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 36 kg (Sect. 1.2.3.6) with a decay heat load of 0.4 W (Sect. 1.2.3.7). This decay heat load and the volumes established for the convenience cans, spacers, silicone rubber pads, and the containment vessel void volume are discussed in Sect. 3.1.2 and Appendix 3.6.4. Sections 2 and 3 of this safety analysis report (SAR) also examine the effects of the lightest weight HEU content [2.77 kg (6.11 lb)]. The evaluations in Sects. 2, 3, and 4 have demonstrated that the ES-3100 shipping package with HEU content weight ranging from 2.77 kg (6.11 lb) to 36 kg (79.37 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 = $2.78 \times 10^{-10}\ A_2$ per second
Hypothetical Accident Conditions (HAC)	$R_A = A_2$ in 1 week = $1.65 \times 10^{-6}\ A_2$ 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

Nominal empty weight	15.10 kg (33.29 lb)
Air fill medium temperature at loading	25°C (77°F)
Air fill medium pressure at loading	101.35 kPa (14.70 psia)
Hydrostatic pressure test	1034 ± 34 kPa (150 ± 5) gauge
Helium acceptance leakage rate [a]	$L_T \leq 2.0 \times 10^{-7}$ cm³/s
Air acceptance leakage rate [a]	$L_T \leq 1 \times 10^{-7}$ ref-cm³/s
Air preshipment and O-ring maintenance verification leakage rate	$L_T \leq 1 \times 10^{-4}$ atm-cm³/s

[a] Acceptance leakage testing includes fabrication, periodic (within 12 months of use), and maintenance testing. According to Sect. 2.1 of ANSI N14.5-1997, *leaktight* is defined as an air leakage rate of 1×10^{-7} ref-cm³/s; under the same conditions, this air leakage rate is ~ equal to a helium leakage rate of 2×10^{-7} cm³/s.

The analysis documented in Appendix 4.6.1 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 [3.112×10^{-1} TBq (8.411 Ci)] of the contents occurs 10 years after initial fabrication. When the maximum activity-to-A_2 value (290.26) is reached at ~50 years from material fabrication, the corresponding activity is 3.104×10^{-1} TBq (8.389 Ci). These values have been determined using a maximum of 36 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.

The initial composition of the content contains several isotopes of uranium (Sect. 1.2.3). 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. 1.2.3 has been calculated in Appendix 4.6.1. Since the HEU can be in the form of oxides (UO_2, UO_3, and U_3O_8), UF_4, or metal and alloy, 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.

4.1 DESCRIPTION OF THE CONTAINMENT BOUNDARY

As shown in Table 4.4, the number of A_2s proposed for shipping exceeds 30 but is less than 3000. In accordance with NUREG 1609, the containment vessel is a Category II vessel. Since this vessel may be used for future contents that exceed 3000 A_2, the containment vessel category has been elevated to 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, Division I, Subsection NB and Section IX.

4.1.1 Containment Boundary

The containment boundary consists of the vessel's body, lid assembly, and inner O-ring (Sect. 1, 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 1.4.1). The first method uses a standard 5-in., schedule 40 stainless-steel pipe per ASME SA-312 Type TP304L, a machined flat-head bottom forging per ASME SA-182 Type F304L, and a machined top flange forging per ASME SA-182 Type F304L. The nominal outside diameter of the 5-in. schedule 40 pipe is machined to match the nominal wall thickness of 0.254 cm (0.100 in.). Each of these pieces is joined with full-penetration circumferential weld as shown on sheet 2 of Drawing M2E801580A012 (Appendix 1.4.1). 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. I, Sect. 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-dove-tailed O-ring grooves in the flat face, to provide locations for two 18-8 stainless-steel dowel pins, and to provide the threaded portion for closure using the lid assembly. The second method of fabrication uses forging, flow forming, or metal spinning to create the complete body (flat bottom, cylindrical body, and flange) from a single forged billet or bar with final material properties in accordance with ASME SA-182 Type F304L. Final machining of the top flange area is identically to that of the welded forging method. The lid assembly, which completes the containment boundary structure, consists of a sealing lid, closure nut, and external retaining ring (Drawing M2E801580A014, Appendix 1.4.1). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.4.1) is machined from Type 304 stainless-steel bar with final material properties in accordance with ASME SA-479. The containment vessel closure nut 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-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 containment vessels remain "leaktight" after the conclusion of the test series documented in *Test Report of the ES--3100 Package* (ORNL/NTRC-013, 2004).

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 (Appendix 2.10.1) 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, or tapped holes that penetrate the containment boundary; therefore, the package does not allow continuous venting during transport.

The containment vessel O-rings (Drawing M2E801580A013, Appendix 1.4.1) are manufactured from an ethylene-propylene elastomer in accordance with *Procurement Specification for 70A Durometer Preformed Packing (O-rings)* [OO-PP-986]. These 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, ethylene-propylene rubber (EPDM), 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 about 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 141.22°C (−40 to 286.2°F) of the ES-3100 containment vessel (Table 3.17). In addition to component testing, an ES-3100 full-scale test unit (Test Unit-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 ethylene-propylene elastomer has been verified by testing.

