0.9108	0.8954
1.0E-20	12	1_12_ω_1	0.9335	0.9215	0.9021	0.8944	0.8731
1.0E-20	11	1_11_ω_1	0.9188	0.8997	0.8873	0.8734	0.8495
1.0E-20	10	1_10_ω_1	0.9053	0.8841	0.8714	0.8539	0.8282
1.0E-20	9	1_9_ω_1	0.8868	0.8659	0.8474	0.8308	0.8023
1.0E-20	8	1_8_ω_1	0.8661	0.8472	0.8253	0.8038	0.7746

Table 6.9.11.37. ES-3100 results for UO_2 at a density of 3 g/cm^3, infinite array, varying amounts of carbon, CV fully flooded, HAC

MOIFR	Oxide mass (kg)	Case hciapdoxt12a_	$k_{eff} + 2\sigma$				
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	5 kg carbon (ω = 6)
1.0E-20	16	2_16_ω_1	**0.9276**	0.9142	0.9007	0.8875	0.8739
1.0E-20	15	2_15_ω_1	0.9195	0.8998	0.8856	0.8731	0.8469
1.0E-20	14	2_14_ω_1	0.9090	0.8900	0.8735	0.8577	0.8345
1.0E-20	13	2_13_ω_1	0.8947	0.8776	0.8593	0.8434	0.8147
1.0E-20	12	2_12_ω_1	0.8811	0.8591	0.8426	0.8252	0.7948
1.0E-20	11	2_11_ω_1	0.8691	0.8468	0.8272	0.8084	0.7762
1.0E-20	10	2_10_ω_1	0.8527	0.8275	0.8069	0.7879	0.7536

Table 6.9.11.38. ES-3100 results for UO_2 at a density of 4 g/cm^3, infinite array, varying amounts of carbon, CV fully flooded, HAC

MOIFR	Oxide mass (kg)	Case hciapdoxt12a_	$k_{eff} + 2\sigma$				
			No carbon (ω = 1)	1 kg carbon (ω = 2)	2 kg carbon (ω = 3)	3 kg carbon (ω = 4)	5 kg carbon (ω = 6)
1.0E-20	21	3_21_ω_1	**0.9417**	0.9257	0.9111	0.8721	0.8810
1.0E-20	20	3_20_ω_1	0.9309	0.9156	0.9030	0.8897	0.8678
1.0E-20	19	3_19_ω_1	0.9044	0.9072	0.8910	0.8787	0.8553
1.0E-20	18	3_18_ω_1	0.9140	0.8934	0.8802	0.8656	0.8432
1.0E-20	17	3_17_ω_1	0.9048	0.8867	0.8701	0.8537	0.8304
1.0E-20	16	3_16_ω_1	0.8946	0.8739	0.8558	0.8419	0.8161
1.0E-20	15	3_15_ω_1	0.8864	0.8639	0.8452	0.8285	0.8020

From the results found in the Tables 6.9.11.33–6.9.11.38, as in the CV and single package cases shown in Tables 6.9.11.5–6.9.11.10, substituting carbon for oxide and adding carbon to a fixed amount of oxide resulted in a decrease of reactivity. The substitution of carbon for oxide results in the highest decrease in reactivity as opposed to adding carbon to a fixed amount of oxide.

6.9.11.6.3 HEU low density oxide

Calculations for both NCT and HAC are performed for various bulk densities ranging from 1.75 to 0.5 g/cm^3 at 100% enrichment and varying the specific gravity outside the CV (MOIFR) from dry to fully flooded. The results of the calculations are found in Tables 6.9.11.39–6.9.11.42 for NCT and HAC cases.

Table 6.9.11.39. Infinite array package model, low density oxide, NCT

UO_2 mass (kg)	MOIFR	Case ncialdoxt11_	1.75 g/cm^3 (ω = 1) [a]			1.50 g/cm^3 (ω = 2) [a]			1.25 g/cm^3 (ω = 3) [a]		
			k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ
12	1.0E-20	ω_21_1	0.9501	0.0015	0.9531						
11	1.0E-20	ω_20_1	0.9358	0.0011	0.9370						
10.75	1.0E-20	ω_19_1	**0.9320**	**0.0012**	**0.9344**						
10.75	1.0E-5	ω_19_2	0.9290	0.0015	0.9320						
10.75	1.0E-4	ω_19_3	0.9292	0.0014	0.9320						
10.75	1.0E-3	ω_19_4	0.9304	0.0010	0.9326						
10.75	1.0E-1	ω_19_6	0.8434	0.0010	0.8454						
10.5	1.0E-20	ω_18_1	0.9282	0.0014	0.9310						
10	1.0E-20	ω_17_1	0.9179	0.0020	0.9219	0.9387	0.0015	0.9427			
9.5	1.0E-20	ω_16_1	N/A	N/A	N/A	0.9300	0.0010	0.9322			
9.5	1.0E-5	ω_16_2	N/A	N/A	N/A	0.9299	0.0012	0.9323			
9.5	1.0E-4	ω_16_3	N/A	N/A	N/A	**0.9313**	**0.0013**	**0.9339**			
9.5	1.0E-3	ω_16_4	N/A	N/A	N/A	0.9280	0.0013	0.9306			
9.25	1.0E-20	ω_15_1	N/A	N/A	N/A	0.9282	0.0014	0.9310			
9	1.0E-20	ω_14_1	N/A	N/A	N/A	0.9202	0.0011	0.9224	0.9474	0.0012	0.9498
8.5	1.0E-20	ω_13_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9379	0.0013	0.9405
8.25	1.0E-20	ω_12_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9293	0.0012	0.9317
8.25	1.0E-5	ω_12_2	N/A	N/A	N/A	N/A	N/A	N/A	**0.9321**	**0.0013**	**0.9347**
8.25	1.0E-4	ω_12_3	N/A	N/A	N/A	N/A	N/A	N/A	0.9309	0.0014	0.9337
8.25	1.0E-3	ω_12_4	N/A	N/A	N/A	N/A	N/A	N/A	0.9307	0.0012	0.9331
8	1.0E-20	ω_11_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9260	0.0011	0.9282

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

Table 6.9.11.40. Infinite array package model, low density oxide, NCT

UO_2 mass (kg)	MOIFR	Case ncialdoxt11_	1.00 g/cm^3 (ω = 4) [a]			0.75 g/cm^3 (ω = 5) [a]			0.50 g/cm^3 (ω = 6) [a]		
			k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$
8	1.0E-20	ω_11_1	0.9598	0.0013	0.9624						
7	1.0E-20	ω_10_1	0.9354	0.0013	0.9380						
6.75	1.0E-20	ω_9_1	**0.9290**	**0.0018**	**0.9326**						
6.75	1.0E-5	ω_9_2	0.9275	0.0014	0.9303						
6.75	1.0E-4	ω_9_3	0.9287	0.0015	0.9317						
6.75	1.0E-3	ω_9_4	0.9274	0.0014	0.9302						
6.5	1.0E-20	ω_8_1	0.9204	0.0013	0.9230						
6	1.0E-20	ω_7_1	0.9081	0.0018	0.9117	0.9445	0.0012	0.9469			
5.75	1.0E-20	ω_6_1	N/A	N/A	N/A	0.9377	0.0012	0.9401			
5.5	1.0E-20	ω_5_1	N/A	N/A	N/A	0.9295	0.0012	0.9319			
5.5	1.0E-5	ω_5_2	N/A	N/A	N/A	**0.9306**	**0.0013**	**0.9332**			
5.5	1.0E-4	ω_5_3	N/A	N/A	N/A	0.9292	0.0010	0.9312			
5.5	1.0E-3	ω_5_4	N/A	N/A	N/A	0.9261	0.0013	0.9287			
5	1.0E-20	ω_4_1	N/A	N/A	N/A	0.9122	0.0012	0.9146			
4.5	1.0E-20	ω_3_1	N/A	N/A	N/A	0.8958	0.0013	0.8984	0.9528	0.0013	0.9554
4.25	1.0E-20	ω_2_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9345	0.0015	0.9370
4	1.0E-20	ω_1_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9218	0.0010	0.9242
4	1.0E-5	ω_1_2	N/A	N/A	N/A	N/A	N/A	N/A	**0.9247**	**0.0012**	**0.9271**
4	1.0E-4	ω_1_3	N/A	N/A	N/A	N/A	N/A	N/A	0.9196	0.0013	0.9222
4	1.0E-3	ω_1_4	N/A	N/A	N/A	N/A	N/A	N/A	0.9212	0.0014	0.9240

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

From the results found in Tables 6.9.11.39 and 6.9.11.40 for an infinite array (CSI of 0.0) with NCT, the highest amount of oxide below the USL is ~10.75 kg (9.46-kg ^{235}U) for 1.75 g/cm^3 (Case **ncialdoxt11_1_19_1** with a $k_{eff} + 2\sigma$ of 0.934), ~9.50 kg (8.36-kg ^{235}U) for 1.5 g/cm^3 (Case **ncialdoxt11_2_16_3** with a $k_{eff} + 2\sigma$ of 0.934), ~8.25 kg (7.26-kg ^{235}U) for 1.25 g/cm^3 (Case **ncialdoxt11_3_12_2** with a $k_{eff} + 2\sigma$ of 0.935), ~6.75 kg (5.94-kg ^{235}U) for 1.0 g/cm^3 (Case **ncialdoxt11_4_9_1** with a $k_{eff} + 2\sigma$ of 0.933), ~5.50 kg (4.84-kg ^{235}U) for 0.75 g/cm^3 (Case **ncialdoxt11_5_5_2** with a $k_{eff} + 2\sigma$ of 0.933), and ~4.00 kg (3.52-kg ^{235}U) for 0.5 g/cm^3 (Case **ncialdoxt11_6_1_2** with a $k_{eff} + 2\sigma$ of 0.927).

Table 6.9.11.41. Infinite array package model, low density oxide, HAC

UO_2 mass (kg)	MOIFR	Case hcialdoxt12_	1.75 g/cm^3 (ω = 1) [a]			1.50 g/cm^3 (ω = 2) [a]			1.25 g/cm^3 (ω = 3) [a]		
			k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ	k_{eff}	σ	k_{eff} + 2σ
12	1.0E-20	ω_21_1	0.9503	0.0013	0.9529						
11	1.0E-20	ω_20_1	0.9340	0.0014	0.9368						
10.75	1.0E-20	ω_19_1	0.9324	0.0012	0.9348						
10.75	1.0E-5	ω_19_2	**0.9324**	**0.0013**	**0.9350**						
10.75	1.0E-4	ω_19_3	0.9309	0.0012	0.9333						
10.75	1.0E-3	ω_19_4	0.9295	0.0011	0.9317						
10.5	1.0E-20	ω_18_1	0.9256	0.0015	0.9286						
10	1.0E-20	ω_17_1	0.9220	0.0013	0.9246	0.9419	0.0014	0.9447			
9.5	1.0E-20	ω_16_1	N/A	N/A	N/A	0.9323	0.0011	0.9345			
9.5	1.0E-5	ω_16_2	N/A	N/A	N/A	**0.9321**	**0.0013**	**0.9347**			
9.5	1.0E-4	ω_16_3	N/A	N/A	N/A	0.9285	0.0012	0.9309			
9.5	1.0E-3	ω_16_4	N/A	N/A	N/A	0.9292	0.0014	0.9320			
9.25	1.0E-20	ω_15_1	N/A	N/A	N/A	0.9262	0.0012	0.9286			
9	1.0E-20	ω_14_1	N/A	N/A	N/A	0.9215	0.0011	0.9237	0.9452	0.0010	0.9482
8.5	1.0E-20	ω_13_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9347	0.0012	0.9371
8.25	1.0E-20	ω_12_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9311	0.0017	0.9345
8.25	1.0E-5	ω_12_2	N/A	N/A	N/A	N/A	N/A	N/A	0.9316	0.0013	0.9342
8.25	1.0E-4	ω_12_3	N/A	N/A	N/A	N/A	N/A	N/A	0.9334	0.0014	0.9362
8.25	1.0E-3	ω_12_4	N/A	N/A	N/A	N/A	N/A	N/A	0.9315	0.0013	0.9341
8	1.0E-20	ω_11_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9242	0.0015	0.9272
8	1.0E-5	ω_11_2	N/A	N/A	N/A	N/A	N/A	N/A	**0.9271**	**0.0014**	**0.9299**
8	1.0E-4	ω_11_3	N/A	N/A	N/A	N/A	N/A	N/A	0.9259	0.0011	0.9281
8	1.0E-3	ω_11_4	N/A	N/A	N/A	N/A	N/A	N/A	0.9247	0.0016	0.9279
7	1.0E-20	ω_10_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9029	0.0014	0.9257

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

Table 6.9.11.42. Infinite array package model, low density oxide, HAC

UO_2 mass (kg)	MOIFR	Case hcialdoxt12_	1.00 g/cm^3 (ω = 4) [a]			0.75 g/cm^3 (ω = 5) [a]			0.50 g/cm^3 (ω = 6) [a]		
			k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$	k_{eff}	σ	$k_{eff} + 2\sigma$
8	1.0E-20	ω_11_1	0.9584	0.0017	0.9618						
7	1.0E-20	ω_10_1	0.9340	0.0011	0.9362						
6.75	1.0E-20	ω_9_1	**0.9301**	**0.0013**	**0.9327**						
6.75	1.0E-5	ω_9_2	0.9271	0.0012	0.9295						
6.75	1.0E-4	ω_9_3	0.9291	0.0013	0.9317						
6.75	1.0E-3	ω_9_4	0.9263	0.0013	0.9289						
6.5	1.0E-20	ω_8_1	0.9212	0.0013	0.9238						
6	1.0E-20	ω_7_1	0.9098	0.0015	0.9128	0.9492	0.0012	0.9516			
5.75	1.0E-20	ω_6_1	N/A	N/A	N/A	0.9372	0.0014	0.9400			
5.5	1.0E-20	ω_5_1	N/A	N/A	N/A	0.9267	0.0015	0.9297			
5.5	1.0E-5	ω_5_2	N/A	N/A	N/A	**0.9290**	**0.0014**	**0.9318**			
5.5	1.0E-4	ω_5_3	N/A	N/A	N/A	0.9289	0.0013	0.9315			
5.5	1.0E-3	ω_5_4	N/A	N/A	N/A	0.9289	0.0013	0.9315			
5	1.0E-20	ω_4_1	N/A	N/A	N/A	0.9118	0.0012	0.9142			
4.5	1.0E-20	ω_3_1	N/A	N/A	N/A	0.8946	0.0015	0.8976	0.9507	0.0016	0.9539
4.25	1.0E-20	ω_2_1	N/A	N/A	N/A	N/A	N/A	N/A	0.9347	0.0014	0.9375
4	1.0E-20	ω_1_1	N/A	N/A	N/A	N/A	N/A	N/A	**0.9234**	**0.0013**	**0.9260**
4	1.0E-5	ω_1_2	N/A	N/A	N/A	N/A	N/A	N/A	0.9219	0.0013	0.9245
4	1.0E-4	ω_1_3	N/A	N/A	N/A	N/A	N/A	N/A	0.9226	0.0014	0.9254
4	1.0E-3	ω_1_4	N/A	N/A	N/A	N/A	N/A	N/A	0.9228	0.0013	0.9250

[a] The shaded sections are masses that would not fit inside the CV at that density, and "N/A" entries denote where additional calculations are not necessary.

From the results found in Tables 6.9.11.41 and 6.9.11.42 for an infinite array (CSI of 0.0) with HAC, the highest amount of oxide below the USL is ~10.75 kg (9.46-kg ^{235}U) for 1.75 g/cm^3 (Case **hcialdoxt12_1_19_2** with a $k_{eff} + 2\sigma$ of 0.935), ~9.50 kg (8.36-kg ^{235}U) for 1.50 g/cm^3 (Case **hcialdoxt12_2_16_2** with a $k_{eff} + 2\sigma$ of 0.935), ~8.00 kg (7.04-kg ^{235}U) for 1.25 g/cm^3 (Case **hcialdoxt12_3_11_2** with a $k_{eff} + 2\sigma$ of 0.930), ~6.75 kg (5.94-kg ^{235}U) for 1.0 g/cm^3 (Case **hcialdoxt12_4_9_1** with a $k_{eff} + 2\sigma$ of 0.933), ~5.50 kg (4.84-kg ^{235}U) for 0.75 g/cm^3 (Case **hcialdoxt12_5_5_2** with a $k_{eff} + 2\sigma$ of 0.932), and ~4.00 kg (3.52-kg ^{235}U) for 0.5 g/cm^3 (Case **hcialdoxt12_6_1_1** with a $k_{eff} + 2\sigma$ of 0.926).

The HAC cases are about as reactive as the NCT cases except at a bulk density of 1.25 g/cm^3. At this bulk density, the HAC cases are slightly more reactive at 8.25-kg oxide (7.2-kg ^{235}U) than the NCT cases and are above the USL. Additional calculations at 8.00-kg oxide (7.0-kg ^{235}U) for HAC are shown to be below the USL.

6.9.11.6.4 Cladding for broken metal

The ES-3100 package is evaluated loaded with broken metal with varying amounts of cladding material [SS304 (stainless steel, Type 304), aluminum, zirconium, and nickel] in an infinite array with the CV fully flooded. The case for 2774 g of broken metal at 100% enrichment is used for these calculations because this case is the basis for the limits for broken metal for CSI 0.0 (Table 6.1c). Calculations for the NCT are performed varying the amount of cladding material from none to 6.0-cm thick. The amount of cladding that is evaluated in this section is larger than what is evaluated for the CV cases because the amount of fissile material analyzed in the array cases is significantly less than the CV cases, which allows for more cladding material to be added to the CV. Only calculations with a specific gravity of 1.0E-20 outside the CV (MOIFR) are shown in this section because this specific gravity is shown to be the most reactive.

The HAC cases are not examined because the behavior of the system would be the same due to the only differences in these models are the outer diameter of the drum, the increase of the density of the Kaolite inside the drum, and essentially no difference in the reactivity between NCT and HAC ($k_{eff} + 2\sigma$ of 0.904 for NCT and 0.905 for HAC from Table 6.1c). The results of the calculations are found in Table 6.9.11.43.

Table 6.9.11.43. ES-3100 results for broken metal with various amounts of cladding CV fully reflected and flooded

Clad thickness (cm)	Case nciabmt11c_	$k_{eff} + 2\sigma$ [a]			
		SS304 ($\omega = 1$)	Aluminum ($\omega = 2$)	Zirconium ($\omega = 3$)	Nickel ($\omega = 4$)
0.0	1_ω	**0.90406**	N/A	N/A	N/A
0.0506	2_ω	0.90365	0.90304	0.90364	0.90224
0.1016	3_ω	0.90219	0.90319	0.90253	0.90249
0.1508	4_ω	0.90212	0.90066	0.90268	0.90104
0.2032	5_ω	0.90008	0.90210	0.90150	0.89994
0.2446	6_ω	0.89904	0.90043	0.90099	0.89884
1.0	7_ω	0.88358	0.89024	0.89169	0.87866
2.0	8_ω	0.84395	0.86485	0.86666	0.83612
4.0	10_ω	0.71260	0.75712	0.76546	0.68986
6.0	12_ω	0.47076	0.51865	0.53007	0.44871

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

From the results found in the Table 6.9.11.43, as in the CV cases (Tables 6.9.11.19 and 6.9.11.20), adding cladding material to broken metal results in a decrease of reactivity. From these calculations, it can be concluded that for stainless steel, aluminum, zirconium, and nickel based cladding, these materials do not need to be controlled for criticality safety purposes.

6.9.11.6.5 Cladding for U_3O_8-Al, oxides of U-Zr, and UO_2-Mg research reactor fuel elements and components

The next set of calculations evaluates the ES-3100 package loaded with research reactor fuel elements and components. This is modeled with varying amounts of cladding material in an infinite array

with the CV fully flooded. Only calculations with a specific gravity of 1.0E-20 outside the CV (MOIFR) are shown because this specific gravity is shown to be the most reactive. These contents are shown to be bounded by the bulk oxide analysis evaluated in this SARP. The HEU oxide model used in these calculations is UO_2 at a bulk density of 2.0 g/cm^3 mixed with 500 g of polyethylene with the void spaces inside the oxide filled with water. The 9.682-kg ^{235}U cases are re-run adding cladding to the oxide matrix because this case is the basis for the limits for bulk oxide for CSI 0.0 (Table 6.2a). The HAC cases are not examined since the behavior of the system would be the same due to the only differences in these models are the outer diameter of the drum and the increase of the density of the Kaolite inside the drum. The results of the calculations are found in Table 6.9.11.44.

Table 6.9.11.44. ES-3100 results for oxide research reactor fuel elements and components with various amounts of cladding at 2.0 g/cm^3

Volume (L)	Case nciapdoxt11c_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	1_1_ω	**0.91889**	N/A	N/A	N/A
0.5	1_2_ω	0.89322	0.89297	0.89436	0.89385
1.0	1_3_ω	0.86928	0.87076	0.87378	0.86813
1.5	1_4_ω	0.84743	0.84974	0.85300	0.84612
2.0	1_5_ω	0.82769	0.83251	0.83501	0.82331
3.0	1_7_ω	0.79572	0.80417	0.80824	0.78927
4.0	1_9_ω	0.77617	0.79397	0.79556	0.76332

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

From the results found in the Table 6.9.11.44, as in the CV cases (Table 6.9.11.21), adding cladding material to oxides resulted in a decrease of reactivity.

6.9.11.6.6 Cladding for Fuel Pellets

This analysis evaluated the ES-3100 package loaded with HEU fuel pellets modeled as rods as in Sect. 6.9.11.5.6. Calculations are performed varying the types and amounts of cladding material as in the reflected and flooded CV cases but for an infinite array of ES-3100 packages. Only calculations with a specific gravity of 1.0E-20 outside the CV (MOIFR) are shown because this specific gravity is shown to be the most reactive. The HAC cases are not examined because the behavior of the system would be the same due to the only differences in these models are the outer diameter of the drum and the increase of the density of the Kaolite inside the drum. The results of the calculations are found in Table 6.9.11.45.

Table 6.9.11.45. ES-3100 results for fuel pellet rods with various amounts of cladding CV fully flooded infinite array

Clad thickness (cm)	Case 5nsiaoxt11c_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	1_ω	**0.86743**	N/A	N/A	N/A
0.050	2_ω	0.85245	0.85959	0.86152	0.84563
0.100	3_ω	0.83506	0.84831	0.85155	0.82322
0.150	4_ω	0.81643	0.83892	0.83852	0.79969
0.200	5_ω	0.79691	0.82402	0.82557	0.77464
0.300	7_ω	0.75648	0.79220	0.79599	0.72561
0.400	9_ω	0.71180	0.75478	0.75858	0.67644
0.450	10_ω	0.68895	0.73640	0.73757	0.65268

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

From the results found in Table 6.9.11.45, the most reactive cases are those with no reflector material surrounding the fuel pellet rod. The more cladding material is added to the fuel pellet rod, the more the reactivity of this system is decreased.

6.9.11.7 Air Transport for Broken Metal

In these calculations, the air transport models are re-evaluated examining the effect of cladding material on these models. For broken metal, Models 1 through 6 are re-run with stainless steel, aluminum, zirconium, and nickel cladding (Tables 6.9.11.46–6.9.11.51). The cladding is homogeneously mixed with the fissile material in all of these models except for Model 6, which homogeneously mixes part of the cladding with fissile material and surrounds the fissile material with the rest of the cladding. A more detailed description of these models is found in Sect. 6.3.1.4 with a brief summary of the models described in this section.

In this analysis, Model 1 is a spherical homogeneous mixture of 10-kg ^{235}U, 500 g of polyethylene, and cladding material surrounded by 20 cm of water. The type and volume of cladding material is varied from none to 5 L in volume.

Model 2 is a spherical homogeneous mixture of 10-kg ^{235}U and 500 g of polyethylene surrounded by cladding material instead of stainless steel, which is surrounded by 20 cm of water. The type and thickness and of cladding material is varied from none to 5.0 cm.

Model 3 a spherical homogeneous mixture of 10-kg ^{235}U, 500 g of polyethylene, and cladding material that is surrounded by wet Kaolite, which is surrounded by 20 cm of water. The amount of Kaolite surrounding the fissile material is varied from none to 60,223.4 g of wet Kaolite (53,419.6 g of dry-baked Kaolite plus 6,803.8 g of free water). The type and volume of cladding material is varied from none to 5 L in volume. If no Kaolite is modeled, Model 3 is the same as Model 1.

Model 4 is a spherical homogeneous mixture of 7-kg ^{235}U, 500 g of polyethylene, wet Kaolite, and cladding material, which is surrounded by 20 cm of water. The amount of water in the Kaolite region is varied from 2,204.7 g in baked-dry Kaolite to 9,008.6 g in wet Kaolite. The type and volume of cladding material is varied from none to 5 L in volume.

Model 5 is a spherical homogeneous mixture of 7-kg ^{235}U, 500 g of polyethylene, excessive moisture from the Kaolite, and cladding material that is surrounded by Kaolite, which is surrounded by 20 cm of water. The amount of water from the Kaolite region in the fissile material region is varied from 2,204.7 g in baked-dry Kaolite to 9,008.6 g in wet Kaolite. The type and volume of cladding material is varied from none to 5 L in volume.

Model 6 is a spherical homogeneous mixture of part of 7-kg ^{235}U, 500 g of polyethylene, wet Kaolite, and part of the cladding material surrounded by a homogeneous mixture of the remaining 7-kg ^{235}U and remaining cladding material, which is surrounded by 20 cm of water. The type and volume of cladding material is varied from none to 5 L in volume.