4.1.2 Special Requirements for Plutonium

The highly enriched uranium contents have only trace amount of the transuranic isotopes. Therefore, this section is not applicable to the ES-3100 shipping container.

4.2 GENERAL CONSIDERATIONS

4.2.1. Type A Fissile Packages

The A_2 value of the proposed contents exceed the limits established for Type A packages.

4.2.2 Type B Packages

Requirements

(1) A Type B package, in addition to satisfying the requirements of 10 CFR 71.41–71.47, must be designed, constructed, and prepared for shipment so that under the tests specified in:

(a) Section 71.71 ("Normal conditions of transport"): There would be no loss or dispersal of radioactive contents as demonstrated to a sensitivity of 10^{-6} A_2/h, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging; and

(b) Section 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.

(2) Where mixtures of different radionuclides are present, the provisions of Appendix A, paragraph IV of this part shall apply, except that for ^{85}Kr-85, an effective A_2 value equal to 10 A_2 may be used.

(3) Compliance with the permitted activity release limits of paragraph (a) of this section may not depend on filters or on a mechanical cooling system.

Analysis. The A_2 value calculated for the ES-3100 shipping package has been determined in accordance with Appendix A of 10 CFR 71, documented in Appendix 4.6.1, and uses the proposed isotopic distribution shown in Table 4.3. Table 4.4 summarizes the results from Appendix 4.6.1 for the proposed contents from 0 to 70 years after original production.

Table 4.3. Isotopic mass and weight percent for the HEU contents [a]

Nuclide	Weight percent	Mass (g)
U-232	0.000004	0.001440
U-233	0.600000	216.000000
U-234	2.000000	720.000000
U-235	57.095996	20554.558560
U-236	40.000000	14400.000000
U-238	0.000000	0.000000
Transuranic	0.004000	1.440000
Np-237	0.300000	108.000000
Total	100.000000	36000.000000

[a] Weight percent values of individual isotopes are those that generate the largest activity within the allowable ranges presented in Sect. 1.2.3.

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	3.052e-01	1.250e-03	2.442e+02	3.052e-01	1.195e-03	2.555e+02	3.052e-01	1.056e-03	2.8892e+02
5	3.107e-01	1.266e-03	2.454e+02	3.107e-01	1.211e-03	2.567e+02	3.107e-01	1.071e-03	2.9006e+02
10	3.112e-01	1.267e-03	2.456e+02	3.112e-01	1.212e-03	2.568e+02	3.112e-01	1.072e-03	2.9019e+02
20	3.110e-01	1.266e-03	2.457e+02	3.110e-01	1.210e-03	2.569e+02	3.110e-01	1.072e-03	2.9021e+02
30	3.108e-01	1.264e-03	2.458e+02	3.108e-01	1.209e-03	2.570e+02	3.108e-01	1.071e-03	2.9021e+02
40	3.106e-01	1.263e-03	2.459e+02	3.106e-01	1.208e-03	2.571e+02	3.106e-01	1.070e-03	2.9022e+02
50	3.104e-01	1.262e-03	2.460e+02	3.104e-01	1.207e-03	2.572e+02	3.104e-01	1.069e-03	2.9026e+02
60	3.103e-01	1.261e-03	2.460e+02	3.103e-01	1.206e-03	2.572e+02	3.103e-01	1.069e-03	2.9019e+02
70	3.102e-01	1.261e-03	2.461e+02	3.102e-01	1.206e-03	2.573e+02	3.102e-01	1.069e-03	2.9017e+02

4.3 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT (TYPE B PACKAGES)

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 4.6.1, the A_2 value [1.0693×10^{-3} TBq (2.8900×10^{-2} Ci)] and the maximum content activity-to-A_2 ratio (290.26) used to qualify this package occurs at about 50 years of decay. As previously stated, these values have been determined using a bounding case maximum of 36 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 (Table1.3). The analyses conducted in Appendix 4.6.2 assumes 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 1980) 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, Section 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 all stages of containment verification for the ES-3100 (i.e., design, fabrication, maintenance, periodic and preshipment).

The design, fabrication, maintenance and periodic leakage rate limit is 1×10^{-7} ref-cm^3/s. The pass criteria for the preshipment and O-ring maintenance leakage rate test, which demonstrates correct assembly of the containment vessels, is 1×10^{-4} ref-cm^3/s, which exceeds the requirements given in ANSI N14.5, paragraph 7.6.4. The preshipment, fabrication, maintenance and periodic leakage rate tests are required to be conducted on each containment vessel in accordance with ANSI N14.5 and are specified in Chapters 7 and 8. 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 3.6.4, the bounding case MNOP is 122.63 kPa (17.786 psia). The stresses at the maximum normal operating pressure [21.30 kPa (3.09 psi) gauge] are insignificant compared to the allowable stresses (Table 2.21). O-ring grooves are designed and fabricated in accordance with guidance from the *Parker*

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	4.5337e-03	4.8470e-03	4.3366e-03	4.6424e-03	3.8445e-03	4.1307e-03

[a] The procedure used to calculate the above criteria is shown in Appendix 4.6.2. This data has been extracted from Table 1 in Appendix 4.6.2.