The most reactive configurations of the models are presented in the tables below. The results of the calculations are found in Tables 6.9.11.46–6.9.11.51.

Table 6.9.11.46. Results for broken metal with various amounts of cladding for air transport Model 1 with 10-kg ^{235}U

Volume (L)	Case atdmrc_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	1_ω	**0.84971**	N/A	N/A	N/A
0.5	2_ω	0.78397	0.77145	0.77785	0.78477
1.0	3_ω	0.73977	0.72595	0.73587	0.73902
2.0	4_ω	0.68695	0.67555	0.68690	0.67948
3.0	5_ω	0.65339	0.64898	0.65839	0.63919
4.0	6_ω	0.62955	0.63199	0.64046	0.61094
5.0	7_ω	0.61142	0.61991	0.62900	0.58934

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

Table 6.9.11.47. Results for broken metal with various amounts of cladding for air transport Model 2 with 10-kg ^{235}U

Thickness (cm)	Case atdmsrc_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	1_ω	**0.84971**	N/A	N/A	N/A
0.5	2_ω	0.82856	0.85140	0.85430	0.81418
1.0	3_ω	0.81128	0.84947	0.85743	0.79864
2.0	5_ω	0.79866	0.84471	0.85945	0.80042
3.0	7_ω	0.79961	0.83717	0.85993	0.81461
4.0	9_ω	0.80535	0.82917	0.85824	0.82952
5.0	11_ω	0.81515	0.82212	0.85636	0.84345

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

Table 6.9.11.48. Results for broken metal with various amounts of cladding for air transport Model 3 with 10-kg ^{235}U

Volume (L)	Case atdm15krc_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
No Kaolite (same as Model 1)					
0.0	1_1_ω	**0.84971**	N/A	N/A	N/A
0.5	2_1_ω	0.78397	0.77145	0.77785	0.78477
1.0	3_1_ω	0.73977	0.72595	0.73587	0.73902
2.0	4_1_ω	0.68695	0.67555	0.68690	0.67948
3.0	5_1_ω	0.65339	0.64898	0.65839	0.63919
4.0	6_1_ω	0.62955	0.63199	0.64046	0.61094
5.0	7_1_ω	0.61142	0.61991	0.62900	0.58934
12.0446-kg Kaolite					
0.0	1_2_ω	**0.70595**	N/A	N/A	N/A
0.5	2_2_ω	0.63285	0.60990	0.61784	0.64469
24.0892-kg Kaolite					
0.0	1_3_ω	**0.68744**	N/A	N/A	N/A
0.5	2_3_ω	0.61131	0.58566	0.59745	0.62464

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

Table 6.9.11.49. Results for broken metal with various amounts of cladding for air transport Model 4 with 7-kg ^{235}U, 9008.5-g H_2O

Volume (L)	Case athmp15krc_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	1_5_ω	**0.59294**	N/A	N/A	N/A
0.5	2_5_ω	0.58845	0.59164	0.59324	0.58584
1.0	3_5_ω	0.58305	0.59327	0.59363	0.57542
2.0	4_5_ω	0.57406	0.59250	0.59469	0.56264
3.0	5_5_ω	0.56461	0.59310	0.59466	0.54832
4.0	6_5_ω	0.55635	0.59277	0.59449	0.53526
5.0	7_5_ω	0.54785	0.59345	0.59422	0.52109

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

Table 6.9.11.50. Results for broken metal with various amounts of cladding for air transport Model 5 with 7-kg ^{235}U, 5442.1-g H_2O

Volume (L)	Case athmpw12krc_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
0.0	1_5_ω	**0.90343**	N/A	N/A	N/A
0.5	2_5_ω	0.88909	0.88024	0.88704	0.89217
1.0	3_5_ω	0.87536	0.85880	0.87092	0.88068
2.0	4_5_ω	0.84699	0.82210	0.84181	0.85351
3.0	5_5_ω	0.81892	0.78912	0.81784	0.82650
4.0	6_5_ω	0.79552	0.75989	0.79505	0.80099
5.0	7_5_ω	0.77264	0.73837	0.77521	0.77475

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

From the results found in the Tables 6.9.11.46–6.9.11.50, adding cladding material to broken metal in the air transport model results in a decrease of reactivity. All cases are below the USL.

Table 6.9.11.51. Results for broken metal with various amounts of cladding for air transport Model 6

Clad [core/shell] (L)	Case athmp15kmrc_	$k_{eff} + 2\sigma$ [a]			
		SS304 (ω = 1)	Aluminum (ω = 2)	Zirconium (ω = 3)	Nickel (ω = 4)
1000-g ^{235}U core/6000-g ^{235}U shell					
0.0/0.0	2_1_ω	0.62987	N/A	N/A	N/A
1.0/0.0	2_2_ω	0.61551	0.62984	0.62938	0.608902
3.0/0.0	2_6_ω	0.59160	0.62745	0.62767	0.57460
5.0/0.0	2_11_ω	0.57231	0.62521	0.62801	0.54875
2000-g ^{235}U core/5000-g ^{235}U shell					
0.0/0.0	3_1_ω	0.63258	N/A	N/A	N/A
1.0/0.0	3_2_ω	0.62142	0.63304	0.63321	0.61582
0.5/0.5	3_3_ω	0.61998	0.63155	0.63049	0.61535
0.3/0.7	3_4_ω	0.61991	0.63035	0.63115	0.61403
0.0/1.0	3_5_ω	0.61933	0.62951	0.63083	0.61412
3.0/0.0	3_6_ω	0.60098	0.63028	**0.63272**	0.58879
1.5/1.5	3_7_ω	0.59907	0.62910	0.62952	0.58132
1.0/2.0	3_8_ω	0.59887	0.62719	0.62953	0.58044
0.5/2.5	3_9_ω	0.59994	0.62869	0.62918	0.58138
0.0/3.0	3_10_ω	0.59889	0.62764	0.62898	0.58066
5.0/0.0	3_11_ω	0.58314	0.62987	0.63134	0.50636
2.5/2.5	3_12_ω	0.57968	0.62701	0.62953	0.55325
1.5/3.5	3_13_ω	0.57852	0.62493	0.63093	0.55169
0.5/2.5	3_14_ω	0.57924	0.62504	0.63070	0.55119
0.0/3.0	3_15_ω	0.57994	0.62642	0.63037	0.55204
3000-g ^{235}U core/4000-g ^{235}U shell					
0.0/0.0	4_1_ω	0.63199	N/A	N/A	N/A
1.0/0.0	4_2_ω	0.62195	0.63091	0.63044	0.61573
3.0/0.0	4_6_ω	0.60327	0.63110	0.63185	0.58907
5.0/0.0	4_11_ω	0.58832	0.62999	0.63171	0.56634

[a] The "N/A" entries denote where additional calculations are not necessary.
SS304 = Type 304 stainless steel.

From the results found in the Table 6.9.11.51, adding stainless steel and nickel cladding results in a decrease in reactivity. Adding aluminum and zirconium cladding results in either no increase or a decrease in reactivity. All cases are well below the USL.

6.9.11.8 UF_4 at CSI 2.0

This section discusses the calculations for the array calculations for UF_4 at a CSI of 2.0. For a CSI of 2.0, the array size for NCT is 7 × 7 × 3. The results of these calculations are found in Table 6.9.11.52. The CV and single package models were evaluated in Sect. 6.9.8.5.5 and were shown to be below the USL for up to 24-kg UF_4 (Table 6.9.8.8-5a for calculation results). From Sect. 6.9.8.6, the analyses presented in Sects. 6.4, 6.5, and 6.6 demonstrate that an insignificant difference is observed between the calculated $k_{eff} \pm 2\sigma$ values for undamaged packages in NCT and damaged packages in HAC. Therefore, the HAC array analysis is redundant and not performed.

Table 6.9.11.52. ES-3100 results for UF_4, 7×7×3 array, CSI 2.0, CV fully flooded, NCT

UF_4 mass (kg)	Case 5ncf3puf4t11_	$k_{eff} + 2\sigma$ [a]					
		MOIFR					
		1.0E-20 (ω = 1)	1.0E-5 (ω = 2)	1.0E-4 (ω = 3)	1.0E-3 (ω = 4)	0.1 (ω = 6)	0.3 (ω = 8)
1	1_ω	0.66509	N/A	N/A	N/A	N/A	N/A
5	5_ω	0.84683	N/A	N/A	N/A	N/A	N/A
10	10_ω	0.86702	0.86718	N/A	N/A	N/A	N/A
12	12_ω	0.86687	0.86603	0.86672	0.86569	0.80323	0.76562
13	13_ω	**0.86965**	0.86783	0.86669	0.86720	0.80158	0.76340
14	14_ω	0.86788	0.86627	0.86643	0.86585	0.80143	0.76409
16	16_ω	0.86523	0.86565	N/A	N/A	N/A	N/A
20	20_ω	0.86207	N/A	N/A	N/A	N/A	N/A
24	24_ω	0.85500	N/A	N/A	N/A	N/A	N/A

[a] The "N/A" entries denote where additional calculations are not necessary.

From the results found in Table 6.9.11.52 for a 7 × 7 × 3 array (CSI of 2.0) with NCT, the most reactive configuration is for 13 kg of UF_4 with no interstitial water between the packages. This case is below the USL (Case **ncf3puft11_13_1** with $k_{eff} + 2\sigma$ of 0.870).

6.9.11.9 Conclusions

For uranium oxides, there are no limits on amount of carbon that may be mixed with the oxide; thus, all carbon limitations are removed. For HEU metal turnings, fines, or powders with enrichments > 80%, the mass limits based on CSI are found in Tables 6.9.11.53 and 6.9.11.54.

Table 6.9.11.53. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 11,097-g ^{235}U	90% < enr. ≤ 95% ≤ 17,581-g ^{235}U	80% < enr. ≤ 90% ≤ 21,667-g ^{235}U
General requirements for each fissile package (§71.55)			
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, . . . so that under the following conditions, maximum reactivity of the fissile material would be attained:" (Paragraph "b")	$k_{eff} + 2\sigma \leq 0.9319$ cvr3cha_12_8_15	$k_{eff} + 2\sigma \leq 0.9344$ cvr3cha_19_7_15	$k_{eff} + 2\sigma \leq 0.9340$ cvr3cha_25_6_15
(1) the most reactive credible configuration consistent with the chemical and physical form of the material,	A mixture of water and HEU metal as turnings, fines, or powder is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used. See Appendix 6.9.3, Sect. 6.9.3.1, for justification of the content model.		
(2) moderation by water to the most reactive credible extent,	Flooding of the containment vessel		
(3) close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may be provided by the surrounding material of the packaging.	30.48-cm H_2O surrounding the containment vessel		

Table 6.9.11.53. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 11,097-g ^{235}U	90% < enr. ≤ 95% ≤ 17,581-g ^{235}U	80% < enr. ≤ 90% ≤ 21,667-g ^{235}U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited under the tests specified in §71.71 (Normal Conditions of Transport) . . ." (Paragraph "d")			
(1) the contents would be subcritical,		$k_{eff} + 2\sigma \leq 0.8844$ ncsrbmt11_36_8_15	
(2) the geometric form of the package contents would not be substantially altered,	A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used.		
(3) there would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under §71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material,		Moderation is present to such an extent as to cause maximum reactivity	
(4) there will be no substantial reduction in the effectiveness of the packaging		30.48-cm H_2O surrounding the drum (d = 18.37 in., h = 43.5 in.)	

Table 6.9.11.53. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 11,097-g ^{235}U	90% < enr. ≤ 95% ≤ 17,581-g ^{235}U	80% < enr. ≤ 90% ≤ 21,667-g ^{235}U
"A package used for shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in §71.73 (Hypothetical Accident Conditions) the package would be subcritical. For this determination, it must be assumed that:" (Paragraph "e")		$k_{eff} + 2\sigma \leq 0.8887$ hcsrbmt12_36_8	
(1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents,	A mixture of HEU metal and water is homogenized over the internal volume of the containment vessel. The amount of water in the flooded containment vessel is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers not used.		
(2) water moderation occurs to the most reactive credible extent consistent with the chemical and physical form of content,	Flooding of the package		
(3) there is full reflection by water on all sides, as close as is consistent with the damage condition of the package.	30.48-cm H_2O surrounding the reduced diameter drum (d = 17.20 in., h = 43.5 in.)		

Table 6.9.11.53. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 11,097-g ^{235}U	90% < enr. ≤ 95% ≤ 17,581-g ^{235}U	80% < enr. ≤ 90% ≤ 21,667-g ^{235}U
Standards for arrays of fissile material packages (§71.59)			
" . . . the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close reflection on all sides of the stack by water: " (Paragraph "a")			
Transport index based on nuclear criticality control, CSI = 0.0	**Load-limited to 1,849-g ^{235}U, no can spacers**	**Load-limited to 2,637-g ^{235}U, no can spacers**	**Load-limited to 2,637-g ^{235}U, no can spacers**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	$k_{eff} + 2\sigma \leq 0.8898$ nciabmt11_2_8_1	$k_{eff} + 2\sigma \leq 0.9283$ nciabmt11_3_7_1	$k_{eff} + 2\sigma \leq 0.9277$ nciabmt11_3_6_1
(2) two times "N" damaged packages, if each package were subject to the tests specified in §71.73 (Hypothetical Accident Conditions) would be subcritical with optimum interspersed hydrogenous moderation,	$k_{eff} + 2\sigma \leq 0.8897$ hciabmt12_2_8_1	$k_{eff} + 2\sigma \leq 0.9287$ hciabmt12_3_7_1	$k_{eff} + 2\sigma \leq 0.9183$ hciabmt12_3_6_1
(3) the value of "N" cannot be <0.5.	N(1,2) = ∞	Same	Same
Transport index based on nuclear criticality control, CSI = 0.4	**Load-limited to 3,699-g ^{235}U, no can spacers**	**Load-limited to 4,395-g ^{235}U, no can spacers**	**Load-limited to 5,000-g ^{235}U, no can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.9251$ ncf1bmt11_4_8_1	$k_{eff} + 2\sigma \leq 0.9317$ ncf1bmt11_5_7_1	$k_{eff} + 2\sigma \leq 0.9330$ ncf1bmt11_6_6_2
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.9021$ hcf2bmt12_4_8_3	$k_{eff} + 2\sigma \leq 0.9076$ hcf2bmt12_5_7_1	$k_{eff} + 2\sigma \leq 0.9114$ hcf2bmt12_6_6_2
(3) the value of "N" . . .	N(1,2) = 202/162	Same	Same

Table 6.9.11.53. Summary of criticality evaluation for HEU metal turnings, fines, or powder

Conditions	95% < enr. ≤ 100% ≤ 11,097-g ^{235}U	90% < enr. ≤ 95% ≤ 17,581-g ^{235}U	80% < enr. ≤ 90% ≤ 21,667-g ^{235}U
Transport index based on nuclear criticality control, CSI = 0.8	**Load-limited to 6,473-g ^{235}U, no can spacers**	**Load-limited to 7,032-g ^{235}U, no can spacers**	**Load-limited to 9,166-g U, no can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.9350$ ncf2bmt11_7_8_3	$k_{eff} + 2\sigma \leq 0.9291$ ncf2bmt11_8_7_2	$k_{eff} + 2\sigma \leq 0.9330$ ncf2bmt11_11_6_2
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.9134$ hcf3bmt12_7_8_4	$k_{eff} + 2\sigma \leq 0.9092$ hcf3bmt12_8_7_3	$k_{eff} + 2\sigma \leq 0.9141$ hcf3bmt12_11_6_1
(3) the value of "N"	N(1,2) = 64/73	Same	Same
Transport index based on nuclear criticality control, CSI = 2.0 [a]	**Load-limited to 11,097-g ^{235}U, no can spacers**	**Load-limited to 14,944-g ^{235}U, no can spacers**	**Load-limited to 16,667-g U, no can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.9332$ ncf3bmt11_12_8_4	$k_{eff} + 2\sigma \leq 0.9346$ ncf3bmt11_16_7_2	$k_{eff} + 2\sigma \leq 0.9334$ ncf3bmt11_19_6_3
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.8948$ hcf4bmt12_12_8_1	$k_{eff} + 2\sigma \leq 0.8990$ hcf4bmt12_16_7_4	$k_{eff} + 2\sigma \leq 0.8953$ hcf4bmt12_19_6_2
(3) the value of "N"	N(1,2) = 29/25	Same	Same
Transport index based on nuclear criticality control, CSI = 3.2 [b]	**Load-limited to 11,097-g ^{235}U, no can spacers**	**Load-limited to 17,581-g ^{235}U, no can spacers**	**Load-limited to 21,667-g U, no can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.9349$ nctf5bmt11_21_8_2	$k_{eff} + 2\sigma \leq 0.9350$ nctf5bmt11_26_7_1	$k_{eff} + 2\sigma \leq 0.9341$ nctf5bmt11_31_6_1
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.9153$ hctf5bmt12_21_8_4	$k_{eff} + 2\sigma \leq 0.9164$ hctf5bmt12_26_7_4	$k_{eff} + 2\sigma \leq 0.9138$ hctf5bmt12_31_6_3
(3) the value of "N"	N(1,2) = 16/24	Same	Same

[a] Neutron multiplication factors and "N" are shown for an NCT array size of 7×7×3 and an HAC array size of 5×5×2; both arrays are nearly cubic arrangements. An HAC array size is not available for CSI=1.8; therefore, CSI for NCT at 1.8 is rounded up to 2.0 as shown.

[b] Neutron multiplication factors and "N" are shown for an NCT array size of 27×3 and an HAC array size of 16×3; where packages in the planar dimension are in explicit triangular-pitch arrangement and stacked three high in the vertical direction. An NCT array size of 81 packages gives a CSI value of 3.12 (50 / 16), while an HAC array size of 48 packages gives a CSI value of 2.08 (50 / 24). The specified CSI value of 3.2 is the larger of the two numbers rounded up to the nearest tenth decimal place as shown.

Table 6.9.11.54. Limits for HEU metal turnings, fines, and powders per ES-3100 package

Enrichment	CSI	No spacers, ^{235}U (kg)
>95%, ≤ 100%	0.0	1.849
	0.4	3.699
	0.8	6.473
	2.0	11.097
	3.2	11.097
>90%, ≤ 95%	0.0	2.637
	0.4	4.395
	0.8	7.032
	2.0	14.944
	3.2	17.581
>80%, ≤ 90%	0.0	2.637
	0.4	5.000
	0.8	9.166
	2.0	16.667
	3.2	21.667

The allowed mass for > 80 ≤ 90% enrichment at CSI of 0.8 (9.166 kg) is higher than the > 70 ≤ 80% enrichment at CSI of 0.8 (8.900 kg). This is due to using SCALE 6.1.1 and its validation with a higher USL with the same safety margin of 0.05 (USL of 0.935 for SCALE 6.1.1 vs USL of 0.925 for SCALE 4.4a). Also, some of the masses shown in Tables 6.9.11.53 and6.9.11.54 are lower than what is evaluated for in the array calculations (as discussed in Sect. 6.9.11.6.1). In some cases, the single reflected CV calculations are more reactive than the array calculations, and the mass limits are reduced to the single reflected CV cases presented in Table 6.9.11.1.

The oxide mass limits based on bulk density are found in Table 6.9.11.55. The total oxide mass remains at 15.13 kg due to hydrogen buildup concerns. For oxides with a bulk density ranging from ≥ 2.0 g/cm^3 to 6.54 g/cm^3 at a CSI of 0.0 and 0.4, the maximum ^{235}U per ES-3100 package is 9,682 g and 12,323 g, respectively, as discussed in Sects. 6.5.3 and Appendix 6.9.9.

Table 6.9.11.55. Limits for low bulk density HEU oxide per ES-3100 package, CSI=0.0

Bulk density (g/cm^3)	^{235}U mass (kg)
≥ 1.75, < 2.0	9.46
≥ 1.50, < 1.75	8.36
≥ 1.25, < 1.5	7.04
≥ 1.0, < 1.25	5.94
≥ 0.75, < 1.0	4.84
≥ 0.5, < 0.75	3.52

From the calculations performed in this appendix, it is shown that for broken metal and research reactor fuel elements and components bounded by bulk oxide, no cladding is the most reactive configuration. As cladding is added to the fissile material, reactivity decreases. In the air transport models, reactivity decreases as cladding is added to the fissile material, except for Model 6 where reactivity increases slightly but remained well below the USL. Thus, it can be concluded that for stainless steel, aluminum, zirconium, and nickel based cladding, these materials do not need to be controlled for criticality safety purposes.

Uranium metal loadings in this package may contain quantities of alloying constituents, none of which are fissile. These constituents act a diluent when mixed with HEU metal. Calculations are performed in Sects. 6.9.11.5.4 and 6.9.11.6.4 for broken metal evaluated uranium homogeneously mixed with various amounts of aluminum, steel, zirconium, or nickel. Adding these materials to the uranium metal resulted in a decrease in reactivity for both single-unit and array calculations. Furthermore, TID-7016 (Sect. 3.1, p. 71) states that when ^{235}U, ^{233}U, or plutonium metal is mixed with any element from $11 \leq Z$ (atomic number) ≤ 83 (from sodium to bismuth), the amount of fissile material required to go critical increases. If the system was shown to be subcritical without the alloying material, then adding alloying material would increase the amount of fissile material required to go critical, thus diluting the system and resulting in a less reactive system. Therefore, alloying materials of any element from $11 \leq Z \leq 83$ do not require any criticality safety controls.

For UF_4 at a CSI of 2.0, the maximum amount of UF_4 per ES-3100 package is 24 kg (18.136-kg ^{235}U).

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7. PACKAGE OPERATIONS

Radioactive material packages shall be operated in accordance with applicable U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Transportation (DOT), and other federal, state, and local regulations to protect the health and safety of the public, workers, and the environment. Furthermore, the packages shall be operated according to a quality assurance (QA) plan approved by the U.S. Department of Energy (DOE), Office of Environmental Management; or DOE, National Nuclear Security Administration (DOE/NNSA); as appropriate.

The user is responsible for following the established NRC regulations for packaging, preparation for shipment, and transportation of radioactive materials given in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] as well as DOT regulations for packaging and shipment of hazardous materials given in Title 49 CFR. DOE nuclear facility users are responsible for implementing DOE regulations given in Title 10, Parts 830 and 835, of the CFR in addition to directives conveyed in DOE Order (O) 232.2, DOE O 414.1D, and DOE O 460.1C or DOE O 461.1B, as appropriate.

Specific operational criteria for the ES-3100 package with highly enriched uranium (HEU) content are presented in this section. Where appropriate, facility management may authorize the adjustment of the explicit implementation sequence in this section to accommodate facility-specific workflow logistics and operational requirements. The package user shall develop detailed, written site-specific operating procedures based on the Certificate of Compliance (CoC), the criteria contained herein, and the facility's operational requirements. These procedures shall be in accordance with 10 CFR 71, Subparts A, G, and H; DOT and DOE regulations; and applicable state, tribal, and local regulations not preempted by DOT. The operating procedures should also describe interim activities to be performed if the package is to be temporarily stored prior to shipment. Storage incident to transportation shall be in accordance with the facility Safety Analysis Report (10 CFR 830) or the Transportation Safety Document (TSD) [DOE O 460.1C or DOE O 461.2, as applicable].

The package operations should be consistent with maintaining occupational radiation exposures as low as reasonably achievable (ALARA) [10 CFR 71.87(i)] in addition to addressing applicable safety aspects or activities such as personal protection (radiation, chemical, and physical); contamination or radiation surveys; nuclear criticality safety; provisions for reporting safety concerns associated with the packaging or its use; and the records and reporting requirements cited in Appendix 7.5.1. The user of the packaging shall:

1. have authorization to acquire, package, or transport radioactive, fissile, or special nuclear materials;

2. have the latest CoC and safety analysis report for packaging (SARP) for the ES-3100 package with HEU content, and comply with all actions and restrictions therein;

3. be registered as a user of the ES-3100 packaging with DOE;

4. comply with the applicable requirements of the DOT regulations in Title 49 CFR, Parts 107, 171–180, and 390–397, as appropriate to the mode of transport (10 CFR 71.5); and

5. have a site-approved QA program that meets the requirements of 10 CFR 71, Subpart H.

The ES-3100 package description is presented in Sect. 1.2 with a schematic shown in Fig. 1.1, and an exploded view of the packaging components is presented in Fig. 1.2. The ES-3100 certification drawing can be found in Appendix 1.3.1. The packaging design drawings (Appendix 1.3.7) provide material lists, dimensions, safety components, welding requirements, and gasket requirements. The largest nominal gross shipping weight of the ES-3100 package with bulk HEU content is 187.81 kg (414.05 lb) and the maximum allowable gross weight is 190.5 kg (420 lb).

The ES-3100 is handled using industry-standard drum-handling equipment. When using a forklift, the ES-3100 can be placed on the tines of the forklift from below, or it is designed for a forklift pincher assembly that can be used to grasp the exterior of the drum assembly. Forklift gripping forces of up to 5400 lb can be used with no detrimental effects on the package (Sect. 1.2.1.1).

The site-specific operating procedures which include the facility's operational requirements shall ensure that:

1. All appropriate documents have been reviewed by operating personnel and are available for further review, if necessary.

2. Certified equipment is used (e.g., torque wrenches, instrumentation, scales, lifting hardware, and radiation survey instruments) in accordance with the site-approved QA program.

3. Segregated work stations, curtains, lead blankets, personnel protective equipment, or other equipment is used, as necessary, to protect workers and nearby personnel from radioactive material hazards.

4. Appropriate material handling equipment is available and approved for use (e.g., forklifts, hoists, and drum handlers). Operating controls shall be implemented for any forklift pincher assembly to limit clamping forces on the drum body (i.e., $\leq$ 5400 lb).

5. Appropriate provisions to decontaminate packages and packaging components are provided consistent with ALARA principles.

6. An optional radio-frequency identification (RFID) monitoring system tag may be secured to the drum assembly in accordance with the applicable requirements of ANL/DIS-09-5. The mounting bracket for the RFID monitoring system tag shall provide the equivalent contact area of a drum washer and the thread engagement for the drum hex nuts shall remain unchanged. When attached, the RFID tag will extend beyond the outside diameter of the drum body, and controls shall be implemented to avoid damage to the RFID tag.

Care should be exercised to control the packaging components when they are removed to ensure that parts are kept with the packaging and not mixed with other loose parts or parts from other packagings. Other preparations should be made to minimize damage or loss of packaging components. The drum and CV are marked with their serial numbers. The numbers are used to control these parts and to accumulate their respective operational and maintenance histories. Applicable serial numbers of packaging components should be verified to ensure that these components are maintained together. Loose parts (e.g., hex nuts, washers, and O-rings) may be reused if it can be shown that they were the parts that were removed and that no damage to the parts has occurred. Otherwise, they shall be discarded and replaced with certified parts. In order to maintain configuration control of the packaging components, the user shall ensure that there are no unauthorized modifications and no substitution of components with unauthorized components. The user may replace certain parts identified in Table 7.1, and the certification of all replacement parts must be traceable. The user shall document any part replacement identifying it to a specific packaging by model and serial number.

Table 7.1. Replacement parts for the ES-3100 packaging

Part	Description	Material	Specification/ Data Sheet [a]
ES-3100 drum assembly (Drawing M2E801580A001, Appendix 1.3.7)			
Drum lid hex nut	5/8-11 UNC hex nut	Silicon bronze	ASTM F 467 per ASME B18.2.2 M2E801580A005-3
Drum lid washer	0.844-in. ID × 1.375-in. OD × 0.25-in.-thick	Stainless steel	ASTM A 240 or ASTM A 276 M2E801580A005-4
Nylon plug	Vent-hole plug (installed around circumference of the drum body and on top of the top plug)	Nylon 6/6	Micro Plastic, Inc. Part 62MP0312 or equivalent M2E801580A002-8 M2E801580A008-7
Silicone rubber pads (CV bottom, CV flange, and plug)		Silicone rubber 22 ± 5 Shore A	M2E801580A009-1 M2E801580A009-2 M2E801580A009-3
Aluminum tape	Duct tape, low temperature (−40 to +250°F), 2-in. wide	Aluminum foil	M2E801580A002-11 McMaster-Carr Part 7616A21 or equivalent
ES-3100 containment vessel assembly (Drawing M2E801580A011, Appendix 1.3.7)			
Outer O-ring	5.859-in. ID × 0.139-in. diam cross section	Ethylene propylene diene monomer (EPDM)	ASTM D 2000, M2E801580A013-2
Inner O-ring	5.359-in. ID × 0.139-in. diam cross section	EPDM	ASTM D 2000, M2E801580A013-1
Modified VCO [b] threaded plug with O-ring	Leak-test-port plug	Brass	Volunteer Industrial P/N 04-2126 M2E801580A011-6

[a] All items beginning with"M2E" or "M8" are part numbers and the parts are shown on the corresponding drawings in Appendix 1.3.7.
[b] VCO—Vacuum coupling O-ring.

If packaging components are stored for an extended period of time, they may be bagged. The packaging components (i.e., complete assembly or individual parts) will be stored in weather-protected indoor facilities and transferred between facilities in an enclosed conveyance for protection from environmental elements. Generally, the exterior surface of the packaging components will remain relatively clean; however, each user will include provisions in the operating procedures to clean packaging components as necessary. Additionally, special precautions should be taken to protect the packaging from inadvertent contamination by radioactive materials. In radiological contamination areas, the packaging or package should be placed onto surfaces that are covered with a disposable covering, such as plastic or paper, to minimize the transfer of contamination.

The reference to nonfixed (removable) surface contamination is repeated throughout the various operating sections. It is essential that radiation exposure be minimized to protect the health and safety of the public, workers, and the environment. As the package is prepared to enter the public domain, the surface contamination level of the package and the conveyance will be maintained ALARA.

All personnel who support and/or perform packaging, transfer and transportation operations will be appropriately trained and qualified in accordance with the site-approved QA program; 49 CFR 171.1; and 49 CFR 172, Subpart H, as appropriate. Auditable training records will be maintained in accordance with site record retention requirements. The Y-12 National Security Complex (Y-12) ES-3100 Program Manager and the Y-12 packaging engineer must be apprised of all planned users of the ES-3100 package to ensure proper operational training has been performed.

7.1 PACKAGE LOADING

This section addresses the operational criteria relating to the preparation for loading, loading of contents, and preparation for transport of the ES-3100 package. Implementation of the operational criteria in this section along with the conditions of the CoC and the requirements of 10 CFR 71.5 will ensure that the package is properly prepared for transport.

7.1.1 Preparation for Loading

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for content and packaging preparation activities.

7.1.1.1 Content preparation

Operating personnel shall ensure that:

1. The HEU material has been verified as being within the limits specified in this SARP and the CoC for content form, material mass, material dimensions, uranium content, and ^{235}U enrichment as presented in Sect. 1.2.2. The contents shall be verified using accountability records and weight measurements.

   Note: A radiation survey of the contents may be conducted prior to loading to measure the content dose rate. The measured dose rate should be compared with known or calculated values. This is not a requirement and generally should only be performed if there are shielding concerns.

2. Packing materials (e.g., convenience cans or bottles, polyethylene bags, silicone can pads, can spacers, stainless-steel scrubbers, etc.) are visually inspected for signs of moisture, corrosion, or physical damage.

3. If the contents are broken HEU metal and alloy, proceed to Step 4. For all other contents, proceed to Step 7.

4. For proper handling of broken HEU metal and alloy, pyrophoric concerns will be addressed by one of the following options:

   a. Treat all broken HEU metal and alloy content as pyrophoric and proceed to Step 6; or

   b. Determine whether or not the broken HEU metal and alloy content is pyrophoric in accordance with Step 5.

5. For pyrophoric categorization of broken HEU metal and alloy content, the specific surface area of the metal pieces (surface area to mass ratio) is evaluated. If the specific surface area is ≤ 1.00 cm^2/g, then the metal pieces are not pyrophoric and are acceptable for loading according to Step 7. If the specific surface area is >1.00 cm^2/g or if the specific surface area cannot be evaluated, characterize the metal using the following methods:

   a. Solid-metal pieces that are clearly larger than 3/8 in. in every dimension do not require additional size-grading determinations and are acceptable for loading according to Step 7.

   b. Items which are unacceptable by definition (Sect. 1.2.2), such as powders, foils, wires, and turnings, will be rejected and do not require additional size-grading determinations. These items will be loaded according to Step 6.

   c. Any items that are not obviously larger than the 3/8 in. in every dimension must be size-graded using a 3/8-in. (9.5-mm) mesh sieve as follows:

      Note: With facility management approval, equivalent size-grading methods may be used [e.g., 3/8-in. (9.5 mm) mesh screens, visual comparison to size standards, etc.].

      i. Any item that falls through the sieve must be rejected and will be loaded according to Step 6.

      Note: Operators need to be alert to items which may not fall through the sieve but can be rejected based on the following criteria:

      - Long, thin shapes such as wires and turnings may not fall through the sieve when shaken. If the wire or turning could be picked up and poked through the mesh it must be rejected, even if it did not fall through unassisted.

      - Wires or turnings may form a tangled ball which will not fall through the sieve. If the wire or turning could be separated and poked through the sieve, it must be rejected.

      - Foils, thin chips or shards (any item less than 1/8-in. thick) must be rejected.

      ii. The metal pieces that are not rejected by the criteria above are acceptable for loading according to Step 7.

6. Load the rejected broken HEU metal and alloy content in a sealed container under an inert cover gas (e.g., argon or nitrogen).

   Note: The sealed container with an inert atmosphere will be leaktight as defined in ANSI N14.5-1997.

7. All contents are loaded in appropriate cans, bottles, or bags with associated packing material in accordance with the allowable loading limits and restrictions specified in Sect. 1.2.2.

7.1.1.2 Packaging preparation

Operating personnel shall ensure that:

1. A valid leak-test sticker is present on the drum to ensure that the required periodic maintenance (Sect. 8.2) and leak testing has been performed.

2. For planning purposes, the following conditions will be satisfied:

a. The package will arrive at its destination prior to the expiration of the CoC;

b. The package must be loaded in the approved conveyance and the conveyance operator must take custody of the package prior to the leak-test expiration date [recorded on the leak-test label (see Fig. 8.1) on the exterior of the drum]; and

c. When shipping HEU oxides or uranyl nitrate crystals (UNX), the shipper must verify that the shipment can be completed within the time period allotted [2 or 4 months from CV closure for UNX crystals (Table 1.3a) or 1 year from CV closure for HEU oxides (Table 1.3)].

3. The level of nonfixed radioactive contamination on the external surfaces of the packaging is ALARA and within the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is more stringent).

4. The exterior surface of the packaging is visually inspected for signs of moisture, corrosion, or physical damage and is in good condition.

5. If installed on the empty packaging, the tamper-indicating devices (TIDs) are removed when authorized.

6. The drum hex nuts and washers are removed.

   Note: If the optional RFID monitoring system tag is installed, remove the RFID tag in accordance with the applicable requirements of ANL/DIS-09-5.

7. The drum lid is removed.

8. Site-approved lifting hardware is attached to the top plug threaded lifting holes and the top plug is removed.

9. Accessible portions of the interior of the drum body and top plug are visually inspected for signs of moisture, corrosion, or physical damage and are in good condition.

10. The silicone rubber CV flange pad is removed from the top of the CV.

    Note: A contamination survey of the exposed drum liner and top of the CV may be conducted if there are contamination concerns.

11. The silicone rubber CV flange pad and plug pad are visually inspected for signs of moisture and physical damage. There are no significant gouges, cuts, tears, or nondesign voids in the pads.

12. The top of the CV is visually inspected for signs of moisture, corrosion, or physical damage and is in good condition. There are no visible signs of damage and the CV sealing lid is secure.

13. The swivel hoist ring is installed in the CV sealing lid and torqued to 16.27 ± 1.36 N·m (12 ± 1 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

14. The CV is lifted from the drum body using the swivel hoist ring and site-approved lifting equipment, and the exterior surface of the CV is visually inspected for signs of moisture, corrosion, or physical damage.

15. Comparisons of the serial number etched on the following locations are in agreement:

    a. trefoil data plate located on the side of the drum body,
    b. side of the CV body,
    c. top of the CV sealing lid, and
    d. top of the CV lid closure nut.

16. The leak-test labels are present on the drum and the CV with the recorded expiration date.

17. The drum liner is visually inspected for signs of moisture, corrosion, or physical damage.

18. The aluminum foil tape applied over the neutron-absorbing material cavity fill and vent holes (four places) located on the drum liner lower shelf (Drawing M2E801580A002, Appendix 1.3.7) is visually inspected for damage such as tears, holes, or loose edges.

19. The silicone rubber CV bottom pad is installed in the bottom of the drum cavity. If necessary, the CV bottom pad is removed and visually inspected for signs of moisture and physical damage. There are no significant gouges, cuts, tears, or nondesign voids in the pad.

20. In order to support the CV during disassembly and loading operations, users have two options:

    a. Install a site-approved support plate on the top of the drum body and lower the CV into the drum body with the CV flange resting on the support plate; or

    b. Lower the CV into a site-approved support stand.

21. The swivel hoist ring is removed from the CV sealing lid.

22. The CV lid assembly is removed and placed on a protective surface to prevent scratching of the sealing surface.

    Note: A contamination survey of the CV interior surfaces may be conducted if there are contamination concerns.

23. Any packing materials (e.g., convenience cans or bottles, polyethylene bags, silicone rubber can pads, can spacers, stainless-steel metal scrubbers), if present, are removed from the CV.

24. The interior of the CV is visually inspected for signs of moisture, corrosion, or physical damage and is in good condition.

25. Isopropyl alcohol and lint-free gloves, cloths, or swabs are used to clean the CV interior surface, as necessary.

7.1.2 Loading of Contents

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for loading content into the CV. Operating personnel shall ensure that:

1. The CV has been emptied of radioactive contents as far as practical.

2. The O-rings and the O-ring grooves on the CV flange are protected from damage during loading operations.

3. The HEU content and associated packing materials (e.g., convenience cans or bottles, polyethylene bags, silicone rubber can pads, can spacers, stainless-steel metal scrubbers) are prepared for loading in accordance with the requirements of Sect. 1.2.2. The weight of the CV payload (HEU content including all packing materials) shall not exceed 40.82 kg (90 lb).

4. The CV payload is loaded into the CV body in accordance with Sect. 1.2.2.

7.1.2.1 CV assembly and leak testing

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for preparing the CV for closure and leak testing. Operating personnel shall ensure that:

1. The CV O-rings and sealing surfaces are cleaned and inspected as follows:

   Note: The O-rings are retained in half-dovetail grooves and may be removed from the CV flange grooves as necessary to facilitate cleaning and inspection activities. Exercise care during removal and installation to avoid damage to the O-rings and O-ring grooves.

   a. Clean the sealing surfaces and O-rings, as required, with isopropyl alcohol and lint-free gloves, cloths, or swabs.

   b. Visually inspect the sealing surfaces for foreign matter, nicks, and scratches. If nicks or scratches are found, review Sect. 8.2.2 for evaluation criteria.

   c. Visually inspect the inner and outer O-rings for roughness, porosity, or surface defects. Damaged O-rings may be replaced with certified replacement O-rings (Table 7.1) subject to the requirements of Sect. 8.1.5.1 and the following:

      i. If the outer O-ring is damaged and requires replacement, then it can be replaced without performing the maintenance leakage rate testing (Sect. 8.2.2).

      Note: The outer O-ring is not part of the containment boundary. The outer O-ring functions as a seal to create the annulus between the O-rings in support of preshipment leak testing.

      ii. If the inner O-ring is damaged and requires replacement, the HEU content shall be removed (see Steps 14-16 in Sect. 7.2.2), and the leakage testing of the containment boundary shall be performed in accordance with Sect. 8.2.2 by qualified personnel.

      Note: Although only the inner O-ring is installed during the leakage testing (Sect. 8.2.2), both O-rings will be replaced during periodic maintenance in accordance with Sect. 8.2.3.1.

2. The O-rings are lubricated as necessary with a thin coat of Super-O-Lube and inserted into the CV flange grooves.

3. The CV lid closure nut threads are visually inspected for damage and foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs.

4. A thin coat of Krytox grease, Grade 240 AC, is applied as necessary to the CV lid closure nut threads (Drawing M2E801580A011, Appendix 1.3.7).

5. The CV lid assembly is positioned over the CV body with the two alignment pins in the CV flange engaged in the slots on the underside of the CV lid assembly.

6. The CV lid closure nut is torqued to 162.7 ± 6.78 N·m (120 ± 5 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

   Note: If the content is HEU oxide or uranyl nitrate crystals (UNX), the seal date is recorded (see Sect. 7.1.1.2, Step 2c).

7. The annulus between the CV O-rings is leak tested to either (1) a leakage rate of not more than the reference air leakage rate, L_R, or (2) no detected leakage when tested to a sensitivity of at least 1×10^{-3} ref-cm^3/s in accordance with the requirements of ANSI N14.5-1997, Subclause 7.6, Preshipment leakage rate test. The preshipment leak-test procedure shall meet the requirements of ANSI N14.5-1997 and the site-approved QA program. Y-12 Product Specification Procedure Y51-01-B2-R-074, *Shipping Container Leak Test* (Appendix 7.5.2) is provided as an example preshipment leak-test procedure. It should be noted that the leakage rate acceptance criteria stated in Procedure Y51-01-B2-R-074 is lower (i.e., more conservative) than the ANSI N14.5-1997 requirements noted above for a preshipment leak test. Operating personnel shall perform the following at a minimum:

   a. Ensure that the preshipment leak testing is performed in accordance with procedures that meet the criteria presented above and that the results are properly documented.

   b. Ensure that leak-test instrumentation has been properly calibrated.

   c. Remove the modified VCO threaded brass plug from the CV lid assembly leak-test port.

      Note: If the plug O-ring is not retained on the VCO threaded plug during plug removal, then use caution when extracting the plug O-ring to prevent damage of the leak-test port O-ring sealing surface.

   d. Connect the leak-test equipment to the leak-test port.

   e. Perform the preshipment leak test under isothermal conditions.

   f. Disconnect the leak-test equipment.

   g. Install the modified VCO threaded brass plug in the CV lid assembly leak-test port.

Following a successful preshipment leak test, the CV is ready to be loaded into the drum body assembly per Sect. 7.1.2.2. However, if the preshipment leak test fails to reach the required vacuum/pressure or fails the leak test, then the following measures should be taken: (1) review the operating procedures; (2) check the leak-test equipment and connections; (3) check the test gauges and instrumentation including verification of calibration and certification records, as necessary; and (4) verify isothermal test conditions. The user is also cautioned to allow sufficient time after applying the required vacuum or pressure for the O-ring annulus to reach thermal equilibrium.

The CV lid assembly shall be removed if none of the measures described above reveal the root cause for the leak-test failure. Care should be taken to control all parts on removal and then Steps 1-7 specified above shall be repeated. If the preshipment leak test fails again, the HEU content shall be removed by performing Steps 14–16 in Sect. 7.2.2. The packaging and O-rings shall be tagged as "potential" nonconforming parts and returned to the packaging maintenance organization for closer examination and disposition.

7.1.2.2 Drum closure

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for preparing the drum assembly for closure. Operating personnel shall ensure that:

1. The CV assembly with HEU content was prepared for loading into the drum body assembly in accordance with Sect. 7.1.2.1.

2. The loaded CV, top plug, drum lid, plug pad, CV bottom pad, CV flange pad, drum nuts and washers, TIDs, and optional RFID monitoring system tag are available.

3. The swivel hoist ring is installed in the CV sealing lid and torqued to 16.27 ± 1.36 N·m (12 ± 1 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

4. The loaded CV is lifted using the swivel hoist ring and site-approved lifting equipment.

5. If the CV was loaded while supported in the drum body, then remove the site-approved support plate.

6. The loaded CV is lowered into the drum body cavity and the swivel hoist ring is removed.

7. The CV flange pad is placed over the top of the CV and the plug pad is placed on the top shelf of the drum liner (Drawing M2E801580A001, Appendix 1.3.7).

8. The nylon plug is installed in the top plug vent hole and site-approved lifting hardware is attached to the top plug threaded lifting holes.

9. The top plug is installed in the drum (Drawing M2E801580A001, Appendix 1.3.7) and the lifting hardware is removed.

10. The drum weld studs and hex nut threads are visually inspected for damage and foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs.

11. The drum lid is positioned over the drum with the holes in the lid aligned with the weld studs and the TID lugs, and the lid is lowered into position.

12. The eight 5/8-11 UNC-2B hex nuts with washers (Drawing M2E801580A005, Appendix 1.3.7) are installed and the nuts are torqued to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) [Drawing M2E801580A001, Appendix 1.3.7]. **An impact wrench shall not be used.**

    Note: An optional RFID monitoring system tag may be installed in accordance with the applicable requirements of ANL/DIS-09-5.

13. A nylon plug is installed in each of the four drum vent holes (Drawing M2E801580A002, Appendix 1.3.7).

14. As required by site-specific requirements, either one or two TIDs are attached through the drum TID links.

15. The gross weight of the package does not exceed 190.5 kg (420 lb).

16. All “EMPTY” or inappropriate labels previously affixed to the drum body in conformance with 49 CFR 172, Subpart E are removed, obliterated, or covered. Leak-test labels should not be removed. The drum body is cleaned as necessary including the removal of any adhesive residue from removed labels.

17. The level of nonfixed radioactive contamination on the external surfaces of the package is ALARA and within the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is the most stringent).

18. The maximum radiation level at the package surface is measured. In addition, the maximum radiation level at 1 m from the external surface shall be measured to establish the transport index (TI) for the package. The radiation levels should be compared with the expected levels (Sect. 5), as appropriate, and evaluated against the allowable radiation levels prescribed in 10 CFR 71.47 and 49 CFR 173.441.

19. The package is labeled in accordance with 49 CFR 172, Subpart E, and the user shall particularly note the requirements of 49 CFR 172.403, *Class 7 (radioactive) material.*

    Note: It is recommended that all labels should be vinyl type or placed on plain vinyl tape and applied to the packaging to facilitate removal during maintenance.

20. The package is marked in accordance with 49 CFR 172, Subpart D. The user shall particularly note the requirements of 49 CFR 172.301, *General marking requirements for non-bulk packagings*, and 49 CFR 172.310, *Class 7 (radioactive) materials.*

    Note: For enriched uranium content in the ES-3100, which in aggregate is less than a Type B quantity of material, the proper shipping name and identification number etched on the data plate (Drawing M2E801580A010, Appendix 1.3.7) are appropriate provided that the shipping papers indicate the hazardous material description (e.g., Type A quantity of material) contained in the Type B(U)F packaging.

21. The DOE CoC number [USA/9315/B(U)F-96 (DOE)] is marked on the drum body by one of the following methods:

    a. **Preferred method.** The NRC CoC number [USA/9315/B(U)F-96] will be covered with opaque vinyl tape and the package will be marked near the data plate with the DOE CoC number in letters at least ½-in. high.

    b. **Alternate method.** A "(DOE)" marking in letters at least ½-in. high will be added adjacent to right-hand side of the data plate in line with the NRC CoC number.

7.1.3 Preparation for Transport

The transfer of the package to an onsite storage or staging area prior to offsite shipment shall be accomplished in accordance with the facility Safety Analysis Report or the TSD, as applicable. The criticality safety index (CSI) may vary from 0–3.2 for the authorized content and fissile mass loading limits (Table 1.3). Because the dose rate (and therefore the TI) presented in Sect. 5 is conservative, the actual TI, which is measured at the time of shipment, should be lower than the maximum calculated TI value for the HEU content (TI = 6.2 for 36 kg of HEU metal and TI = 5.1 for 24 kg of HEU oxide (Tables 5.1 and 5.2, respectively). These TI values are greater than or equal to the TI values for the other authorized content and fissile mass loading limits (Sect. 5.1.1).

In support of criticality safety evaluations (Sect. 6.3.1.4) and due to the potential exposure to environmental elements during transfer or handling operations, all packages prepared for air transport will be appropriately covered with an industry-standard drum cover or other waterproof cover to protect against water from entering the drum cavity. After loading in the aircraft, the drum covering may be removed to facilitate tie down of the package.

7.1.3.1 Package transfer or handling

The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below for preparing the package for transfer or handling. Operating personnel shall ensure that:

1. The level of nonfixed radioactive contamination on the external surfaces of the package is ALARA and within the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is more stringent).

2. Appropriate package labels are affixed to the package's surface and TIDs are properly installed.

3. Placement restrictions associated with onsite handling, storage, staging, or transfer of radioactive materials for onsite operations are identified. These activities are governed by the applicable requirements of the TSD (DOE O 460.1C or DOE O 461.2, as appropriate) and the facility Safety Analysis Report (10 CFR 830).

4. All packages prepared for air transport will be appropriately covered with an industry-standard drum cover or other waterproof cover to protect against water from entering the drum cavity. After loading in the aircraft, the drum covering may be removed to facilitate tie down of the package.

7.1.3.2 Decontamination

As the package is prepared to enter the public domain, the surface contamination level of the package will be maintained ALARA. The user shall develop detailed operating procedures for decontaminating packages that consider, at a minimum, the items listed below:

1. The drum is austenitic stainless steel.
2. The drum nuts are silicon bronze.
3. The drum vent holes are covered with nylon plugs (Drawing M2E801580A002, Appendix 1.3.7).
4. The labels and markings on the drum must remain legible.

7.1.3.3 Requirements prior to shipment

The shipper shall notify the receiver of the scheduled shipment [49 CFR 173.22(c)] and verify that the receiver has agreed to accept the shipment. If needed, the shipper shall provide any special instructions to the receiver to safely open the package (10 CFR 71.89), including special tools and precautions for handling or unloading. In addition, the shipper will submit appropriate documentation to the receiver to ensure that the physical characteristics and hazards of the HEU content are conveyed (49 CFR 172, Subpart C).

Before each shipment, the shipper shall ensure that the appropriate routine determinations (10 CFR 71.87) and the quality control requirements (49 CFR 173.475) have been satisfied. Detailed operating procedures shall provide evidence that the requirements stated above are met and ensure that:

1. The package has been loaded properly and preparation for shipment has been followed, witnessed, and checked.

2. When shipping HEU oxides or UNX, the shipper provides the receiver with the date that the CV was sealed. The shipper must verify that the shipment can be completed within the time period allotted [2 or 4 months for UNX crystals (Table 1.3a) or 1 year for HEU oxides (Table 1.3)].

3. All records for the shipment are prepared and maintained (Sect. 7.5.1.1) [10 CFR 71.91(a)].

4. The shipping papers including the appropriate shipper's certification (declaration) statement are prepared in accordance with 49 CFR 172, Subpart C.

5. The placarding requirements of 49 CFR 172, Subpart F, are addressed.

6. The emergency response information in accordance with 49 CFR 172, Subpart G, is addressed.

7. As determined by 49 CFR 172.800, security plans are developed in accordance with 49 CFR 172, Subpart I.

7.1.3.4 Securing to the approved conveyance

The package shall be secured against movement within the conveyance in which it is being transported under conditions normally incident to transportation. The user shall develop detailed operating procedures that include, at a minimum, the process steps listed below for loading and securing the package on the approved conveyance. Operating personnel shall ensure that:

1. An approved conveyance is used in accordance with the CoC-authorized mode of transport.

2. Reasonable precautions such as wheel chocking are taken to prevent motion of the conveyance during package loading.

3. The package must be loaded in the approved conveyance and the conveyance operator must take custody of the package prior to the leak-test expiration date [recorded on the leak-test label (see Fig. 8.1) on the exterior of the drum].

4. The consignment is positioned on the conveyance under the direction of qualified personnel in such a way that the weight is properly distributed over the width and length of the conveyance.

5. The ends, sides, or doors of the conveyance are not relied upon to prevent shifting of loads.

6. The package is secured in the conveyance using blocking, bracing, and tie-down equipment that meet industry-standard practices to prevent shifting during Normal Conditions of Transport (NCT) [49 CFR 173.448(a); 49 CFR 175.88(c) and 49 CFR 177.842(d)].

7.2 PACKAGE UNLOADING

Placement restrictions associated with onsite handling, storage, staging, or transfer of radioactive materials for onsite operations will be identified. These activities are governed by the applicable requirements of the TSD (DOE O 460.1C or DOE O 461.2, as appropriate) and the facility Safety Analysis Report (10 CFR 830).

If HEU oxide or UNX are being shipped, the receiver shall check the seal time and date before opening the container (shipment time restrictions for these contents are discussed in Sect. 1.2.2.8). The receiver shall open the CV prior to the seal time expiring or take special precautions in accordance with the facility Safety Analysis Report requirements when handling and opening the container. Special precautions are associated with the potential buildup of >5 mol % hydrogen in the CV (Appendix 3.5.4). Typical precautions may include, but are not limited to, elimination of ignition sources, gradually opening the CV in a well-ventilated area, or opening the CV in an inert glove box.

7.2.1 Receipt of Package from Carrier

The user shall develop detailed operating procedures that include, at a minimum, the process steps listed below for receiving a package and performing contamination and radiation surveys of the package. Operating personnel shall ensure that:

1. Documentation is received that conveys the physical characteristics and hazards of the package including any special instructions provided in accordance with Sect. 7.1.3.3.

2. When offered by the carrier for delivery, the TIDs on the conveyance (if required) and on the package are examined for signs of tampering. The general appearance of the conveyance and the package are noted.

3. The shipping papers are compared with the consignment, and the package is accepted.

4. The enclosed cargo space of the conveyance is examined for moisture and free liquids. If present, they will be surveyed for contamination and removed.

5. The external surfaces of the package are surveyed for removable radioactive contamination and radiation levels (10 CFR 835.405).

    a. The package nonfixed surface contamination levels are within the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is more stringent).

    b. The radiation levels do not exceed the limits specified in 10 CFR 71.47 and 49 CFR 173.441.

6. The conveyance restraint gear was properly used to secure the package.

7. Appropriate labeling and marking of the package is checked for compliance.

8. The package restraint gear is removed and the package is removed from the conveyance.

9. The package is visually inspected for exterior surface damage during shipping or handling.

    Note: If the package surface is damaged, a nonconformance tag shall be completed and attached to the package for subsequent maintenance (10 CFR 71.131).

All users shall include provisions for reporting safety concerns associated with the packaging or its use. The user shall comply with reporting requirements in accordance with DOE O 232.2, which delineates specific reporting periods in accordance with the category of the occurrence. In addition to the requirements of Sect. 7.5.1.3, incidents requiring notification include the following:

1. Nonfixed radioactive surface contamination is in excess of the limits specified in 49 CFR 173.443.

2. Radiation levels are in excess of the limits specified in 10 CFR 71.47 and 49 CFR 173.441.

3. Discrepancies exist between the shipping papers and the consignment.

4. TIDs are found to be compromised.

5. Adverse conditions are found (i.e., entrapped moisture, noncompliant items/conditions, or visible damage that may significantly reduce the package performance).

7.2.2 Removal of Contents

The user shall develop detailed operating procedures that include, at a minimum, the process steps listed below for removing the contents from the package. Operating personnel shall ensure that:

1. Appropriate labels and markings for the content are affixed to the exterior surface of the drum body.

2. The TIDs remain intact until authorized for removal.

   Note: Notify DOE in accordance with DOE O 232.2 if they are found to be compromised.

3. The drum hex nuts and washers are removed.

   Note: If the optional RFID monitoring system tag is installed, remove the RFID tag in accordance with the applicable requirements of ANL/DIS-09-5.

4. The drum lid is removed.

5. Accessible portions of the top plug and interior of the drum body are visually inspected for signs of moisture, corrosion, or physical damage and are in good condition.

6. Site-approved lifting hardware is attached to the top plug threaded lifting holes, and the top plug is removed.

7. The silicone rubber CV flange pad is removed from the top of the CV.

8. A contamination survey of the exposed drum liner and top of the CV is conducted to determine if there was a release of radioactive material.

   Note: If the nonfixed surface contamination levels exceed the limits specified in 49 CFR 173.443 for alpha-, beta-, and gamma-emitting radionuclides, notify DOE in accordance with DOE O 232.2.

9. The top of the CV is visually inspected for signs of moisture, corrosion, or physical damage and is in good condition.

10. The swivel hoist ring is installed in the CV sealing lid and torqued to 16.27 ± 1.36 N·m (12 ± 1 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

11. The CV is lifted from the drum body using the swivel hoist ring and site-approved lifting equipment and the external surfaces of the CV are visually inspected for signs of moisture, corrosion, or physical damage.

12. In order to support the CV during disassembly and unloading operations, users have two options:

    a. Install a site-approved support plate on the top of the drum body and lower the CV into the drum body with the CV flange resting on the support plate; or

    b. Lower the CV into a site-approved support stand.

13. The swivel hoist ring is removed from the CV sealing lid.

14. The CV lid assembly is removed and placed on a protective surface to prevent scratching of the sealing surface.

Note: A contamination survey of the CV interior surface may be conducted if there are contamination concerns.

15. The O-rings and the O-ring grooves on the CV flange are protected from damage.

16. The HEU content and associated packing materials (e.g., convenience cans or bottles, polyethylene bags, silicone rubber can pads, can spacers, stainless-steel metal scrubbers) are removed from the CV in accordance with site-specific radioactive material handling procedures.

    Note: A contamination survey of the CV interior surfaces and packing materials may be conducted if there are contamination concerns.

17. The HEU content and shipping configuration are compared with the applicable information on the shipping papers and the conditions of approval in the CoC. Instances in which the conditions of approval in the CoC were not observed in making a shipment shall be reported in accordance with Sect. 7.5.1.3.

7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

General requirements for shipping an empty packaging are provided in 49 CFR 173.428, *Empty Class 7 (radioactive) materials packaging*. The user shall develop detailed operating procedures which include, at a minimum, the process steps listed below to prepare an empty package for transport. Operating personnel shall ensure that:

1. The package has been emptied of radioactive contents as far as practical and the CV internal contamination level does not exceed 100 times the limits in 49 CFR 173.443(a).

2. Isopropyl alcohol and lint-free gloves, cloths, or swabs are used to clean the CV as necessary.

3. The CV sealing surfaces are visually checked for foreign matter, nicks, and scratches. If nicks or scratches are found, review Sect. 8.2.2 for evaluation criteria.

4. The O-rings are free from debris and have not been damaged. The O-rings can be cleaned with isopropyl alcohol and wiped with lint-free gloves, cloths, or swabs.

5. The O-rings are lubricated as necessary with a thin coat of Super-O-Lube and inserted into the CV flange grooves.

6. The CV lid closure nut threads are visually inspected for damage and foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs.

7. A thin coat of Krytox grease, Grade 240 AC, is applied as necessary to the CV lid closure nut threads (Drawing M2E801580A011, Appendix 1.3.7).

8. The CV lid assembly is positioned over the CV body with the two alignment pins in the CV flange engaged in the slots on the underside of the CV lid assembly.

9. The CV lid closure nut is torqued to 162.7 ± 6.78 N·m (120 ± 5 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

10. The modified VCO threaded brass plug is installed in the CV lid assembly leak-test port.

11. The CV, top plug, drum lid, plug pad, CV bottom pad, CV flange pad, drum nuts and washers, TIDs, and optional RFID monitoring system tag (depending on site-specific requirements) are available.

12. The aluminum foil tape applied over the neutron-absorbing material cavity fill and vent holes (four places) located on the drum liner lower shelf (Drawing M2E801580A002, Appendix 1.3.7) is visually inspected for damage such as tears, holes, or loose edges.

13. The swivel hoist ring is installed in the CV sealing lid and torqued to 16.27 ± 1.36 N·m (12 ± 1 ft-lb) [Drawing M2E801580A011, Appendix 1.3.7].

14. The CV is lifted using the swivel hoist ring and site-approved lifting equipment.

15. If the CV was supported in the drum body, then remove the site-approved support plate.

16. The CV bottom pad is installed in the bottom of the drum cavity.

17. The CV is lowered into the drum body cavity and the swivel hoist ring is removed.

18. The CV flange pad is placed over the top of the CV and the plug pad is placed on the top shelf of the drum liner (Drawing M2E801580A001, Appendix 1.3.7).

19. The nylon plug is installed in the top plug vent hole and site-approved lifting hardware is attached to the top plug threaded lifting holes.

20. The top plug is installed in the drum (Drawing M2E801580A001, Appendix 1.3.7) and the lifting hardware is removed.

21. The drum weld studs and hex nut threads are visually inspected for damage and foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs.

22. The drum lid is positioned over the drum with the holes in the lid aligned with the weld studs and the TID lugs, and the lid is lowered into position.

23. The eight, 5/8-11 UNC-2B, hex nuts with washers (Drawing M2E801580A005, Appendix 1.3.7) are installed and the nuts are torqued to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) [Drawing M2E801580A001, Appendix 1.3.7]. **An impact wrench shall not be used.**

    Note: An optional RFID monitoring system tag may be installed in accordance with the applicable requirements of ANL/DIS-09-5.

24. A nylon plug is installed in each of the four drum vent holes (Drawing M2E801580A002, Appendix 1.3.7).

25. If required by site-specific requirements, TIDs are attached through the drum TID links.

26. Any inappropriate labels previously affixed to the drum body in conformance with 49 CFR 172, Subpart E are removed, obliterated, or covered. Leak-test labels should not be removed. The drum body is cleaned as necessary including the removal of any adhesive residue from removed labels.

27. The level of nonfixed radioactive contamination on the external surfaces of the package is ALARA and within the limits specified in 49 CFR 173.443(a) for alpha-, beta-, and gamma-emitting radionuclides or the user's site-specific criteria (whichever is more stringent).

28. The “EMPTY” label prescribed in 49 CFR 172.450 is affixed to the drum. Labels should be vinyl type or placed on plain vinyl tape and applied to the packaging to facilitate removal during maintenance.

29. The “Radioactive Material, Type B(U) Package, Fissile UN3328” marking on the ES-3100 data plate is covered with opaque vinyl tape, and the package is marked “UN2908” in accordance with 49 CFR 173.428.

30. The radiation level at any point on the external surface of the package does not exceed 0.5 mrem/h.

31. The package is prepared for shipment as specified in 49 CFR 173.422.

7.4 OTHER OPERATIONS

There are no additional special controls unique to this package.

7.5 APPENDICES

7.5.1 Records and Reporting Requirements

7.5.2 Example Leak-test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-074, *Shipping Container Leak Test*

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Appendix 7.5.1

Records and Reporting Requirements

7.5.1.1 Records for each shipment

A record of each shipment shall be maintained for a period of 3 years after the shipment in accordance with Title 10, Part 71, Sect. 91(a), of the Code of Federal Regulations (CFR) [10 CFR 71.91(a)]. As specified in 10 CFR 71.91(c), records are only valid if stamped, initialed, or signed and dated by authorized personnel, or otherwise authenticated. These records shall include:

1. The identification of the packaging by model and serial number.
2. Verification that there were no significant defects in the packaging as shipped.
3. Type and quantity of radioactive material in each package and total quantity for each shipment.
4. Date of the shipment.
5. Any special controls exercised.
6. Name and address of the transferee (receiver).
7. Address to which the shipment was made.
8. Results of the determinations required by 10 CFR 71.87 and 49 CFR 173.475 (including documentation of replacement parts) and conditions of approval in the Certificate of Compliance (CoC).

If requested, records of the package shipping history or other information shall be forwarded to the Y-12 National Security Complex in support of recertification efforts. Additionally, each packaging user shall maintain a file of procedures and operating records associated with the ES-3100. These records shall be available for the U.S. Department of Energy (DOE) Headquarters Certifying Official audits and appraisals upon reasonable notice.

7.5.1.2 Records of packaging history

Users shall maintain sufficient written records to furnish evidence of the quality of packagings for a period of three years after the life of the packaging to which they apply in accordance with 10 CFR 71.91(d). As specified in 10 CFR 71.91(c), records are only valid if stamped, initialed, or signed and dated by authorized personnel, or otherwise authenticated. Inspection, tests, and audit records must identify the packaging by model and serial number, the inspector, the type of observation, the results, the acceptability, and the action taken in connection with any deficiencies noted. These records shall include:

1. Results of determinations required by 10 CFR 71.85 and 49 CFR 173.474.
2. Design, fabrication, and assembly records.
3. Results of reviews, inspections, tests, and audits.
4. Results of monitoring work performance and materials analyses.
5. Results of maintenance, modification, and repair activities.

The user shall permit the DOE Headquarters Certifying Official, or designee, at all reasonable times to inspect the radioactive material, packaging, premises, and facilities in which the radioactive material or packaging is used, provided, constructed, fabricated, tested, stored, or shipped [10 CFR 71.93(a)]. Authorized users shall perform any tests deemed necessary or appropriate by the DOE Headquarters Certifying Official in accordance with 10 CFR 71.93(b).

7.5.1.3 Reports

Users shall include provisions in their operating procedures for reporting safety concerns associated with the packaging or its use. The user shall comply with 10 CFR 71.95 by providing written notification to the DOE Headquarters Certifying Official in accordance with DOE O 232.2 for the following:

1. Instances where there is a significant reduction in the effectiveness of the packaging during use.

2. Details of any defects with safety significance of the packaging after first use.

3. Instances in which the conditions of approval in the CoC were not observed in making a shipment.

In addition, the U.S. Department of Transportation will be notified of hazardous materials incidents during loading, unloading, and temporary storage operations in accordance with 49 CFR 171.15 and 171.16, as appropriate. The user shall particularly note the requirements of 49 CFR 171.15(b)(2) and 49 CFR 171.16(a)(2) and (4).

Appendix 7.5.2

Example Leak-Test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-074,
Shipping Container Leak Test

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Master Distribution Being Maintained

Consolidated Nuclear Security, LLC Y-12 Management Requirements	Product Specification Procedure Title: Shipping Container Leak Test	Number: Y51-01-B2-R-074 Revision: A.8 Supersedes: A.7 Page: 1 of 10 Use Category: REFERENCE

Responsible Organization/Department Assembly/Disassembly Operations		
	Responsible Manager for R. Mullins 4/14/2015 Signature Date	
Quality Engineer Signature 4/22/15 Date	Packaging Engineer Signature 4-28-2015 Date	CC Review PTH 04-28-15 Initials Date
	Approved for Practice Signature Date	
Verified to be the latest revision Initials Date	4-30-15 Effective Date	
Concurrence by the following is documented in the Procedure History File:		
ADO Support Manager Criticality Safety Officer Facility Operations Management (Operations Manager) (Shift Technical Advisor)	Industrial Safety and Hygiene (Industrial Hygiene) (Industrial Safety) Radiological Control	Safety Analysis Engineering (Nuclear Criticality Safety) Subject Matter Expert

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

Name: Darrell Lott / Engr

Date: 29-Jan-15

Revision Number	Modification Description	Affected Page(s)
A.7	On Record	
A.8	**14-PMR-787**, Non-intent modification to incorporate bluesheet changes.	1

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1 APPLICABILITY AND SCOPE

To provide instructions for operating the shipping container leak test stations. The VTI Smart Station consists of a touch screen PC, printer, two MKS vacuum gauges, reference volume, vacuum pump, air compressor, automatic valve manifold, and temperature sensor mounted on a rolling cart. Either one of the systems may be used to perform leak tests on shipping containers.

Applies to the leak test of the O-ring seal found in leak testable inner containers. The VTI Smart Station is capable of determining a leak rate of 1.0×10^{-4} atm-cm^3/sec.

The Orifice Leak Test Station correlates the pressure drop across an orifice as compared to the pressure drop across the orifice when a calibrated leak is installed.

The VTI Smart Station performs a pressure (vacuum) rate of rise test using air as the test gas with the part under vacuum.

Program: WC

2 PRECAUTIONS AND LIMITATIONS

A. Use of standard tools and equipment, as needed, is acceptable without being listed in the tooling/equipment list.

B. The VTI Smart Station leak rate is displayed with the units of measure of "atm-cc/s" which is equivalent to "atm-cm^3/sec."

3 ACCEPTANCE CRITERIA

A. Container has passed the leak test **WHEN** the test result is PASS.

4 PREREQUISITE ACTIONS

4.1 Special Tools, Test Equipment, Parts and Supplies

Supervisor

[1] Ensure the following equipment is available:

- Leak Tester (Appendix A)
- Test Cap
- FAIL Test Standard Leak
- O-ring lube
- Container Leak Test Adapter.

4.2 Field Preparations

Assemblyperson

NOTE *Facility Instrument Air may be connected to the VTI Smart Station via quick disconnect (if equipped) in lieu of on-board compressor.*

[1] Verify leak tester vacuum pump oil level is between minimum and maximum line on gauge.

[2] **IF** the leak tester vacuum pump is **NOT** between the minimum and maximum line on the gauge, **THEN** notify Supervisor.

[3] Ensure printer is ready (i.e., turned on, has paper and ink) for operation.

[4] Ensure leak tester is turned on.

[5] **IF** system was started from power off condition, **THEN** ensure MKS Baratron transducer is allowed at least four (4) hours warm up time.

[6] **WHEN** compressor has stopped charging the accumulator, **THEN** purge leak tester air compressor to remove water accumulation using drain valve or drain plug.

[7] Verify certification sticker(s) is **NOT** expired.

4.3 Approvals and Notifications

Supervisor

[1] Obtain permission from the Shift Manager to start the Performance Section of this procedure.

5 PERFORMANCE ACTIVITIES

5.1 VTI Smart Station

5.1.1 VTI Smart Station - System Functional Check

Assemblyperson

NOTE 1 *The operator may log in to the leak tester, as necessary, by entering login password.*

NOTE 2 *After the login password is entered, a "Manual Commands" screen may display momentarily, but the screen is not used.*

NOTE 3 *If "Welcome to HP Product Assistant" screen appears, the operator may clear this screen and continue.*

NOTE 4 *A system functional check is to be performed prior to the first leak test of the day/shift in order to verify proper function of the leak tester. Two test volumes (one PASS test and one FAIL test) are run to ensure acceptable operation.*

NOTE 5 *Operator I.D. time limit may expire. Operator I.D. may be re-entered, as necessary.*

[1] **IF** system functional check has already been performed during the current shift, **THEN GO TO** Section **5.1.2**, *VTI Smart Station – Leak Testing.*

[2] Ensure pigtail at back of leak tester is installed.

[3] Perform a PASS function test as follows:

- **[a]** Ensure free end of pigtail is capped.
- **[b]** Double touch VTI icon, as needed.
- **[c]** Enter Operator ID (badge number).
- **[d]** Enter "DT22" in the location designated for Package Model.
- **[e]** Enter "CAP" in the location designated for serial number.
- **[f]** Press the "Start Test" icon.
- **[g]** **IF** alarm lights (e.g., evac. fault or settle press, etc.) activate during test, **THEN** press "ABORT TEST" icon **AND** notify Supervisor.
- **[h]** Receive the printout of the test results.
- **[i]** **IF** result is FAIL (the first attempt), **THEN REPEAT** Steps **5.1.1[3]** - **5.1.1[3][h]** to perform test again.
- **[j]** **IF** result is FAIL (the second attempt), **THEN** notify Supervisor.
- **[k]** **IF** result is PASS, **THEN GO TO** Step **5.1.1[4]**.

5.1.1 VTI Smart Station - System Functional Check (cont.)

Assemblyperson

[4] Perform a FAIL function test as follows:

[a] Remove cap from free end of pigtail.

[b] Connect the FAIL Test Standard Leak (labeled "FAIL") to the free end of the pigtail.

[c] Double touch VTI icon, as needed.

[d] Enter Operator ID (badge number).

[e] Enter "DT22" in the location designated for Package Model.

[f] Enter "FAIL" and the serial number on the standard leak tag (if applicable) in the location designated for serial number.

[g] Press the "Start Test" icon.

[h] **IF** alarm lights (e.g., evac. fault or settle press) activate during test, **THEN** press "ABORT TEST" icon **AND** notify Supervisor.

[i] Receive the printout of the test results.

[j] **IF** result is PASS (the first attempt), **THEN REPEAT** Steps **5.1.1[4]** - **5.1.1[4][i]** to perform test again.

[k] **IF** result is PASS (the second attempt), **THEN** notify Supervisor.

[l] **IF** result is FAIL, **THEN** remove FAIL Test Standard Leak **AND GO TO** Step **5.1.2**.

5.1.2 VTI Smart Station – Leak Testing

Assemblyperson

NOTE 1 *The operator may log in to the leak tester, as necessary, by entering login password.*

NOTE 2 *After the login password is entered, a "Manual Commands" screen may display momentarily, but the screen is not used.*

NOTE 3 *If "Welcome to HP Product Assistant" screen appears, the operator may clear this screen and continue.*

NOTE 4 *Operator I.D. time limit may expire. Operator I.D. may be re-entered, as necessary.*

[1] Ensure the leak test port plug has been removed from the test port on the container to be tested.

[2] Ensure flexible hose from the VTI Smart Station to the container test port, (using the container leak test adapter if necessary is connected).

[3] Double touch VTI icon, as needed.

[4] Enter Operator ID (badge number).

[5] Enter Package Model (e.g., DT22, ES 3100, etc).

[6] Enter Serial Number (last five digits of inner container serial number).

[7] Press "Start Test" icon.

[8] **IF** alarm occurs, **THEN** press "ABORT TEST" icon, **AND** notify Supervisor.

[9] **IF** test results printout is "FAIL," **THEN** perform the following:

- **[a]** Clean **OR** replace O-ring at the end of the pigtail **AND** add O-ring lube, as necessary.
- **[b]** Check pigtail for leaks at leak tester connection **AND** repair or replace, using new metal sealing washer, as necessary.
- **[c]** Notify Supervisor for determination on whether to **RETURN TO** Step **5.1.2[2] OR** disconnect drum **AND** exit procedure.

5.1.2 VTI Smart Station – Leak Testing (cont.)

Assemblyperson

[10] **IF** test result is PASS, **THEN** perform the following:

[a] Attach leak test printout to the associated container documentation.

[b] Verify the serial number of the container matches the serial number of the container on the printout.

[c] Disconnect pigtail from container.

[d] **IF** additional containers will be leak tested, **THEN REPEAT** Steps **5.1.2[1] – 5.1.2[10][c]** until all containers are leak tested.

[e] Install cap onto pigtail.

6 POST-PERFORMANCE ACTIVITIES

6.1 Extended Shutdown

Assemblyperson

[1] **IF** placing the VTI Smart Station into extended shutdown, **THEN** turn off all power to VTI Smart Station.

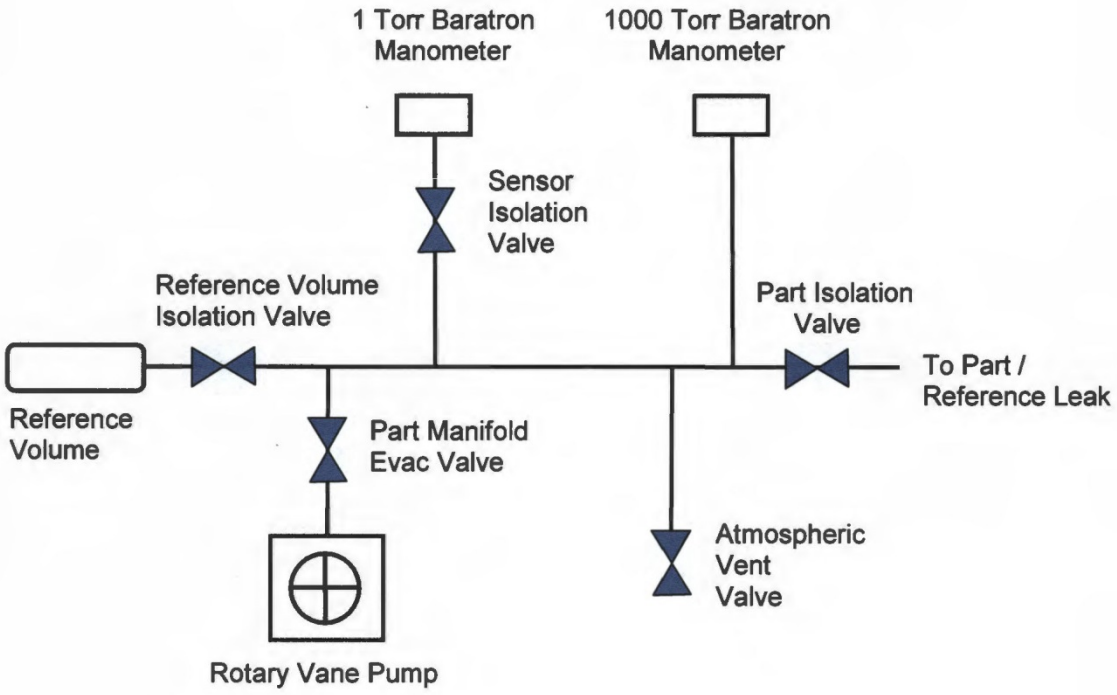
7 RECORDS

No records are generated by the performance of this procedure.

8 APPENDIX

A. VTI Smart Station Manifold

APPENDIX A
VTI Smart Station Manifold
(Page 1 of 1)



SECTION 7 REFERENCES

10 CFR 71, *Packaging and Transportation of Radioactive Material*, January 2015.

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8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Radioactive material packagings shall be fabricated, procured, and maintained in accordance with applicable U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Transportation (DOT), and other federal, state, and local regulations to protect the health and safety of the public, the workers, and the environment. The basis of the ES-3100 acceptance tests and maintenance requirements is primarily established in the design drawings and equipment specifications that are applied to the packaging components during design and fabrication. The packaging must continue to meet these requirements during its useful lifetime. Acceptance tests and maintenance activities are used to ensure that the design requirements and the conditions of approval in the Certificate of Compliance (CoC) are satisfied in addition to ensuring the integrity of the packaging components with respect to the structural, thermal, containment, shielding, and criticality evaluations in this safety analysis report for packaging (SARP). Furthermore, the packagings shall be fabricated, procured, and maintained according to a quality assurance (QA) plan approved by the U.S. Department of Energy (DOE), Office of Environmental Management; or DOE, National Nuclear Security Administration (DOE/NNSA), as appropriate.

The user is responsible for following the established NRC regulations for packaging, preparation for shipment, and transportation of radioactive materials given in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] as well as DOT regulations for packaging and shipment of hazardous materials given in Title 49 CFR. DOE nuclear facility users are responsible for implementing DOE regulations given in Title 10, Parts 830 and 835, of the CFR in addition to directives conveyed in DOE Order (O) 232.2, DOE O 414.1D, and DOE O 460.1C or DOE O 461.1B, as appropriate.

Specific acceptance testing and maintenance criteria for the ES-3100 are presented in this section. Where appropriate, facility management may authorize the adjustment of the explicit implementation sequence in this section to accommodate facility-specific workflow logistics and operational requirements. The packaging owner and user shall develop detailed, written site-specific procedures based on the CoC and the criteria contained herein. These procedures shall be in accordance with 10 CFR 71, Subparts A, G, and H; DOT and DOE regulations; and applicable state, tribal, and local regulations not preempted by DOT.

The packaging acceptance testing and maintenance operations should be consistent with maintaining occupational radiation exposures as low as reasonably achievable (ALARA) [10 CFR 71.87(i)] in addition to addressing applicable safety aspects or activities such as personal protection (radiation, chemical, and physical); contamination or radiation surveys; provisions for reporting safety concerns associated with the packaging or its use; and the records and reporting requirements cited in Appendix 7.5.1.

The ES-3100 packaging description is presented in Sect. 1.2 with a schematic shown in Fig. 1.1 and an exploded view of the packaging components presented in Fig. 1.2. The ES-3100 certification drawing can be found in Appendix 1.3.1. The packaging design drawings (Appendix 1.3.7) provide material lists, dimensions, safety components, welding requirements, and gasket requirements. The maximum gross weight of the ES-3100 package is 190.5 kg (420 lb).

The requirements for fabricating, procuring, and maintaining the packaging are presented in this section. Nonconforming conditions or deficiencies will be appropriately dispositioned to satisfy the applicable design requirements in accordance with 10 CFR 71.131. Rework or repair authorization for packaging components would include applicable nondestructive examinations and pressure/leak testing as specified in the design requirements. Fabrication requirements for the ES-3100 components are listed on the design drawings (Appendix 1.3.7) and the following specifications:

1. JS-YMN3-801580-A001, *ES-3100 Containment Vessel* (Appendix 1.3.3);

2. JS-YMN3-801580-A002, *ES-3100 Drum Assembly* (Appendix 1.3.2);

3. JS-YMN3-801580-A003, *Manufacturing Process Specification for Casting Kaolite 1600TM into the ES-3100 Shipping Package* (Appendix 1.3.4);

4. JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package* (Appendix 1.3.5);

5. SPC-M801580-0002, *ES-3100 Ethylene Propylene Diene Monomer (EPDM) Containment Vessel (CV) O-rings* (Appendix 1.3.9).

The containment vessel (CV) is designed and built to meet American Society of Mechanical Engineers *Boiler and Pressure Vessel Code* (ASME Code), Sect. III, Div. 1, Subsection NB. The ES-3100 includes the following packaging components/assemblies:

1. A drum assembly: body weldment, lid weldment, top plug weldment, CV bottom pad, CV flange pad, plug pad, hex nuts, washers, and paint (Drawing M2E801580A001, Appendix 1.3.7); with a data plate and a trefoil data plate (Drawing M2E801580A010, Appendix 1.3.7).

2. A CV assembly: CV body assembly; CV lid assembly (sealing lid, closure nut, and retaining ring); O-rings; brass VCO (vacuum coupling O-ring) threaded plug; and swivel hoist ring (Drawing M2E801580A011, Appendix 1.3.7).

3. Packing materials, as appropriate: convenience cans or bottles, polyethylene bags, metal scrubbers, silicone rubber can pads (Drawing M2E801580A024, Appendix 1.3.7), and heavy can spacer assemblies (Drawing M2E801580A043, Appendix 1.3.7).

Care should be exercised to control the packaging components when they are removed to ensure that parts are kept with the packaging and not mixed with other loose parts or parts from other packagings. Other preparations should be made to minimize damage or loss of packaging components. The drum assembly and containment vessel are marked with serial numbers. The numbers are used to control these parts and to accumulate their respective operational and maintenance histories. Applicable serial numbers of packaging components should be verified to ensure that these components are maintained together. Loose parts (e.g., hex nuts, washers, O-rings) may be reused if it can be shown that they were the parts that were removed and that no damage to the parts has occurred. Otherwise, they shall be discarded and replaced with certified parts. In order to maintain configuration control of the packaging components, the user shall ensure that there are no unauthorized modifications and no substitution of components with unauthorized components. The certification of all replacement parts must be traceable. The user shall document any part replacement identifying it to a specific packaging by model and serial number.

The ES-3100 is handled using industry-standard drum-handling equipment. When being moved using a forklift, it can be placed on the tines of the forklift from below. The ES-3100 is also designed for

a forklift pincher assembly that can be used to grasp the exterior of the drum assembly. Forklift gripping forces of up to 5400 lb can be used with no detrimental effects on the packaging (Sect. 1.2.1.1).

Site-specific maintenance procedures including the facility's operational requirements shall ensure the following:

1. All appropriate documents have been reviewed by operating personnel and are available for further review, if necessary.

2. Certified equipment is used (e.g., torque wrenches, instrumentation, scales, lifting hardware, and radiation survey instruments) in accordance with the site-approved QA program.

3. Segregated work stations, curtains, lead blankets, personnel protective equipment, or other equipment are used, as necessary, to protect workers and nearby personnel from radioactive material hazards.

4. Appropriate material handling equipment is available and approved for use (e.g., forklifts, hoists, drum handlers). Operating controls shall be implemented for any forklift pincher assembly to limit clamping forces on the drum body (i.e., $\leq$ 5400 lb).

5. Appropriate provisions to decontaminate packaging components are provided consistent with ALARA principles.

All personnel who support and/or perform fabrication, assembly, testing, and maintenance operations will be appropriately trained and qualified in accordance with the site-approved QA program; 49 CFR 171.1; and 49 CFR 172, Subpart H, as appropriate. Auditable training records will be maintained in accordance with site record retention requirements.

8.1 ACCEPTANCE TESTS

Before the first use of the packaging, the owner shall determine that the packaging has been fabricated in accordance with the approved design including the preliminary determinations (10 CFR 71.85), the quality control for construction of packaging (49 CFR 173.474), and the conditions of approval in the CoC. Guidance provided in NUREG/CR-6314, *Quality Assurance Inspections for Shipping and Storage Containers*, for conducting QA inspections of packaging suppliers may be used as necessary. Acceptance test requirements in Sect. 8.1 are derived from the design drawings and equipment specifications, and their determinations shall be present in the owner's or appropriate supplier's fabrication records as described in Sect. 7.5.1.2. The minimum certification requirements are shown on the ES-3100 certification drawing (Appendix 1.3.1).

The design drawings and specifications indicate the applicable inspections, testing, records, and reports required to properly document the quality of the packaging. The minimum acceptance test and inspection requirements for the packaging components (Tables 8.1 and 8.2) and packing materials (Table 8.3) are presented in the following sections. Prior to first use of the packaging, the user, packaging suppliers, or both shall meet these requirements.

8.1.1 Visual Inspections and Measurements

Visual inspections with the unaided eye of all pertinent features of the packaging shall be performed during fabrication. There shall be no cracks, pinholes, uncontrolled voids, or other defects that could significantly reduce the effectiveness of the packaging [10 CFR 71.85(a)]. These inspections include paint color; surface condition; marking content; gauging (toleranced dimensions, positioning, edge breaks, surface finish); and welding. The required inspections are summarized in Tables 8.1–8.3.

Table 8.1. Acceptance tests for the drum assembly

Component [a]	Inspection	Structural and pressure tests	Leak tests
Double open head drum	Material certification [b], gauging [c], marking, liquid penetrant, weld examinations [d], corrosion, dents	Tensile, percent elongation, yield point, chemistry, pneumatic pressure test [e], rough handling test [e]	NA [f]
Weld studs	Part certifications, gauging	Tensile, percent elongation, yield point, chemistry	NA
Inner liner weldment	Material certification, weld examinations, gauging	Tensile, percent elongation, yield point, chemistry	NA
Flat cover (drum bottom)	Material certification, gauging	Tensile, percent elongation, yield point, chemistry	NA
Lid weldment	Material certification, weld examinations, gauging	Tensile, percent elongation, yield point, chemistry	NA
Top plug weldment	Material certification, weld examinations, gauging	Tensile, percent elongation, yield point, chemistry	NA
Kaolite 1600 insulation	C of C [g], damage	NA	NA
Cat 277-4 neutron-absorber material	C of C, damage	NA	NA
Hex nuts	C of C, gauging, damage	NA	NA
Washers	C of C, damage	NA	NA
TID [h] lugs	C of C, damage	NA	NA
Data plate and trefoil data plate	Material certification, gauging, marking	NA	NA
Nylon plug	C of C	NA	NA
Paint	C of C, color comparison	NA	NA
Aluminum tape	C of C, damage	NA	NA
Silicone rubber pads (CV bottom pad, CV flange pad, and plug pad)	C of C, damage, marking	NA	NA
RFID monitoring system [i]	NA	NA	NA

[a] ES-3100 drum assembly components (Drawing M2E801580A001, Appendix 1.3.7).
[b] Material certification – Certified quantitative data (physical, mechanical, chemical, functional, dimensional, and/or visual) demonstrating compliance with the drawing/specification requirements.
[c] Gauging refers to dimensional inspections for height, width, thickness, diameter, position, edge breaks, and surface finish.
[d] Weld examinations in accordance with Sect. 8.1.2.
[e] Pneumatic pressure test and rough handling test in accordance with Sect. 8.1.3.3.
[f] NA—Not applicable.
[g] C of C—Certificate of Conformance. A document signed or otherwise authenticated by an authorized individual certifying the degree to which items or services meet the specified requirements.
[h] TID—Tamper-indicating device.
[i] An optional radio-frequency identification (RFID) monitoring system tag may be secured to the drum assembly in accordance with the applicable requirements of ANL/DIS-09-5.

Table 8.2. Acceptance tests for the CV assembly

Component [a]	Inspection	Structural and pressure tests	Leak tests
Body assembly and lid assembly (as applicable)	Material certification [b], gauging [c], marking, liquid penetrant, weld examinations, qualification tests, corrosion, scratches	Tensile, percent elongation, yield point, chemistry, hydrostatic pressure test [d]	Helium leak test [e]
Inner O-ring	Material certification, gauging, packaging, marking	Shore A durometer, elongation	NA [f]
Outer O-ring	Material certification, gauging, packaging, marking	Shore A durometer, elongation	NA
External retaining ring	C of C [g], damage	NA	NA
Modified VCO [h] threaded plug with O-ring	C of C, damage	NA	NA

[a] ES-3100 CV assembly components (Drawing M2E801580A011, Appendix 1.3.7).
[b] Material certification – Certified quantitative data (physical, mechanical, chemical, functional, dimensional, and/or visual) demonstrating compliance with the drawing/specification requirements.
[c] Gauging refers to dimensional inspections for height, width, thickness, diameter, position, edge breaks, and surface finish.
[d] Hydrostatic pressure test in accordance with Sect. 8.1.3.3.
[e] Leakage test in accordance with Sect. 8.1.4.
[f] NA—Not applicable.
[g] C of C—Certificate of Conformance. A document signed or otherwise authenticated by an authorized individual certifying the degree to which items or services meet specified requirements.
[h] VCO—Vacuum coupling O-ring.

Table 8.3. Acceptance tests for packing materials

Component [a]	Inspection	Structural and pressure tests	Leak tests
Silicone rubber pad [b] (can pad)	C of C [c], damage, marking	NA [d]	NA
Heavy can spacer assembly [e]	Material certification [f], sample pour	NA	NA
Convenience cans	C of C, damage	NA	NA
Convenience bottles	C of C, damage	NA	NA
Polyethylene bags	C of C, damage	NA	NA
Metal scrubbers	C of C	NA	NA

[a] ES-3100 CV packing materials, as appropriate (see Sect 1.2.2.4).
[b] Drawing M2E801580A024, Appendix 1.3.7.
[c] C of C—Certificate of Conformance. A document signed or otherwise authenticated by an authorized individual certifying the degree to which items or services meet specified requirements.
[d] NA—Not applicable.
[e] Packing material, as appropriate, not part of CV (Drawing M2E801580A043, Appendix 1.3.7).
[f] Material certification – Certified quantitative data (physical, mechanical, chemical, functional, dimensional, and/or visual) demonstrating compliance with the drawing/specification requirements.

8.1.1.1 Paint color

Paint color, which is not a safety item, is used to identify, segregate, and document packagings. The acceptance criteria for paint color are given in the drawings (Appendix 1.3.7). Incorrect or incomplete application of paint is cause for rejection. An application of incorrect letters or misspelled words is also cause for rejection.

8.1.1.2 Surface condition

The surfaces of the drum assembly and CV shall be visually inspected for penetrations, dents, and corrosion. Dents >1-in. deep in the drum body will be cause for the drum body to be reworked to remove the dent. The CV surfaces must be in accordance with the dimensional requirements on the drawings (Appendix 1.3.7). Penetrations (e.g., cracks, pinholes, other defects) in the drum or CV will be cause for the component to be rejected.

The packaging components (i.e., complete assembly or individual parts) will be stored in weather-protected indoor facilities. However, before acceptance of any component, accessible surfaces shall be inspected for corrosion. The presence of surface corrosion on any component will be cause for further inspection. If the corrosion can be easily wiped off and no pitting is apparent beneath it, the component is acceptable. If the corrosion cannot be easily wiped off, if scaling is present, or if pitting is observed, the component must undergo a dimensional inspection, including nondestructive examinations as necessary, to determine the extent of the damage before the packaging component can be used. If the corrosion has compromised the structural integrity of the component (i.e., the component no longer meets dimensional or surface finish criteria for a new part as specified on the design drawings), then the component shall be rejected.

8.1.1.3 Marking packaging components

Markings on the packaging components provide traceability for the fabrication, operation, and maintenance of the packaging components. All markings (e.g., model number, serial numbers, instructions, identification) shall be compared with the acceptance criteria (e.g., paint color, etching, dimensions) for markings on the design drawings (Appendix 1.3.7) or equipment specifications, as appropriate. Incorrect or incomplete marking is cause for rejection.

8.1.1.4 Gauging

The ES-3100 design drawings list the dimensions/tolerances; positions (e.g., bolt holes, grooves, leak-test port); edge breaks; and surface finishes. A "Diamond I" symbol is used on the drawings or equipment specifications to designate significant dimensions or features, which are specifically inspected and documented in the inspection reports. Inspection of gauging features will be performed on dimensions to ensure that each component meets the applicable tolerances, which are provided on the drawings. Gauging outside the tolerance is cause for rejection.

8.1.2 Weld Examinations

As discussed in Sect. 2.3, *Fabrication and Examination*, all welded or weld-repair surfaces shall be visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity using a written weld examination procedure. Weld examiners are qualified to perform weld inspections in accordance with the techniques specified on the applicable design drawings and equipment specifications. Weld symbols are provided on the design drawings indicating for each weld the type of weld and dimensions of weld. These weld symbols are interpreted in accordance with American Welding Society (AWS) A2.4. For a detailed description of the drum assembly and CV manufacturing requirements, see the appropriate equipment specification and the following SARP sections:

Drum Assembly [JS-YMN3-801580-A002 (Appendix 1.3.2)]

- Section 2.3.1.1, Drum assembly fabrication.
- Section 2.3.2.1, Examination of the drum assembly fabrication.

Containment Vessel [JS-YMN3-801580-A001 (Appendix 1.3.3)]

- Section 2.3.1.2, Containment boundary fabrication.
- Section 2.3.2.2, Examination of the containment vessel fabrication.

8.1.3 Structural and Pressure Tests

Structural tests for the drum and CV include mechanical properties and chemical tests to ensure that the correct materials are used. The CV is hydrostatically pressure tested to ensure that the supplier's fabrication meets the requirements. These tests are discussed below. The drum body is mechanically tested (handling test) and pressure tested (Sect. 8.1.3.3) in accordance with the QA provisions in Military Specification MIL-D-6054F, *Drum, Metal—Shipping and Storage*.

8.1.3.1 Mechanical property tests

The design drawings or equipment specifications specify the requirements for the packaging materials. The mechanical properties and specifications for these materials are discussed in Sect. 2.2.1 and summarized in Tables 2.12–2.17. Visual examination and mechanical property testing requirements for the O-rings are discussed in Sect. 8.1.5.1. An out-of-specification property is cause for rejection.

8.1.3.2 Chemical tests

Tests shall be performed to determine the chemical properties of the packaging materials. The acceptance criteria and their sensitivity are provided in the appropriate national material standard specified on the design drawings (Appendix 1.3.7). An out-of-specification chemical property is cause for rejection. Material that cannot be traced to the mill or heat-treatment lot shall be rejected.

8.1.3.3 Pressure tests

The CV assembly shall be hydrostatically pressure tested at 150 ± 5 psig per Sect. 3.7 of JS-YMN3-801580-A001 (Appendix 1.3.3). Visible indication of a leak on the exterior surface of the CV is cause for rejection. This testing exceeds the regulatory requirement in 10 CFR 71.85(b) [1.5 × maximum normal operating pressure] and the requirement stipulated in ASME Code, Sect. III, Div. 1, NB-6200 (1.25 × design pressure). The CV maximum normal operating pressure is 16.518 psig (Appendix 3.5.1) and the CV design pressure is 101.5 psig (DAC-M900000-0003).

The drum pressure test is performed in accordance with Drawing M2E801580A004 (Appendix 1.3.7) to verify the integrity of the welded seam. Typically, two sample drums in each lot fabricated are pressure tested; one drum is only pressure tested (MIL-D-6054F, Para. 4.6.1), while the other drum is pressure tested following "rough handling" tests (MIL-D-6054F, Para. 4.6.2). The pressure test is performed prior to the drilling of the four vent holes with the opened ends of the drum sealed. This test is observed by the owner during the First Article Evaluation of the drum. To conduct the pressure test, the drum is pressurized with air to 10 psig as specified in MIL-D-6054F. The compressed air supply line is closed, but the pressure gauge is left connected to the drum. The initial pressure is recorded. All joints and seams are coated with a bubble-supporting film. The drum is turned so that all surfaces may be observed for leakage. Five minutes after the initial pressure is recorded, the final gauge pressure is recorded. If a loss of pressure is observed and no leaks were detected by bubbles, the bubble-supporting film operation is repeated to find any leaks that were not detected initially. Any evidence of leakage is cause for rejection.

8.1.4 Leakage Tests

Following the hydrostatic pressure test, a leak test of the containment boundary shall be performed with the inner O-ring installed in accordance with American National Standards Institute (ANSI) N14.5-1997, Subclause 7.3, *Fabrication leakage rate test*, as prescribed in Sect. 3.9 of JS-YMN3-801580-A001 (Appendix 1.3.3). This leak testing demonstrates that the CV is fabricated properly and that the containment boundary is "leaktight." An integrated air leakage rate exceeding 1×10^{-7} ref-cm^3/s (or equivalent) is cause for rejection. Per ANSI N14.5-1997, the test procedure shall have a sensitivity of 5×10^{-8} ref-cm^3/s (one-half the reference air leakage rate) or equivalent.

As required in JS-YMN3-801580-A001 (Appendix 1.3.3), the containment vessel leakage rate testing will be performed by trained and qualified personnel using certified equipment and written leak-test procedures in accordance with the applicable sections of ANSI N14.5-1997. Y-12 Product Specification Procedure Y51-01-B2-R-140, *He Leak Testing in B2* (Appendix 8.3.1) is provided as an example leak-test procedure.

In addition, a leakage rate test will be performed at initial fabrication on the fully assembled CV with both O-rings installed to demonstrate the functionality of the leak-test port and sealing capability of the outer O-ring. The leak testing acceptance criterion is that the CV shall not have an air leakage rate $>1 \times 10^{-4}$ ref-cm^3/s. Y-12 Product Specification Procedure Y51-01-B2-R-074, *Shipping Container Leak Test* (Appendix 7.5.2) is provided as an example leak-test procedure.

8.1.5 Component and Material Tests

8.1.5.1 Containment vessel O-rings

The O-ring visual inspection and mechanical tests are described below. Additionally, the fabrication leak test (Sect. 8.1.4), the periodic and maintenance leak tests (Sect. 8.2.2), and the preshipment leak test (Sect. 7.1.2.1) verify the functionality of the O-rings.

Visual inspection

A visual inspection of the O-ring surface shall be performed. The surface shall be smooth, nonporous, and free of skin defects. O-rings that do not meet these requirements shall be rejected.

Each O-ring shall be packaged separately to provide traceability. Each O-ring package shall be marked with the O-ring identification number, lot number, cure date, compound number, and established expiration date. The material identification numbers shall be assigned uniquely to each lot and to each size of O-ring. The identifications shall be adequate to trace the O-rings to their raw material

master batch. Improper packaging or marking is cause for rejection. Additionally, no O-ring shall be installed after the established expiration date noted on the manufacturer's packaging.

Mechanical properties

The O-ring material mechanical properties and acceptance criteria shall be in accordance with SPC-M801580-0002 (Appendix 1.3.9) for EPDM O-rings.

8.1.5.2 Valves and pressure-relief devices

The ES-3100 packaging does not incorporate any valves or pressure-relief devices.

8.1.5.3 Neutron-absorber material

The Cat 277-4 neutron-absorber material is specifically designed for criticality safety. Acceptance testing for the Cat 277-4 procurement, preparation, and casting is described in JS-YMN3-801580-A005 (Appendix 1.3.5).

8.1.6 Shielding Tests

No gamma or neutron radiation shielding features are integral to the packaging.

8.1.7 Thermal Tests

A thermal acceptance test is not required for the passive thermal features of this packaging. The maximum decay heat generated by the radioactive material is 5 W (Sects. 1.2.2.7 and 3.1.2), which is negligible. The QA and technical requirements for weighing, mixing, pouring, vibrating, curing and baking the Kaolite 1600 thermal insulation is described in JS-YMN3-801580-A003 (Appendix 1.3.4).

8.1.8 Miscellaneous Tests

No additional tests are required prior to the use of the ES-3100 packaging.

8.2 MAINTENANCE PROGRAM

The ES-3100 maintenance program ensures that the packaging continues to meet the design requirements and the conditions of approval in the CoC. Periodic maintenance inspections and testing requirements verify that the performance of the packaging has not deviated or degraded during use from the authorized configuration. Incidental maintenance activities and routine determinations/quality control requirements (10 CFR 71.87 and 49 CFR 173.475) are authorized and performed during package operations as described in Sect. 7 of this SARP.

Although Subclause 7.5.2 of ANSI N14.5-1997 states that the periodic leakage rate testing shall be conducted within 12 months prior to each shipment, periodic maintenance of the ES-3100 packaging shall be performed on a 2-year basis as discussed in Sect. 4.4. Periodic maintenance is not required during a period of nonuse (i.e., extended storage or inactivity). The user shall verify that the ES-3100 periodic leakage rate testing (ANSI N14.5-1997, Subclause 7.5) and any necessary maintenance leakage rate testing (ANSI N14.5-1997, Subclause 7.4) [including any required corrective maintenance associated with noncompliant conditions] have been performed within the 2-year period prior to shipment to ensure full compliance with the containment requirements of 10 CFR 71.

Maintenance requirements presented in Sect. 8.2 shall be considered as minimum requirements, and their determinations shall be included in the owner's or user's packaging maintenance records as described in Sect 7.5.1.2. Packaging components may be repaired, reworked, or replaced in accordance with the requirements specified in 10 CFR 71.131 and Sect. 9.3.15.

8.2.1 Structural and Pressure Tests

The ES-3100 packaging does not require any structural tests or pressure tests during periodic maintenance. Welding and structural repair/rework of the containment vessel or drum assembly would involve operations that are considered beyond the scope of routine maintenance.

8.2.2 Leakage Tests

The fabrication leak test (Sect. 8.1.4) must be performed before the first use of the packaging and the periodic leak test is performed on a 2-year basis thereafter while the packaging is in use. The maintenance leak test is performed following the structural repair/rework or replacement of a containment boundary component (e.g., weld repair or inner O-ring replacement).

The user shall develop detailed maintenance procedures which include, at a minimum, the process steps listed below for CV leak testing. Maintenance personnel shall ensure that:

1. The CV periodic maintenance has been performed in accordance with Sect. 8.2.5.2 and the O-ring grooves and sealing surfaces are cleaned, as necessary, with isopropyl alcohol and lint-free gloves, cloths, or swabs.

2. Certified replacement O-rings are obtained in accordance with Sect. 8.2.3.1 and the O-rings are cleaned, as necessary, with isopropyl alcohol and lint-free gloves, cloths, or swabs.

3. The inner O-ring is lubricated with a thin coat of Super-O-Lube and inserted into the CV flange groove.

   Note: Only the inner O-ring is installed during the maintenance or periodic leakage rate testing of the containment boundary.

4. The leak-test fixture is installed as follows:

   a. The leak check flange assembly (Drawing T2E801827A008, Appendix 1.3.7) is positioned over the CV body and lowered into the CV flange.

   b. The leak check flange O-ring has been installed in the O-ring groove.

   c. The CV lid assembly is placed on top of the leak check flange assembly.

      Note: The above fixture installation sequence assumes the use of a leak check flange assembly (Drawing T2E801827A008, Appendix 1.3.7). With facility management approval, an alternate leak-test fixture and installation sequence may be used.

5. The CV is leak tested with the inner O-ring installed in accordance with ANSI N14.5-1997, Subclause 7.4, *Maintenance leakage rate test*, or Subclause 7.5, *Periodic leakage rate test*, to demonstrate that the containment boundary is "leaktight." An integrated air leakage rate exceeding 1×10^{-7} ref-cm^3/s (or equivalent) is cause for rejection. Per ANSI N14.5-1997, the test procedure shall have a sensitivity of 5×10^{-8} ref-cm^3/s (one-half the reference air leakage rate) or equivalent. Maintenance personnel shall ensure the following, at a minimum:

   a. The leak testing is performed by trained and qualified personnel in accordance with the requirements of ANSI N14.5-1997 and the site-approved QA program.

      Note: Y51-01-B2-R-140 (Appendix 8.3.1) is provided as an example leak-test procedure.

   b. Leak-test instrumentation has been properly calibrated.

   c. The leak-test equipment is connected to the leak-test port in the leak check flange assembly.

   d. The leak test is performed under isothermal conditions.

      Note: If the leak test fails, the following measures should be performed: (1) review the operating procedures; (2) check the leak-test equipment and connections; and (3) check the test gauges and instrumentation including verification of calibration and certification records, as necessary. If none of these measures reveal the root cause for the leak-test failure, the following inspections should be considered: (1) visually inspect the O-rings per Sect. 8.2.3.1; (2) visually inspect the O-ring grooves and sealing surfaces per Sect. 8.2.5.2; (3) visually inspect the containment boundary; and (4) perform other nondestructive examinations, as appropriate.

6. Following successful completion of the leak test, the leak-test equipment is disconnected.

7. The CV lid assembly and the leak check flange assembly (or approved alternate leak-test fixture) are removed from the CV body.

8. The outer O-ring is lubricated with a thin coat of Super-O-Lube and inserted into the CV flange groove.

9. The CV lid closure nut threads are visually inspected for foreign matter. If necessary, clean the threads with lint-free gloves, cloths, or swabs and apply a thin coat of Krytox grease, Grade 240 AC, to the threads, as required [Drawing M2E801580A011, Appendix 1.3.7].

10. The CV lid assembly is positioned over the CV body with the two alignment pins in the CV flange engaged in the slots on the underside of the CV lid assembly.

11. The CV lid closure nut is hand tightened.

12. The CV lid assembly has a brass VCO threaded plug installed in the leak-test port.

13. The expiration date (2 years from the leak-test date) and signature of the person who performed the testing or certified the test results shall be entered on two copies of a leak-test label (see example label in Fig. 8.1). One label will be attached to the exterior surface of the CV, and the second label will be attached to the exterior surface of the drum. The leak-test label must contain organization information, "LEAK TEST APPROVED," "DO NOT REMOVE," expiration date, and the name of the person (who performed the testing or certified the test results), at a minimum.



Fig. 8.1. Example label for use on the exterior surface of the containment vessel and the drum.

14. An optional radio-frequency identification (RFID) monitoring system tag may be secured to the drum assembly in accordance with the applicable requirements of ANL/DIS-09-5.

    Note: The mounting bracket for the RFID monitoring system tag shall provide the equivalent contact area of a drum washer and the thread engagement for the drum hex nuts shall remain unchanged.

8.2.3 Component and Material Tests

8.2.3.1 Containment vessel O-rings

The inner and outer O-rings will be replaced during periodic maintenance of the packaging. Certified replacement O-rings (see Sect. 8.1.5.1) are visually inspected for defects such as roughness, porosity, and surface defects. Defective O-rings are discarded. Replacement O-rings (stored in sealed containers) will have an established expiration date marked on the O-ring manufacturer's packaging, and no O-rings shall be installed after the established expiration date.

8.2.3.2 Thermal insulation and neutron-absorber material

Since the Kaolite insulation and Cat 277-4 are encapsulated within the stainless-steel liner, no damage or deterioration is expected. However, the drum, liner, internal flange, flat cover, and top plug shall all be visually inspected for tears or punctures or other defects that would allow for the escape of insulating or neutron-absorbing material. The drum assembly and top plug will be weighed prior to first use and during periodic maintenance to evaluate density variations in the Kaolite 1600 or the Cat 277-4. For the purpose of weight comparisons, the drum does not include the lid, pads, nuts, or washers. Weights recorded during periodic maintenance will be compared to the recorded weights prior to first use, and the packaging components will be rejected and evaluated for rework if the weight change of the drum is >10 lb or the weight change of the top plug is >2 lb.

8.2.4 Thermal Tests

There are no periodic maintenance thermal test requirements for the passive thermal features of this packaging.

8.2.5 Miscellaneous Tests

8.2.5.1 Visual inspection for corrosion

The ES-3100 packaging will be stored in weather-protected indoor facilities; thus, surface corrosion is not expected. However, during periodic maintenance inspections, accessible surfaces shall be visually inspected for corrosion, moisture, and damage. The observation of surface corrosion on any component will be cause for further inspection. If the corrosion can be easily wiped off and no pitting is apparent beneath it, the package is acceptable for use. If the corrosion cannot be easily wiped off, if scaling is present, or if pitting is observed, the component must undergo a dimensional inspection, including nondestructive examinations as necessary, to determine the extent of the damage before the packaging component can be used. If the corrosion has compromised the structural integrity of the component (i.e., the component no longer meets dimensional or surface finish criteria for a new part as specified on the design drawings), then the component shall be rejected.

8.2.5.2 Containment vessel maintenance

The CV must be removed from the drum assembly for periodic maintenance inspections. After removing the CV lid assembly, interior and exterior CV surfaces shall be examined for signs of moisture, corrosion, or physical damage. Any CV exhibiting signs of moisture inside will be tagged and segregated until the cause is determined and corrected and the CV has been successfully reinspected. If physical damage has compromised the structural integrity of the CV [i.e., the component no longer meets dimensional requirements specified on the design drawings (Appendix 1.3.7) or JS-YMN3-801580-A001 (Appendix 1.3.3)] the component shall be rejected. Repair/rework authorization of damaged surfaces would include any nondestructive examinations and pressure/leak-test requirements in accordance with the design requirements. A repaired component shall meet the established acceptance criteria in Sect. 8.1.

The CV closure nut and CV flange threads shall be cleaned, as necessary, and visually inspected for damage. Minor defects such as small nicks or burrs may be smoothed with a thread file; however, components with damaged threads (evidence of cross-threading, or flattened threads) or excessive wear (visually apparent rounding of the fastener threads) are cause for rejection. Repair/rework of damaged threads on the CV closure nut or body flange would involve operations that are considered beyond the scope of routine maintenance.

The CV sealing lid leak-test port and brass VCO plug threads shall be cleaned, as necessary, and visually inspected for damage. Minor defects such as small nicks or burrs may be smoothed with a thread file or chased with a tap or die, as appropriate; however, components with damaged threads (as determined by the criteria noted above) must be replaced with certified replacement parts. Repair/rework of damaged threads on the CV sealing lid leak-test port would involve operations that are considered beyond the scope of routine maintenance.

The CV lid assembly (Drawing M2E801580A014, Appendix 1.3.7) will be evaluated to ensure that the CV closure nut rotates freely on the CV sealing lid. If there is excessive binding or varying resistance, the external retaining ring will be removed, and the CV lid assembly will be disassembled. The contact surface between the CV sealing lid and closure nut will be cleaned and lubricated with a thin film of Krytox grease, Grade 240 AC (Drawing M2E801580A011, Appendix 1.3.7). The CV sealing lid, closure nut, and external retaining ring will be assembled per Drawing M2E801580A014 (Appendix 1.3.7), and a thin coat of Krytox grease, Grade 240 AC, will be applied to the CV closure nut threads.

If installed, the O-rings will be removed from the CV flange grooves. The sealing surfaces of the CV sealing lid and CV flange grooves will be cleaned, as necessary, with isopropyl alcohol and lint-free

gloves, cloths, or swabs. The O-ring grooves and sealing surfaces will be visually inspected for foreign matter, nicks, and scratches. If nicks or scratches are found, the affected sealing surfaces may be smoothed with a stone or with fine sandpaper to return them to specification. Surface defects or imperfections that impact containment performance and cannot be removed without taking the component out of dimensional specification constitute cause for rejection of the component. Welding and structural repair/rework of the CV would involve operations that are considered beyond the scope of routine maintenance.

8.2.5.3 Subsystem maintenance

Touch-up paint that complies with drawing requirements should be applied to worn or faded packaging markings as necessary. The data plate and trefoil data plate (Drawing M2E801580A010, Appendix 1.3.7) shall be visually examined for legibility of all required information, and the plates will be securely attached to the drum as shown in Drawing M2E801580A031 (Appendix 1.3.7). Interior and exterior surfaces of the drum body shall be visually inspected for signs of moisture, corrosion, or physical damage. Defects in the drum assembly (e.g., tears, broken welds, dents >1-in. deep) are cause for rejection and possible reporting in accordance with Sect. 7.5.1.3.

8.2.5.4 Drum fastener inspection

The drum lid fasteners (5/8-11 UNC silicon-bronze hex nuts and stainless-steel weld studs) shall be cleaned as necessary and visually inspected for damage. Minor defects such as small nicks or burrs may be smoothed with a thread file or chased with a tap, as appropriate; however, fasteners with damaged threads (evidence of cross-threading, or flattened threads) or excessive wear (visually apparent rounding of the fastener threads) must be replaced with certified replacement parts. In addition, the drum hex nuts will be inspected for proper certification markings. If there is any question about the certification status of the hex nuts, all suspect parts shall be replaced with certified replacement parts. Welding and structural repair/rework of a drum weld stud would involve operations that are considered beyond the scope of routine maintenance.

8.2.5.5 Valves and pressure-relief devices

The ES-3100 packaging does not incorporate any valves or pressure-relief devices.

8.2.5.6 Miscellaneous

The silicone rubber pads (Drawing M2E801580A009, Appendix 1.3.7) shall be visually inspected during periodic maintenance to verify that there are no signs of moisture and no significant gouges, cuts, tears, or nondesign voids in the pads that would cause them to be unusable. Additional assessment, if needed, shall be directed to Packaging and Transportation Engineering for appropriate disposition.

8.3 APPENDIX

8.3.1 Example Leak-test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-140, *He Leak Testing in B2*

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Appendix 8.3.1

Example Leak-test Procedure,
Y-12 Product Specification Procedure Y51-01-B2-R-140, *He Leak Testing in B2*

Babcock & Wilcox Technical Services Y-12, LLC Management Requirements	Product Specification Procedure Title: He Leak Testing in B2	Number: Y51-01-B2-R-140 Revision: B.2 Supersedes: B.1 Page: 1 of 11 Use Category: REFERENCE

Responsible Organization/Department Assembly/Quality Evaluation Production		
	Responsible Manager J. A. Hagemann (Signature) 12/18/2013 (Date)	
Quality Engineer J. C. Chang (Signature) 12/19/2013 (Date)	**Packaging Engineer** Rick D. Michelhaugh (Signature) 12/18/2013 (Date)	**CC Review** C. Lowery (Signature) 12/18/2013 (Date)
	Approved for Practice (Signature) (Date)	
Verified to be the latest revision (Initials) (Date)		12/19/2013 Effective Date
Concurrence by the following is documented in the Procedure History File:		
Subject Matter Expert AQEP Industrial Hygiene	Packaging Engineer Safety Shift Technical Advisor	Systems Engineer Radiological Control Weapons Quality Engineer

Revision Number	Modification Description	Affected Page(s)
B.1	On Record.	
B.2	13-PMR-840, On-the-Spot Intent to clarify leak test station component certification. Certification performed on components of leak test station, not the overall leak test station assembly. Delete leak test station from certification requirements. Deletions are not denoted by a revision bar.	4

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

Name: Eddie Price Date: 12/18/2013

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1 APPLICABILITY AND SCOPE

To provide instructions for operating the helium leak test stations in Building 9204-2. The leak stations consist of Veeco MS-50 leak detectors, vacuum pumps, pressure gauges, and the connecting valve manifold. This system has a multiple unit capability which allows the system operator to pump down the other units while running a leak test. Although there are multiple roughing pump valves, multiple manifold valves, and multiple vacuum gauges, during Section **5.2**, *Pumping Down*, **NO** specific valve number alpha designator is given. These valves and gauges are referred to as "valve (gauge) associated with the part under test" to allow the operator to perform a leak test on whichever unit roughs down first.

Applies to leak test equipment used to determine leak rates. The equipment, as currently set-up, is sensitive to Helium leak rates as low as 1×10^{-8} cc/sec.

The component to be tested is first vacuum evacuated. Then the component's exterior surfaces are exposed to a helium atmosphere. The atmosphere internal to the part is then valved into the leak detector to check for the presence of helium. A gross leak is indicated by a severe leak rate that exceeds the value normally encountered for the component being tested, and in some instances, may also exceed the pumping capacity of the vacuum system. A gross leak may be the result of an unacceptable part, or a poor quality vacuum test connection.

Program: WC (Weapons Container)

2 PRECAUTIONS AND LIMITATIONS

Industrial Hygiene

A. Nitrile gloves SHALL be worn when using organic solvents (isopropyl alcohol, Right Stuff, etc.).

Safety

B. Safety shoes SHALL be worn while performing material activities detailed in this procedure.

C. Leather gloves or approved work gloves SHALL be worn, as needed, for work requiring tooling.

Radiological Control

D. RADCON SHALL perform any surveys requested or surveys that are deemed necessary by RADCON.

3 ACCEPTANCE CRITERIA

None

4 PREREQUISITE ACTIONS

4.1 Special Tools, Test Equipment, Parts and Supplies

Supervisor

[1] Ensure the following equipment is available to perform this procedure, as needed:

- LT-283, LT-285, LT-286, or LT-287 Leak Test Station(s)
- Helium supply bottle with regulator and tubing
- Leak Rate Results form.

4.2 Field Preparations

Assemblyperson

[1] Ensure all equipment, fixtures, and accessories are:

- Operable
- Current on required inspection and/or maintenance
- Determined to be in good condition.

[2] Ensure helium supply bottle pressure is 200 psig or greater.

[3] Ensure certification stickers are attached and **NOT** expired on the following:

- Internal Standard Leak
- Internal Thermistor
- Vacuum Gauges.

[4] Ensure printer is on and ON LINE or READY/DATA is displayed **AND** Leak Rate Results forms are in the paper tray.

5 PERFORMANCE ACTIVITIES

NOTE 1 *A Veeco operational check is performed, once per day, before each day's run.*

NOTE 2 *Valve number labels will consist of the appropriate Leak Test system ID (i.e., LT-283, LT-285, LT-286, LT-287) and the valve number.*

5.1 Veeco Operational Check

Assemblyperson

[1] Ensure the following valves are CLOSED:

- -PV-101A, TEST POINT A PUMP ISOLATION
- -PV-102A, TEST POINT A LD ISOLATION
- -PV-101B, TEST POINT B PUMP ISOLATION
- -PV-102B, TEST POINT B LD ISOLATION
- -PV-101C, TEST POINT C PUMP ISOLATION
- -PV-102C, TEST POINT C LD ISOLATION
- -PV-101D, TEST POINT D PUMP ISOLATION
- -PV-102D, TEST POINT D LD ISOLATION.

NOTE *The vertically arranged blue soft-keys (numbered 1-5) correspond to settings and selections that appear on the CRT.*

[2] **IF** Veeco Screen Saver is on, **THEN** press any key to wake up.

[3] **IF** Veeco is in SLEEP MODE, **THEN** press 1, POWER UP, on the front panel **AND GO TO** Step **5.1[5]**.

[4] **IF** the Veeco is turned off, **THEN** turn on the POWER I/O switch located on the unit's front panel.

[5] Verify the READY TO TEST screen is displayed.

5.1 Veeco Operational Check (cont.)

Assemblyperson

[6] **IF** the FIL ON/OFF LED light is off, **THEN** press the FIL ON/OFF key **AND** wait 15 seconds.

[7] Perform calibration check.

[a] Press the CAL CHECK key.

[b] **IF** ABORT is displayed, **THEN** press CAL CHECK key again.

[c] **WHEN** the Display Screen displays *Leak Rate Should Read*, **THEN** compare the TEST PORT reading to the value of the LEAK RATE reading.

[8] **IF** the TEST PORT reading is within ± 10% of the internal LEAK RATE reading, **THEN** press 3, END CAL CHECK, **AND GO TO** Section **5.2,** *Pumping Down*.

[9] **IF** reading is within ± 15% of the LEAK RATE reading, **THEN** press 1, CALIBRATE.

[10] **IF** reading is now within ± 10% of the LEAK RATE reading, **THEN** press 3, END CAL CHECK, **AND GO TO** Section **5.2**.

[11] **IF** reading is greater than ± 15% of the LEAK RATE reading, **THEN** press 2, FINE TUNE, **AND REPEAT** Steps **5.1[7], 5.1[8],** and **5.1[9]** once each.

[12] **IF** the CAL Check is **NOT** within ± 10% of the internal leak rate standard, **THEN** notify Supervisor.

5.2 Pumping Down

Assemblyperson

[1] Ensure the following valves are CLOSED:

- -PV-101A, TEST POINT A PUMP ISOLATION
- -PV-102A, TEST POINT A LD ISOLATION
- -PV-101B, TEST POINT B PUMP ISOLATION
- -PV-102B, TEST POINT B LD ISOLATION
- -PV-101C, TEST POINT C PUMP ISOLATION
- -PV-102C, TEST POINT C LD ISOLATION
- -PV-101D, TEST POINT D PUMP ISOLATION
- -PV-102D, TEST POINT D LD ISOLATION.

NOTE *A vacuum source may be used to aid in collapsing the bag and removing air pockets.*

[2] Encapsulate, fully, the Containment Vessel (CV) to be leak tested within a plastic bag.

[3] Remove the air in the bag as far as practical to ensure the leak rate will be correctly measured.

[4] **IF** test line(s) are capped, **THEN** remove cap.

[5] Connect each CV's Leak Test Flange to station test line(s).

[6] Open PUMP ISOLATION valve(s) (-PV-101A through -PV-101D) associated with the parts under test to evacuate parts.

5.3 Leak Testing

Assemblyperson

NOTE 1 *Leaks may be repaired and the test repeated, as directed by Supervisor.*

NOTE 2 *To ensure a helium atmosphere, helium must flow into the bag and be purged from a point below the part being tested throughout the test. This continuous purge may be at a lower helium pressure than the pressure used to inflate the bag.*

[1] Insert the helium fill tube **AND** secure, as needed.

[2] Open the Helium Tank Valve **AND** fill the plastic bag with Helium.

[3] **WHEN** Granville Phillips (GP) vacuum gauge, for the Containment Vessel (CV) being tested, reads 15 mTorr or less, **THEN** close the PUMP ISOLATION valve (i.e., -PV-101A, -101B, -101C, or -101D).

[4] Verify the CRT shows READY TO TEST **AND** the appropriate REJECT POINT is displayed.

[5] **IF** the appropriate REJECT POINT is **NOT** displayed, **THEN** perform the following steps:

- **[a]** Press 5, SETTINGS/HELP on READY TO TEST screen.
- **[b]** Press 3, SELECT UP, **OR** 4, SELECT DOWN, on HELP/SETTINGS menu, until TEST RECIPE field is highlighted.
- **[c]** Press 2, CHANGE, to access SELECT TEST RECIPE menu.
- **[d]** Press 3, SELECT UP, or 4, SELECT DOWN, to specify test recipe with appropriate REJECT point.
- **[e]** Press 5, EXIT, to return to test mode.

[6] Open the leak detector (LD) isolation (LD ISOLATION) valve (i.e., -PV-102A, -102B, -102C, or -102D) associated with the part under test.

NOTE 1 *Pressing START a second time after testing begins will halt testing.*

NOTE 2 *To ensure a helium atmosphere, a slight purge of helium may be necessary during testing.*

NOTE 3 *Based on initial pressure, the system requires 1½ to 2 minutes to accurately read the calibrated standard leak.*

[7] Press and hold START button until leak test begins.

[8] Leak test for at least two minutes (minimum time to assure detector stability) before continuing with procedure.

5.3 Leak Testing (cont.)
Assemblyperson

[9] **IF** LEAK RATE is less than REJECT set point **AND** the ACCEPT is displayed, **THEN** end test by performing the following:

[a] Press **AND** hold VENT button until test ends.

[b] Close leak detector (LD) isolation valve.

[10] The Leak Detector will print the leak test results.

[11] Record part number and expiration date, Standard Leak SAP # and Expiration Date on the Leak Rate Results form **AND** attach to the part card.

[12] **IF** LEAK RATE is more than REJECT set point **AND** the REJECT is displayed, **THEN** end test by performing the following:

[a] Press **AND** hold VENT button until test ends.

[b] Close leak detector (LD) isolation valve.

[c] Print leak test results **AND** discard.

[d] Repair leaks **AND** repeat test, as necessary.

[e] **IF** CV continues to fail leak test, **THEN** contact Supervisor.

[13] **IF** another part has been attached **AND** the part has been roughed down (i.e., pumped down) for testing, **THEN GO TO** Step **5.3[1]**.

[14] Ensure the following valves are CLOSED:

- -PV-101A, TEST POINT A PUMP ISOLATION
- -PV-102A, TEST POINT A LD ISOLATION
- -PV-101B, TEST POINT B PUMP ISOLATION
- -PV-102B, TEST POINT B LD ISOLATION
- -PV-101C, TEST POINT C PUMP ISOLATION
- -PV-102C, TEST POINT C LD ISOLATION
- -PV-101D, TEST POINT D PUMP ISOLATION
- -PV-102D, TEST POINT D LD ISOLATION.

[15] Disconnect CV from/leak test station test line(s).

[16] Turn off Helium Supply.

[17] **IF NO** other CVs are to be leak tested, **THEN** replace cap.

6 POST-PERFORMANCE ACTIVITIES

None

7 RECORDS

All records generated as a result of this procedure are maintained in accordance with Y15-101, *Records and Controlled Documents*.

Record Copy Owner	Record Type
Assembly & Quality Evaluation Production	Print outs of leak test results.

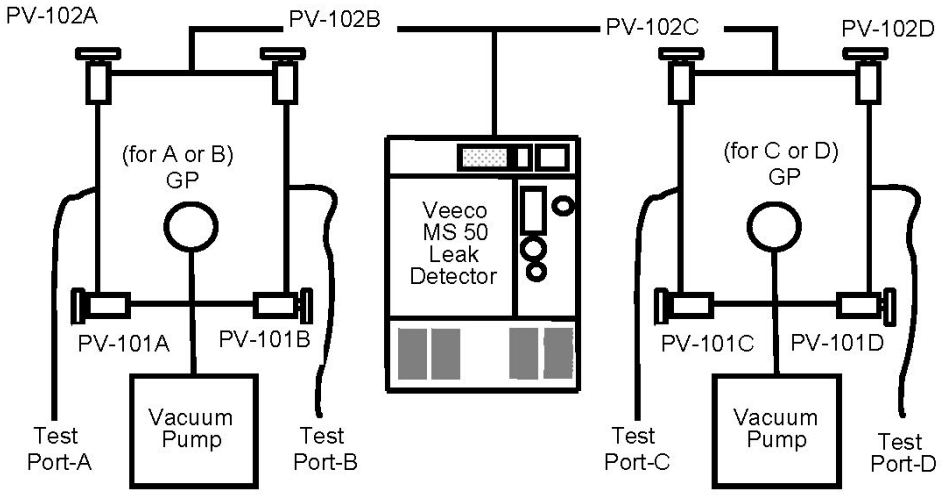
8 SOURCE REQUIREMENTS

- *VIC Leak Detection, MS-50 Automatic Leak Detector, Operation and Maintenance Manual, Vacuum Instrument Corporation, Vacuum Metrology Division, New York.*

9 APPENDIXES

A. Leak Test Station

Appendix A
Leak Test Station



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SECTION 8 REFERENCES

10 CFR 71, *Packaging and Transportation of Radioactive Material*, January 2015.

10 CFR 830, *Nuclear Safety Management*, January 2015.

10 CFR 835, *Occupational Radiation Protection*, January 2015.

49 CFR, *Transportation*, October 2014.

ANL/DIS-09-5, *Guide to the RFID Monitoring System*, Argonne Natl. Lab., latest revision.

ANSI N14.5-1997, *Radioactive Materials—Leakage Tests on Packages for Shipment*, American Natl. Standards Institute, Feb. 5, 1998.

ASME Boiler and Pressure Vessel Code, Sect. III, Div. 1, Subsection NB, *Class 1 Components*, American Society of Mechanical Engineers, New York, revision at time of fabrication.

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*, American Welding Society, Miami, Fla., 2012.

DAC-M900000-0003, C. R. Hammond, *Stress Analysis of ES-3100 Containment Vessel with Viton O-rings*, B&W Y-12, Y-12 National Security Complex, May 23, 2012.

DOE O 232.2, Admin Chg 1, *Occurrence Reporting and Processing of Operations Information*, U.S. DOE, March 2014.

DOE O 414.1D, Admin Chg 1, *Quality Assurance*, U.S. DOE, May 2013.

DOE O 460.1C, *Packaging and Transportation Safety*, U.S. DOE, May 2010.

DOE O 461.1B, *Packaging and Transportation for Offsite Shipment of Materials of National Security Interest*, U.S. DOE, December 2010.

MIL-D-6054F, Amendment 1, *Drum, Metal—Shipping and Storage*, U.S. DoD, June 30, 1989.

NUREG/CR-6314, H. M. Stromberg et al., *Quality Assurance Inspections for Shipping and Storage Containers*, U.S. NRC and Idaho Natl. Engineering Lab., April 1996.

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9. QUALITY ASSURANCE

This section of the safety analysis report for packaging (SARP) describes the ES-3100 package quality assurance (QA) requirements that apply to packaging-related activities necessary for the design, fabrication, assembly, testing, maintenance, and use in accordance with applicable U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Transportation (DOT), and other federal, state, and local regulations to protect the health and safety of the public, workers, and the environment. Furthermore, these packaging-related activities shall be performed according to a QA program approved by the U.S. Department of Energy (DOE), Office of Environmental Management; or National Nuclear Security Administration (NNSA), as appropriate.

The established NRC regulations for packaging, preparation for shipment, and transportation of radioactive materials are given in Title 10, Part 71, of the Code of Federal Regulations (CFR) [10 CFR 71] and DOT regulations for packaging and shipment of hazardous materials are given in Title 49 CFR. DOE nuclear facility users are also responsible for implementing DOE regulations given in Title 10, Parts 830 and 835, of the CFR in addition to directives conveyed in DOE Order (O) 232.2, DOE O 414.1D, and DOE O 460.1C or DOE O 461.1B, as appropriate.

Title 10 CFR 71.101 requires the establishment, maintenance, and implementation of a QA program that satisfies each of the applicable criteria of 10 CFR 71, Subpart H. The applicable criteria shall be executed in a graded approach to an extent that is commensurate with their respective importance to safety in accordance with implementing guidance from NRC Regulatory Guide 7.10. All personnel including users, subcontractors, and suppliers who perform quality-affecting activities relative to the packaging shall be subject to the requirements of this section in accordance with their degree of involvement in the packaging activities.

As used in 10 CFR 71, QA comprises all planned and systematic actions necessary to provide adequate confidence that a system or component will perform satisfactorily in service. Consequently, QA includes quality control, which comprises those QA actions related to control of the physical characteristics and quality of the material or component to predetermined requirements.

9.1 INTRODUCTION

A packaging QA program is established at the Y-12 National Security Complex (Y-12) in accordance with the *Packaging and Transportation Quality Assurance Program Plan* (QAPP) [QAP-Y-91-273860-1], which is approved by the NNSA Office of Packaging and Transportation. The program uses a graded approach to selectively apply the QA elements contained in 10 CFR 830, DOE O 414.1D, 10 CFR 71, American Society of Mechanical Engineers (ASME) NQA-1-2008 with 2009 Addenda, DOE O 460.1C, and DOE O 461.1B, as applicable.

This program applies to all activities related to the storage, transfer, or transportation of hazardous materials, radioactive/hazardous waste, and materials of national security interest. The QA requirements and quality control provisions of the program apply to packaging-related activities and services necessary for the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of radioactive material packagings.

These requirements are incorporated into an integrated body of packaging activities established to ensure quality. Achieving quality of design, conformance, and performance that meets or exceeds all packaging standards is the essential purpose of this program.

9.2 SCOPE

The design agency (Y-12) and owners of the ES-3100 packaging will implement a QA program that addresses appropriate suspect/counterfeit item (S/CI) and software quality assurance (SQA) requirements as well as the following 18 QA elements of 10 CFR 71, Subpart H:

- § 71.103, *Quality assurance organization*;
- § 71.105, *Quality assurance program*;
- § 71.107, *Package design control*;
- § 71.109, *Procurement document control*;
- § 71.111, *Instructions, procedures, and drawings*;
- § 71.113, *Document control*;
- § 71.115, *Control of purchased material, equipment, and services*;
- § 71.117, *Identification and control of materials, parts, and components*;
- § 71.119, *Control of special processes*;
- § 71.121, *Internal inspection*;
- § 71.123, *Test control*;
- § 71.125, *Control of measuring and test equipment*;
- § 71.127, *Handling, storage, and shipping control*;
- § 71.129, *Inspection, test, and operating status*;
- § 71.131, *Nonconforming materials, parts, or components*;
- § 71.133, *Corrective action*;
- § 71.135, *Quality assurance records*; and
- § 71.137, *Audits*.

In accordance with their site-approved QA program, authorized users of the ES-3100 packaging must address the following QA elements, as a minimum:

- § 71.103, *Quality assurance organization*;
- § 71.105, *Quality assurance program*;
- § 71.111, *Instructions, procedures, and drawings*;
- § 71.113, *Document control*;
- § 71.115, *Control of purchased material, equipment, and services*;
- § 71.117, *Identification and control of materials, parts, and components*;
- § 71.121, *Internal inspection*;
- § 71.123, *Test control*;
- § 71.125, *Control of measuring and test equipment*;
- § 71.127, *Handling, storage, and shipping control*;
- § 71.129, *Inspection, test, and operating status*;
- § 71.131, *Nonconforming materials, parts, or components*;
- § 71.133, *Corrective action*;
- § 71.135, *Quality assurance records*; and
- § 71.137, *Audits*.

Additional QA elements may also be addressed as commensurate with the user's scope of responsibility (i.e., if authorized for packaging-related design, fabrication, maintenance, repair, or modification activities). All providers of items and/or services must demonstrate that they meet the applicable QA requirements for their respective work scope. Each user of the ES-3100 package must also develop an appropriate site-approved QA plan and related implementing documentation.

9.3 QUALITY ASSURANCE PLAN

The QA requirements from 10 CFR 71, Subpart H are to be selectively applied using a graded approach to the specific packaging programs being developed and implemented. This selective application requires that the detail and magnitude of resources expended for a packaging-related activity be commensurate with the activity's importance to safe and reliable operations, environmental compliance, safeguards and security, programmatic mission, and/or other packaging-specific requirements. As stated in NRC Regulatory Guide 7.10, "structures, systems, and components important to safety mean the features of a Type B or fissile material package that are intended to (1) maintain the conditions required to safely transport the package contents; (2) prevent damage to the package during transport; or (3) provide reasonable assurance that the radioactive contents can be received, handled, transported, and retrieved without undue risk to the health and safety of the public or the environment."

Y-12 has embraced the quality concepts and principles identified in the ASME Nuclear Quality Assurance document NQA-1. This national consensus standard is integrated, where practicable and consistent with contractual or regulatory requirements, as the basis for the Y-12 QA Program. The Y-12 QAPP identifies the requirements that apply to packaging-related activities for radioactive material packages for offsite transportation and describes the method of control over those structures, systems, and components (SSCs) important to safety. A crosswalk matrix that documents the Y-12 packaging QA program conformance to the 18 QA elements of 10 CFR 71, Subpart H as well as requirements for SQA is provided in Y17-69-PE-335PD. Section 9.3 discusses how these requirements are implemented at Y-12 for the ES-3100 package with highly enriched uranium content.

9.3.1 Quality Assurance Organization

As described in Sect. 1 of the QAPP, the organizations ultimately responsible for QA within the Y-12 offsite packaging and transportation program are: (1) Packaging and Transportation Engineering (PTE); (2) Production Operations; (3) Quality Performance & Analysis (QP&A); (4) Program Integration; and (5) Transportation. Other Y-12 organizations have QA functions in support of the organizations identified above. An organization chart that depicts PTE and its relationship with the functional and technical support groups that provide items and services or that conduct other activities in support of radioactive material packagings is provided in Fig. 9.1.

PTE is responsible for the development of the QAPP and quality requirements for packaging components designed at Y-12. The manager of PTE has the responsibility for the technical leadership of the program. The PTE organization is part of the Y-12 Engineering division, which reports to the vice president of Mission Engineering (Fig. 9.1). They also ensure that packagings fully comply with the applicable regulations, requirements, and standards. PTE and the Y-12 QA organizations ensure that the quality of packagings is maintained throughout the design, testing, fabrication, and maintenance processes. PTE is the design authority and primary contact for all packaging-related activities and services necessary for the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of Y-12 Type B and Type AF radioactive material packagings, such as the ES-3100. PTE provides requested technical assistance for other Type B radioactive material packages. The complete description of the engineering roles and responsibilities is described in Y17-69-PE- 335PD.

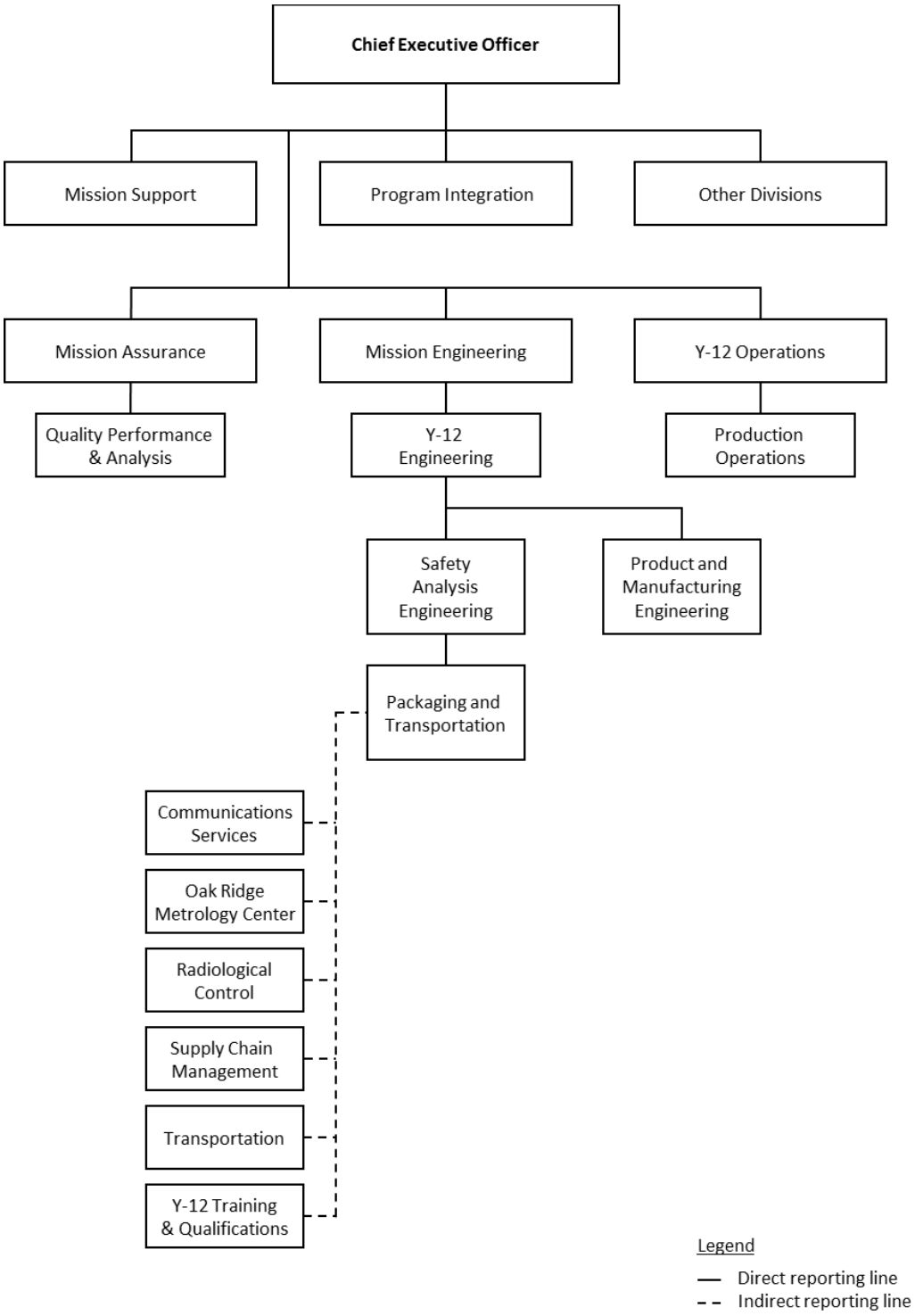


Fig. 9.1. Y-12 Packaging and Transportation Engineering organizational support.

In conjunction with Program Integration management, the PTE manager plans, schedules, and assigns work activities and also obtains adequate funding to accomplish program goals and milestones. Production Operations conducts packing, maintenance, loading, and material handling activities with qualified personnel. Production Operations activities related to packaging are controlled by procedures approved by PTE and overseen by the QP&A organization. Production Operations reports to the Y-12 Site Manager, is funded by the program integration organizations, and receives technical support from PTE and quality oversight from QP&A. Production Operations is responsible for complying with implementing procedures, instructions, and/or checklists for loading, unloading, and maintenance of the packagings. Production Operations owns the content and the packaging and has the primary responsibility for the proper use of the package.

The QP&A organization is responsible for the management and execution of the overall Y-12 QA Program. QP&A is also responsible for providing qualified personnel for assessments and oversight for operations, vendor qualifications, and independent component inspections. The QP&A manager reports to the vice president of Mission Assurance.

Program Integration management provides the funding for the daily maintenance and compliance activities necessary to ensure that the Y-12 packaging and transportation program complies with NRC, DOT, and DOE regulations. These activities include DOE order compliance, programmatic training, assessments, QA, investigations, shipping package maintenance, and user support. The vice president of Program Integration reports to the Chief Executive Officer.

The Transportation organization provides compliance oversight to ensure compliance with DOE orders and federal, state, and local laws for the offsite shipment of radioactive materials. Other organizations provide services to PTE as shown in Fig. 9.1. Every individual and organization that produces an item, performs an activity, or provides a service for radioactive material packagings has direct responsibility for the quality of that item, activity, or service. Every organization using a package is responsible for ensuring proper procedures, training, and qualifications are in place.

9.3.2 Quality Assurance Program

Through the effective implementation of the QAPP, Y-12 management provides control over activities affecting the quality of ES-3100 packaging materials and components to the extent commensurate with their importance to safety. The QAPP provides for activities affecting quality to be accomplished under suitably controlled conditions to ensure conformance with the approved design of the packaging. The QAPP complies and implements the requirements of 10 CFR 71.101 through 71.137 through the implementation of an ASME NQA-1–based QA program. In accordance with Sect. 2 of the QAPP, packaging responsibilities are delineated to the PTE manager, and activities affecting quality are verified by individuals who are not directly responsible for performance of work. Personnel or organizations responsible for establishing and executing the QAPP may delegate work; however, they retain overall responsibility for delegated work.

The management assessment process is designed to focus on the compliance and flow down of contractual requirements, including applicable standards and codes, how those requirements are implemented in procedures, and the measurement of implementation effectiveness. Management assessments are conducted by members of the line organization or program to evaluate and determine whether packaging-related activities are properly focused on achieving desired results. These assessments serve as a periodic self-analysis tool and include reviewing the processes, systems, and programs that are important to the specified mission, goals, and objectives as well as identifying areas for continuous improvement. The assessment process includes provisions to appropriately evaluate all aspects of the Y-12 packaging process, determine how well the management system meets specified requirements, and assess methods to safely perform packaging-related activities.

Training and qualifications are required for personnel within Y-12 performing packaging activities related to design, fabrication, testing, procurement, loading, unloading, leak testing, quality oversight, transportation, and record keeping. Each activity is evaluated and the proper training plan is developed and documented in accordance with established procedures. Vendors performing packaging activities will require training or qualifications as defined in accordance with the established contract. Activities involving special processes as defined in 10 CFR 71, Subpart H, may require specialized qualifications in accordance with established approved training requirements or through a nationally recognized standard such as the American Society for Nondestructive Testing, ASME, or American National Standards Institute.

As previously discussed, Y-12 uses a graded approach to selectively apply QA requirements to the ES-3100 packaging components and related services and activities in accordance with 10 CFR 71.105. The purpose of the graded approach is to select the appropriate QA controls and verification actions to be applied (selective application) to the various types of packagings and packaging-related components. To ensure conditions are controlled in accordance with their safety importance, a documented graded approach has been adopted. The degree to which the plan is applied is based on a graded approach to quality, commensurate with the identified risk associated with the failure of items, processes, or services related to the safety of employees and the public, protection of the environment, and achievement of Y-12 programmatic missions.

The graded approach is consistent with that defined in NRC Regulatory Guide 7.10. This process involves (1) classifying packaging SSCs as "important to safety" or "not important to safety" (NITS); (2) grouping SSCs classified as "important to safety" into quality categories; and (3) specifying the applicable level of QA effort for each category. Approved procedures provide instructions to analyze packaging SSCs to determine whether their functions or physical characteristics are essential to safety, and they provide the criteria for grouping SSCs into one of the following quality categories as defined below. Table 9.1 shows the typical level of QA effort for each element of 10 CFR 71, Subpart H, relative to the graded safety-related quality categories. Each packaging component is graded by the Quality Category Committee using the quality category definitions in a manner similar to the procedure described in NRC Regulatory Guide 7.10, Appendix A. The results of the quality category grading for ES-3100 packaging components are given in Table 9.2, and the correlation between the NRC Regulatory Guide 7.10–based quality categories and the Y-12 quality levels (based on ASME NQA-1) is presented in the QAPP.

- **Category A** (critical to safe operation) components whose failure or malfunction will directly result in an unacceptable condition of containment, shielding, or nuclear criticality.
- **Category B** (major impact on safety) components whose failure or malfunction will indirectly result in an unacceptable condition of containment, shielding, or nuclear criticality (if the primary event occurred in conjunction with a secondary event, another failure, or an environmental event).
- **Category C** (minor impact on safety) components whose failure or malfunction does not result in an unacceptable condition of containment, shielding, or nuclear criticality regardless of other failures in this category.
- **NITS** (not important to safety).

As described in Sect. 2 of the QAPP, document and record requirements have been developed for packaging design drawings, specifications, safety documentation, policies, procedures, assessments, surveillances, records, forms, procurement requisitions, communications, and training. Documents for activities that affect quality relative to procurement, fabrication, assembly, and the use of packaging are considered to be records and will be maintained in compliance with appropriate regulations. Controlled documents affecting quality will be maintained under revision control as required and in an appropriate document management system.

Table 9.1. Typical level of quality assurance effort by graded quality category

10 CFR 71, Subpart H, level of quality assurance effort	Graded quality category		
	A	B	C
§ 71.103, *Quality assurance organization*			
– Quality assurance program established	✓	✓	✓
– Responsibilities defined	✓	✓	✓
– Quality assurance functions executed	✓	✓	✓
– Reporting levels established	✓	✓	✓
– Management endorsement	✓	✓	✓
§ 71.105, *Quality assurance program*			
– 10 CFR 71, Subpart H, compliant quality assurance program	✓	✓	
– Written procedures and instructions	✓	✓	✓
– Activities affecting quality are appropriately controlled and performed by trained personnel	✓	✓	✓
– Management review	✓	✓	✓
§ 71.107, *Package design control*			
– Most stringent Codes and Standards	✓		
– Formal test for complex items (first article evaluation)	✓		
– Codes and Standards	✓	✓	
– Formal engineering design process (control of design inputs, outputs, reviews, verifications, testing, changes/deviations, analyses, and interfaces)	✓	✓	
– Software quality assurance	✓	✓	
– Catalog/off-the-shelf components			✓
– Design change approval required for certifier controlled design conditions	✓	✓	✓
§ 71.109, *Procurement document control*			
– Traceability	✓	✓	
– Qualified supplier lists	✓	✓	
– Suppliers and subtier suppliers meet the applicable provisions of 10 CFR 71, Subpart H–*Quality Assurance*	✓	✓	
– Commercial grade dedication of items or services	✓	✓	
– Catalog/off-the-shelf components			✓
§ 71.111, *Instructions, procedures, and drawings*			
– Written and controlled	✓	✓	
– Quantitative or qualitative acceptance criteria	✓	✓	
– Controlled changes and deviations for certifier controlled design conditions	✓	✓	✓
§ 71.113, *Document control*			
– Controlled issuance	✓	✓	
– Controlled changes and deviations	✓	✓	

Table 9.1. Typical level of quality assurance effort by graded quality category

10 CFR 71, Subpart H, level of quality assurance effort	Graded quality category		
	A	B	C
§ 71.115, *Control of purchased material, equipment, and services*			
– Source evaluation and selection	✓		
– Inspections, audits, or surveillances at supplier facilities in accordance with specified requirements	✓	✓	
– Objective evidence of quality furnished by the supplier	✓	✓	
– Commercial grade dedication of items or services	✓	✓	
– Documentary evidence provided to ensure that material, equipment, and services conform to the procurement documents and specified requirements	✓	✓	✓
– Packaging components identified upon receipt and checked for damage	✓	✓	✓
§ 71.117, *Identification and control of materials, parts, and components*			
– Positive identification and traceability of each packaging component	✓		
– Control, identification, and traceability to heat number, part number, or other appropriate means throughout fabrication, installation, and use	✓	✓	
– Identification to end use instructions, procedures, specifications, or drawings	✓	✓	✓
§ 71.119, *Control of special processes*			
– Special processes including welding, heat treating, and nondestructive testing performed with qualified personnel and procedures	✓	✓	
– Special process qualification records	✓	✓	
– Special processes conducted in accordance with specified requirements	✓	✓	✓
§ 71.121, *Internal inspection*			
– Documented inspection to verify conformance with instructions, procedures, drawings, and specifications	✓	✓	
– Process monitoring provided as appropriate to assure quality control	✓	✓	
– Examination, measurements, or tests of material or products processed in accordance with specified requirements	✓	✓	
– Qualified inspectors independent of those performing the activities being inspected	✓	✓	
– Visual examination in accordance with specified requirements	✓	✓	✓
§ 71.123, *Test control*			
– Formal test program implemented using written test procedures	✓	✓	
– Formal test for complex items (first article evaluation)	✓		
– Test results are documented and evaluated	✓	✓	
– Observation and evaluation of supplier acceptance tests in accordance with specified requirements	✓	✓	
– Testing and acceptance criteria in accordance with specified requirements	✓	✓	✓
§ 71.125, *Control of measuring and test equipment*			
– Formal calibration program to ensure that tools, gauges, instruments, and other measuring and testing devices are controlled, calibrated, and adjusted	✓	✓	
§ 71.127, *Handling, storage, and shipping control*			
– Written procedures for handling, storing, shipping, cleaning, and preservation of packaging components to prevent damage or deterioration	✓	✓	
– Routine handling activities			✓

Table 9.1. Typical level of quality assurance effort by graded quality category

10 CFR 71, Subpart H, level of quality assurance effort	Graded quality category		
	A	B	C
§ 71.129, *Inspection, test, and operating status*			
– Status or condition of individual packaging components is identified	✓	✓	
– Stamps, tags, labels, or other suitable means indicate the status or condition	✓	✓	✓
§ 71.131, *Nonconforming materials, parts, or components*			
– Written procedures to identify, document, segregate, disposition, notify affected organizations, and to prevent inadvertent use or installation	✓	✓	✓
– Nonconforming conditions must be documented and closed in accordance with written procedures	✓	✓	✓
– Records of disposal (i.e., reject or scrap) required	✓	✓	
§ 71.133, *Corrective action*			
– Written procedures to identify and correct conditions adverse to quality	✓	✓	✓
– Cause and corrective action documented	✓	✓	
– Significant conditions adverse to quality reported	✓	✓	✓
§ 71.135, *Quality assurance records*			
– Records of reviews, inspections, tests, audits, surveillances, and material analyses	✓	✓	
– Records of design, fabrication, acceptance testing, and maintenance retained for the life of the packaging plus 3 years	✓	✓	
– Records of each shipment of radioactive materials for 3 years after the shipment	✓	✓	✓
– Qualification records of personnel, procedures, and equipment in accordance with specified requirements	✓	✓	✓
– Procurement records and nonconformance reports	✓	✓	✓
– Records managed by written program	✓	✓	✓
§ 71.137, *Audits*			
– All auditors are qualified	✓		
– Lead auditor is qualified	✓	✓	
– Written plan of periodic audits	✓	✓	✓
– Implementation by written procedures or checklists	✓	✓	✓

Table 9.2. Quality category for ES-3100 packaging components

ES-3100 component	Quality category
ES-3100 drum assembly (Drawing M2E801580A001, Appendix 1.3.7)	
Drum, inner liner, lid, and top plug weldments	B
Weld studs	B
Hex nuts	B
Washers	C
TID lugs, data plate, and trefoil data plate	C
Kaolite 1600 insulation	B
277-4 neutron-absorbing material	A
Silicone rubber pads (CV bottom pad, CV flange pad, and plug pad)	C
Aluminum foil duct tape	C
Nylon plug	C
Paint	C
RFID monitoring system tag	NITS [a]
ES-3100 containment vessel assembly (Drawing M2E801580A011, Appendix 1.3.7)	
Body [b]	A
Lid assembly	
Sealing lid and closure nut	A
Round bar and weld filler material	B
External retaining ring	C
Inner O-ring	A
Outer O-ring	C
Super-O-Lube	C
Modified VCO threaded plug with O-ring	C
Krytox grease, grade 240 AC	C
Hoist ring	C
ES-3100 packing materials (Sect. 1.2.2.4)	
Convenience cans	C
Convenience bottles	C
Silicone rubber pad [c] (can pad)	C
Heavy can spacer assembly [d]	
Can body and end cover	B
277-4 neutron-absorbing material	A
Lanyard, band clamp, and labels	C
Metal scrubbers	C
Polyethylene bag	C

[a] An optional radio-frequency identification (RFID) monitoring system tag (categorized as not important to safety) may be secured to the drum assembly. The QA requirements for the design, procurement, operation, and maintenance of the RFID monitoring system tag and support programs are presented in ANL/DIS-09-5.
[b] Component including any weld filler material.
[c] Drawing M2E801580A024, Appendix 1.3.7.
[d] Drawing M2E801580A043, Appendix 1.3.7.

9.3.3 Package Design Control

PTE is responsible for the ES-3100 package design control. This organization develops, prepares, approves, and issues the packaging system requirements document that includes the physical, functional, and performance requirements and identifies the regulatory requirements. In accordance with Sect. 3 of the QAPP, PTE is also responsible for the design process, including design verification activities. Design input such as the design basis, structural analysis, thermal analysis, radiation shielding analysis, and nuclear criticality analysis for the ES-3100 package are identified and documented, and their selection is reviewed and approved by the PTE manager.

Once the design has been translated into drawings and specifications, a design review is conducted and documented. The ES-3100 packaging certification drawing (Appendix 1.3.1) specifies those details of the package design that affect its evaluation under 10 CFR 71. The packaging design drawings (Appendix 1.3.7) and the equipment specifications (Appendices 1.3.2–1.3.5 and 1.3.9) provide detailed fabrication and acceptance criteria for the packaging components.

Test requirements for the conduct of the physical testing to ensure compliance with 10 CFR 71.71 and 71.73 are identified. A test plan, test procedures, and the test report are prepared by the testing organization and submitted to PTE for review and approval. Results of the package-testing program are incorporated into the certification documentation (SARP). All packaging activities, including design, are controlled with the use of approved procedures and instructions.

A change to Category A and B components (Sect. 9.3.2 and Tables 9.1 and 9.2) that affects a design feature, requirement, or specification shown on the ES-3100 certification drawing (Appendix 1.3.1) or condition of approval in the Certificate of Compliance shall be submitted to DOE Headquarters Certifying Official for review and approval, and the change shall not be implemented until the DOE Headquarters Certifying Official has provided approval of the change in writing. Once approved, PTE must revise the affected packaging design documents and/or SARP sections, as applicable, and provide copies of the changes to the Certifying Official and all the organizations having a controlled copy of the SARP as soon as possible.

A change to Category C or NITS components may be approved by PTE (the design authority and SARP owner). PTE must revise the affected packaging design documents and/or SARP sections, as applicable, and provide copies of the changes to the Certifying Official and all the organizations having a controlled copy of the SARP in a timely manner.

9.3.4 Procurement Document Control

In accordance with Sect. 4 of the QAPP, the Y-12 procurement process, which is ASME NQA-1 based, establishes the system to ensure that applicable technical and quality requirements are included in the procurement documents for packaging material, equipment, and services, whether purchased by Y-12 or its suppliers. This procurement process ensures that those items and/or services provided by approved suppliers meet the 10 CFR 71, Subpart H requirements. Using a graded approach, Y-12 executes the procurement process by performing vendor qualification reviews, assessments, and first article evaluations, as required, ensuring that:

- requirements are accurately, completely, and clearly communicated to the supplier;
- suppliers comply with regulatory qualification requirements;
- suppliers fabricate according to the design documentation, and
- the requested documentation is provided.

Applicable QA requirements are flowed down and verified through reviews, assessments, audits, and inspections of suppliers and sub-tier suppliers, as required, to ensure that they are capable of and continue to meet the specified technical and quality requirements. Packaging components identified as either Category A or B must be purchased from qualified vendors or through commercial grade dedication in accordance with established procedures.

Controls are implemented to ensure that procurements are planned and applicable technical and quality requirements are included or referenced in the procurement documents, that procurement documents are reviewed, and that changes are subject to the same degree of control used in preparation of the original documents. These controls also ensure that the items, materials, or services have been assigned a quality category. The proper quality category for each component is determined and documented by the Quality Category Committee (Sect. 9.3.2).

9.3.5 Instructions, Procedures, and Drawings

In accordance with Sect. 5 of the QAPP, packaging activities that affect quality are performed in accordance with written and approved instructions, procedures, drawings, and specifications that identify the QA requirements and acceptance criteria applicable to each packaging-related item, service, or activity. Y-12 organizations responsible for specific packaging-related operations and activities prepare the required procedures, instructions, checklists, and other required implementing documents for their particular packaging activities. These documents provide quantitative or qualitative acceptance criteria to ensure that the activities are performed satisfactorily and that they meet the applicable requirements.

The packaging activities that are important to safety are accomplished and controlled in accordance with written and approved instructions, procedures, drawings, and other documents that identify the quality requirements for each item, service, or activity and should include the methods for complying with applicable sections in 10 CFR 71, Subpart H. Packaging activities will be described to a level of detail commensurate with the complexity of the operation and the need to ensure consistent and acceptable results.

9.3.6 Document Control

In accordance with Sect. 6 of the QAPP, Y-12 has an established system to ensure that documents within the scope of the QAPP, including changes thereto, are prepared, reviewed for adequacy and completeness, approved for release, and used at the work location. The documents necessary to accomplish and/or verify packaging activities affecting quality are identified and controlled. Typical documents that are controlled include design documents, procurement documents, QA manual, procedures, nonconformance reports (NCRs), design change requests, and corrective action reports.

The PTE manager ensures that necessary controlled documents are identified, prepared, reviewed, and approved. PTE maintains responsibility for and control of packaging-related documents that are issued by PTE. These documents are reviewed and approved for adequacy by the PTE manager, the designee, or the packaging engineer. This control system ensures:

- changes to documents are reviewed and approved by the same organizations that performed the original review and approval;
- approved documents are available at all locations when operations, which are essential to the effective functioning of the quality system, are performed; and
- recipients are notified when documents are superseded, so they can be promptly removed from all points of issue or use, and originals are maintained for establishing history and maintaining traceability.

9.3.7 Control of Purchased Material, Equipment, and Services

In accordance with Sect. 7 of the QAPP, PTE has an established system for planning and executing packaging-related procurements to ensure that purchased material, equipment, and services conform to the procurement documents. Y-12 procedures document the methods and responsibilities for procuring packaging-related items and services to ensure that they conform to the specified requirements. The procurement documents specify the test/inspection requirements, the acceptance criteria for safety-related items, and the identity of all documents to be submitted for information, review, or approval by the purchaser. The time of submittal of the required documentation is established in the procurement documents. These documented evidence files must be determined to be acceptable before an item can be used in a packaging. When PTE requires the supplier to maintain specific records, the retention times and disposition requirements are prescribed in the purchase order.

Purchased items and services are controlled using the Y-12 procurement procedures and instructions, which include QA requirements for commercial grade dedication of items or services in accordance with ASME NQA-1. Depending on the quality category level required, control measures for purchased items and services may include verifying the supplier's capability before the order is placed. This process also includes the evaluation and selection of packaging component suppliers. Procurement documents contain provisions from the Y-12 S/CI program to ensure that suppliers are aware of any S/CI issues.

First article evaluations are used for items of a critical nature or to evaluate a supplier's performance. The evaluation, which is performed at the supplier's location, is completed before release for production is granted. NUREG/CR-6314 may also be used to conduct QA inspections of the supplier's QA programs and operations.

Supplier performance is monitored and reviewed at intervals consistent with the complexity and technical requirements of the packaging component supplied. Records are prepared and maintained to identify each supplier's acceptability.

9.3.8 Identification and Control of Materials, Parts, and Components

In accordance with Sect. 8 of the QAPP, Y-12 has an established process for the identification and control of packaging-related materials, parts, and components. Implementing procedures require that proper identification shall be maintained on the items, in documents traceable to the items, or in a manner that ensures identification is established and maintained. Serial numbers are permanently marked on the ES-3100 containment vessels and drum assemblies according to the design drawings and equipment specifications. Users shall segregate and maintain certified replacement part inventories to ensure traceability according to their site-approved QA plan.

Controls are established to ensure that only correct and accepted items are used or installed. Various methods for acceptance of packaging-related materials, parts, and components include supplier evaluations, certificates of conformance, source verifications, receiving inspections, post-installation testing, or a combination of these methods. Items designated for destructive testing or special evaluations are controlled to prevent their inadvertent use. Limited life materials or components such as O-rings are identified and controlled to preclude use of expired items and to provide for recall if necessary.

Y-12 has incorporated DOE guidance regarding S/CIs. This guidance strengthens the procurement process, identifies and eliminates S/CIs, and improves the S/CI reporting process. The purpose of this program is to control or eliminate the hazards posed by the use of S/CIs, which can lead to unexpected equipment failures and undue risks to the NNSA mission, the environment, and personnel.

9.3.9 Control of Special Processes

In accordance with Sect. 9 of the QAPP, Y-12 has an established system to ensure that special processes are performed by trained and qualified personnel under controlled conditions using approved and qualified procedures or instructions in accordance with applicable codes, standards, specifications, criteria, and other requirements. Processes to be controlled as special processes shall meet the following criteria: (1) the results are highly dependent on the control of the process; (2) the results are highly dependent on the skill of the operator; and (3) the quality of the results cannot be readily determined by inspection or test of the item or component. Implementing procedures or instructions shall be used to ensure that process parameters are controlled and that the specified environmental conditions are maintained.

The special processes identified for the ES-3100 packaging are those that involve mixing, casting, and curing of Kaolite 1600 insulation and 277-4 neutron-absorbing material; welding; heat treating of materials; and conducting nondestructive examinations (such as radiographic, liquid penetrant, etc.). For welded components, certified welders perform welding operations in accordance with Y-12 or approved supplier welding procedures. The welding records for each of these operations identify the welder and the welding procedures used for each weld. Qualification records for special processes, including personnel qualifications where required, are maintained for the life of the packaging plus 3 years.

9.3.10 Internal Inspection

Inspection activities are planned and performed using approved instructions, procedures, and checklists to verify conformance of an item or activity to specified requirements. In accordance with Sect. 10 of the QAPP, these documents will include methods for inspection, acceptance and rejection criteria, and identification of those responsible for performing the inspection. Inspections for acceptance shall be performed by individuals other than those who performed or directly supervised the work being inspected, and those individuals shall not report directly to the supervisor immediately responsible for performance of the work.

Inspections include receipt inspections, in-process inspections, nondestructive evaluations, destructive testing, and required national standards and code inspections. Inspections shall be conducted on activities or items affecting quality and/or nuclear safety to verify conformance with applicable codes, standards, regulatory requirements, procedures, and procurement documents or because of specific management requests. Inspection activities shall be documented and controlled by instructions, procedures, specifications, drawings, checklists, travelers, or other appropriate means. These requirements apply to both procured items and items produced in-house at Y-12. Qualified inspectors document the inspection results before the ES-3100 packaging is approved for use.

As described in Sect. 8.1.1.4, a “Diamond I” symbol is used on the drawings or equipment specifications to designate significant dimensions or features, which are specifically inspected and documented by qualified personnel during fabrication. Minimum certification requirements are shown on the ES-3100 certification drawing (Drawing M2E801580A037, Appendix 1.3.1).

The package operations (Sect. 7) and maintenance program (Sect. 8) requirements are derived from the design drawings and equipment specifications, and their determinations shall be present in documentation records as described in Sects. 7.5.1.1 and 7.5.1.2. Detailed site-specific operations and maintenance procedures shall include appropriate inspection provisions, including quality control hold points, to ensure that the compulsory minimum requirements in Sects. 7 and 8 are properly performed.

9.3.11 Test Control

PTE has established a test program in accordance with Sect. 11 of the QAPP, which ensures required testing will demonstrate that the packaging components will perform satisfactorily in service/use. This testing is performed in accordance with written and approved test procedures, which incorporate the necessary requirements and acceptance limits (contained in the package design documents and federal regulations) and ensure that qualification testing of prototype packages is performed under the most adverse design conditions. The packaging and certain components are subject to acceptance and verification testing in accordance with written test procedures to ensure compliance with 10 CFR 71.71, *Normal conditions of transport*, and 10 CFR 71.73, *Hypothetical accident conditions*. Testing records and results documentation are maintained by the organization responsible for the tests, and copies are sent to PTE. Approved test reports describing the ES-3100 compliance testing were compiled for use in the preparation of this SARP. Pertinent information from these test reports is discussed primarily in Sects. 2, 3, and 4, as appropriate.

The ES-3100 packaging design drawings and equipment specifications as well as the procurement documents, indicate the tests required for the acceptance of the packaging components. Either PTE or the supplier prepares the required test plans that identify the tests to be performed and the requirements and conditions of each test. The test procedures define the test objectives, prerequisites, equipment, test conditions, and acceptance criteria.

9.3.12 Control of Measuring and Test Equipment

The Y-12 Standards and Calibration Program is administered by the Y-12 Oak Ridge Metrology Center through established procedures in accordance with Sect. 12 of the QAPP. The Standards and Calibration Program ensures measuring and test equipment (M&TE) is calibrated and controlled. This control process ensures that tools, gauges, and other instruments used for packaging-related inspections, tests, and measurement activities are of the proper range, type, accuracy, and precision and that they are handled, stored, and maintained within specified calibration limits. Typical packaging-related M&TE includes torque wrenches, scales, leak-testing equipment, calipers, micrometers, and tape measures.

Calibration of M&TE is required whenever the equipment is used to determine conformance or acceptance to customer or regulatory compliance or whenever the measurement is required to meet safety, health, environmental, or quality parameters. Y-12 calibration organizations supporting packaging and transportation activities (e.g., Analytical Chemistry; Industrial Hygiene; Oak Ridge Metrology Center; Radiological Control) are responsible for maintaining measurement standards and calibrating M&TE by trained personnel and approved procedures or work instructions.

The ES-3100 packaging suppliers are required to provide a system for calibration of M&TE in accordance with the guidance provided by Y-12 procurement documents and the supplier's QA program. Other users will control M&TE in accordance with their site-approved QA plan.

9.3.13 Handling, Storage, and Shipping Control

In accordance with Sect. 13 of the QAPP, Y-12 has established procedures for handling, storing, shipping, cleaning, loading, unloading, and maintenance of ES-3100 packaging that satisfies the 10 CFR 71 requirements. If packaging components will be stored for an extended period of time, they may be bagged. The packaging components (i.e., complete assembly or individual parts) will be stored in weather-protected indoor facilities and transferred between facilities in an enclosed conveyance for protection from environmental elements. The organizations that use the ES-3100 package follow approved procedures (Sect. 7) for all operations related to handling, loading, shipping, and unloading of hazardous materials. Prior to shipment, operators will ensure (1) that packages have been prepared in

accordance with the approved drawings, procedures, specifications, regulatory requirements, DOE directives, SARP, and Certificate of Compliance; (2) that packages have passed all applicable inspections and tests; (3) that packages are properly identified by physical markings or tags; and (4) that all shipping papers have been prepared as required and reviewed by qualified personnel to verify completeness and accuracy.

9.3.14 Inspection, Test, and Operating Status

The status of inspection and test activities is provided on packaging items and in documents traceable to those items. This provision applies to Y-12 and suppliers of Category A and B packaging components. A component or item that does not pass inspection is not allowed to be used or installed in a package. In accordance with Sect. 14 of the QAPP, procedures describe the use of markings such as stamps, tags, labels, routing cards, or other suitable means and the status of inspections, tests, and operating conditions (including maintenance of items) that may be performed on packaging components. Status shall be maintained through indicators, such as physical location and tags, markings, travelers, stamps, inspection records, or other suitable means. The authority for application and removal of tags, markings, labels, and stamps shall be specified in implementing procedures.

Y-12 uses a production control system in which scheduled inspections, tests, or other activities are recorded. The Y-12 production control system is a developed software package, which contains operations, routes, bills of materials, data collection, operator instructions, error actions, and inventory movement for product being produced at Y-12. Lots (work in process inventory) are created to represent serialized parts. Manufacturing areas use the production control system to track these lots across the shop floor. Complete histories of lot transactions are stored along with lot genealogy and traceability. In addition, the production control system is used in inventory processes for accountable materials, and it is also the mechanism for communicating schedule requirements and work prioritization reports to manufacturing areas. After assembling the components into a packaging, the inspection, test, and operational statuses can be determined from the database entries. The QA organization uses data stored in the production control system for the certification of parts and materials.

9.3.15 Nonconforming Materials, Parts, or Components

Nonconformances represent a deficiency in a characteristic, documentation, or procedure that renders the quality of an item or activity unacceptable or indeterminate. Once identified, the nonconforming materials, parts, or components will be appropriately tagged, segregated when practical, and dispositioned in accordance with approved procedures. These nonconformance control activities are necessary to prevent further processing, delivery, installation, or inadvertent use of nonconforming items until affected organizations (including QA) are notified and the proposed technical disposition, remedial actions, or corrective actions are approved.

In accordance with Sect. 15 of the QAPP, Y-12 staff members are responsible for identifying and documenting nonconformances. Procurement documents will include provisions for (1) supplier reporting of nonconformances that do not meet specified requirements and (2) obtaining Y-12 approval of the NCR disposition. Noncompliances to the procurement specification, drawings, statement of work, or any other procurement document must be documented and dispositioned using the request for waiver or deviation (RFWD) process before the item can be accepted and released for shipment to Y-12. The packaging engineer and packaging design engineer must be involved in the review of RFWDs and concur with their disposition. If the RFWD alters QA requirements or QA activities (e.g., hold or witness points), then the Procurement quality engineer must review and sign the RFWD. Items that cannot be returned to an acceptable condition are appropriately controlled to prevent inadvertent installation or use.

Each user of the ES-3100 package is responsible for processing NCRs in accordance with their site-approved QA program. At the direction of the DOE Headquarters Packaging Certification Program, the user is also responsible for obtaining approval from the PTE organization for NCRs that are dispositioned "use-as-is" or "repair." In support of package recertification efforts and for trending purposes, the user will forward a copy of the NCR, including supporting documentation, to:

Consolidated Nuclear Security, LLC
Y-12 National Security Complex
Attn: Packaging and Transportation Engineering Manager
P.O. Box 2009
Oak Ridge, TN 37831-8008.

9.3.16 Corrective Action

Corrective actions related to packaging items, components, or activities are submitted to the PTE manager and processed in accordance with established Y-12 procedures. These procedures ensure that the identification, cause, and corrective actions for conditions adverse to quality are documented and reported to the appropriate levels of management. For significant conditions adverse to quality, the cause of the condition is determined, and corrective action is taken to prevent recurrence.

In accordance with the Sect. 16 of the QAPP, Y-12 procedures establish the process to be used for conditions that may be noncompliant with respect to the Consolidated Nuclear Security, LLC contractual requirements or that are adverse to safety, health, environment, operations, quality, safeguards and security, or mission performance. These issues are managed in accordance with the significance of the issues and the associated risk.

9.3.17 Quality Assurance Records

The Y-12 records management process is established in accordance with approved formal written procedures (QAPP, Sect. 17) and implemented to ensure that sufficient records are specified, prepared, completed, reviewed, approved, and maintained to accurately reflect completed work. A QA record is a completed document that furnishes evidence of the quality of items and/or activities affecting quality. General examples of quality records are listed in Table 9.3; specific records associated with operations are listed in Appendix 7.5.1.

Records are to be legible, complete, retrievable, and protected from damage, deterioration, and loss. Approved procedures provide for the retention, protection, preservation, traceability, accountability, and retrievability of records. In accordance with 10 CFR 71.91(a), records of each shipment of radioactive material are maintained for 3 years after the shipment, and quality records are maintained for 3 years beyond the life of the packaging (i.e., following decommissioning and destruction of the packaging) as required by 10 CFR 71.91(d). Users shall maintain records in accordance with 10 CFR 71.91 and their site-approved QA plan, and these records shall be made available upon request.

Table 9.3. Typical quality assurance records

System requirements documents	SARPs
Design drawings	Work requests
Data sheets	Manufacturing and assembly procedures
Design criteria documents	Personnel qualification records
Graded approach results	Operating and maintenance procedures
Equipment specifications	Supplier certification evidence
Design review documentation	Product Information and Control Summary
Design change documentation	Preshipment leak-test records
Test plans and procedures	Offsite fissile material container inspection forms
Test reports	NCRs and log sheets
QA/control manuals	Corrective action reports
Procurement specifications	Quality Certification and Procurement Instructions
Material specifications	Certification data verification work requests
Manufacturing specifications	Certification procedures
Supplier QA program evaluation results	Self-appraisal reports
Audit reports	Surveillance reports
Weld radiographs	Liquid penetrant reports
Prototype data certification	Dimensional inspection results
Packing follow sheets	Maintenance follow sheets
Calibration procedures	Equipment calibration records

9.3.18 Audits

In accordance with Sect. 18 of the QAPP, a comprehensive system of planned and scheduled audits, assessments, and surveillances are conducted using written procedures to: (1) verify compliance with the requirements of all packaging-related activities in accordance with the QAPP; (2) determine the plan's effectiveness; and (3) focus on improving items and processes. The results of each audit report are reviewed, and the managers assigned responsibility for an issue shall ensure that corrective actions addressing the cause are planned, implemented, and tracked to closure. Completion of corrective actions shall be verified. Areas of improvement that are not findings but may warrant strengthening are also considered as potential quality improvements.

The Y-12 Performance Assurance organization is responsible for planning, scheduling, and conducting independent internal audits (assessments). The independent assessment process is primarily designed to focus on the compliance and flow down of contractual requirements, including applicable standards and codes, how requirements are implemented in procedures, and the measurement of implementation effectiveness. Independent assessments are led by a qualified lead assessor and conducted by qualified personnel who are: (1) technically knowledgeable/experienced in the functional area being assessed; (2) independent with no direct responsibilities in the functional area being assessed; and (3) granted organizational freedom and authority to perform an effective assessment. Once the audit is complete and the report has been submitted to the responsible parties, management will review the results and will take appropriate action to resolve any findings.

Management assessments are conducted by members of the line organization or program to evaluate and determine whether packaging-related activities are properly focused on achieving desired results. These assessments serve as a periodic self-analysis tool and include reviewing the processes, systems, and programs that are important to the specified mission, goals, and objectives as well as identifying areas for continuous improvement. Whether compliance-based or performance-based, the process includes provisions to appropriately evaluate all aspects of the Y-12 packaging and transportation

QA program, determine how well the management system meets specified requirements, and assess methods to safely perform packaging-related activities. Management assessments are administered by the Y-12 Performance Assurance organization in compliance with the annual assessment schedule.

Internal surveillances provide monitoring or observation of ongoing packaging-related activities to evaluate compliance with specified requirements. PTE surveillance plans and checklists are developed and executed on a routine basis by personnel who are qualified in surveillance techniques with sufficient authority, technical expertise, and knowledge for the subject area being assessed. The PTE surveillance coordinator provides administrative oversight of the annual surveillance program. These surveillances are documented and identified issues are processed in accordance with the requirements of the Y-12 Issues Management System.

Audits of suppliers are based on the component graded quality category. Category A and B item/service suppliers are audited to determine the adequacy and effectiveness of implementation of the supplier's QA program using a methodology that evaluates processes or activities on the basis of their performance and reviews documentation generated by the supplier and their sub-tier(s). An Evaluated Suppliers List (ESL), which is maintained by the Materials and Suppliers QA organization, identifies suppliers, the commodity for which the evaluation was conducted (if a specific commodity was evaluated), supplier status (i.e., approved or disapproved), any restrictions noted, and the minimum re-evaluation timeframe. To remain active on the ESL, re-evaluations of Category A and B item/service suppliers are primarily performed within 3 years of the effective date designated on the ESL. However, some evaluations are performed annually or when appropriate to ensure that suppliers continue to provide acceptable items and services. Category C and NITS commodities are commercial off-the-shelf items/services, and their suppliers are typically not audited, but supplier-generated paperwork is subject to an in-house quality desk audit before the items are used to ensure their compliance with applicable drawings, specifications, and subcontract requirements.

9.3.19 Software Quality Assurance

Y-12 has developed and implemented computer software programs, including configuration controls, which will improve safety, increase the reliability of packaging operations and data, and support the achievement of programmatic missions. Software controls include verification, validation, and configuration management. Software is used in accordance with the responsibilities and requirements for developing, procuring, implementing, maintaining, and applying computer software as described in Sect. 19 of the QAPP.

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SECTION 9 REFERENCES

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