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, Rev. A.1 (Appendix 8.3.1)
Pre-shipment and O-ring seal maintenance (air)	$L_T \leq 1.0 \times 10^{-4}$ ref-cm^3/s	Y51-01-B2-R-074, Rev. A.1 (Appendix 7.5.1)

O-ring Handbook. In accordance with Fig. 3-2 of ORNL/NTRC-013/V1–3, 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), Test Unit-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 using a CALT5 leak tester. This unit recorded a leak rate between the O-rings of 2.4773 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 criteria is documented in the ES-3100 test plan (ORNL/NTRC-013, 2004). 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. Each vessel is then leak tested with either air or helium to $\leq 1 \times 10^{-7}$ ref-cm^3/s or 2×10^{-7} cm^3/s, respectively. 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 evacuated and checked to leak $\leq 1 \times 10^{-4}$ ref-cm^3/s. This leak-test procedure is a pressure rise air leak test prescribed by *DT-Type Shipping Container Leak Test* (Appendix 7.5.1). 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 leakage rate of the containment boundary, before and after testing, was verified to be leaktight.

4.4 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS (TYPE B PACKAGES)

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 that 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 4.6.2 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, Section B.15 examples 13, 27, and 29. Design leakage rate verification testing of the containment boundary (Table 4.8) was conducted on Test Units-1 through -6 and documented in 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 Table 2.21, 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 Test Unit-6. Test Unit-6 was subjected to the test specified by paragraph 10 CFR 71.73(c)(6). After completion of this test, the containment vessel was removed and the

Table 4.7. Regulatory leakage criteria for HAC [a]

Verification activity	Fast absorption		Medium absorption		Slow absorption	
	L_{RA-air} (ref-cm³/s)	L_{RA-He} (cm³/s)	L_{RA-air} (ref-cm³/s)	L_{RA-He} (cm³/s)	L_{RA-air} (ref-cm³/s)	L_{RA-He} (cm³/s)
Design	1.2402e+01	1.1831e+01	1.1863e+01	1.1319e+01	1.0517e+01	1.0041e+00

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

Table 4.8 Containment vessel design verification tests for HAC

Test Type	Test Values	Leakage test procedure
	Design and compliance leakage testing	
Design verification of O-ring seal (air)	$L_T \leq 1.0 \times 10^{-4}$ ref-cm³/s	See ORNL/NTRC-013/V1
Design verification of containment vessel boundary (helium)	$L_T \leq 2.0 \times 10^{-7}$ cm³/s	See ORNL/NTRC-013/V1

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

To verify the entire containment boundary to the leaktight criteria, the containment vessels of Test Units-1 through -5 were helium leak tested using the procedure shown in the test report (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 Test Unit-4, which had been first subjected to the testing in accordance with 10 CFR 71.71. The maximum recorded helium leak rate for any of these containment vessels was 2.0×10^{-7} cm³/s after 20 min of testing on Test Unit-4 as documented on pages 90 and 91 of ORNL/NTRC-013/V1. Test Units-2 and -5 displayed some unusual pulsing action during leak testing. The peak amplitude changed after adding helium in a manner expected for diffusion through the O-rings rather than a rise immediately following the addition of helium that would indicate a leak to the outside of the containment vessel. This is further discussed and graphically presented on pages 88 through 91 of ORNL/NTRC-013/V1. These measured leakage rates verify that the containment vessels are leaktight in accordance with ANSI N14.5-1997. Therefore, the containment boundary of the ES-3100 package was maintained during the HAC testing.

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

4.5 LEAKAGE RATE TESTS FOR TYPE B PACKAGES

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

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

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

4.6 APPENDICES

Appendix	Description
4.6.1	DETERMINATION OF A_2 FOR THE ES-3100 PACKAGE WITH HEU CONTENTS
4.6.2	CALCULATION OF THE ES-3100 CONTAINMENT VESSEL'S REGULATORY REFERENCE AIR LEAKAGE RATES

APPENDIX 4.6.1

DETERMINATION OF A_2 FOR THE ES-3100 PACKAGE WITH HEU CONTENTS

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APPENDIX 4.6.1

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) ($\leq 10^{-6} \cdot A_2$/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. 1.2.3. The weight percents shown in Table 1 are the ones that generate the largest activity within the known weight percent ranges. 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 oxides, compounds, and metal pieces. 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	0.001440
U-233	0.600000	216.000000
U-234	2.000000	720.000000
U-235	57.095996	20554.558560
U-236	40.000000	14400.000000
U-238	0.000000	0.000000
Transuranic	0.004000	1.440000
Np-237	0.300000	108.000000
Total	100.000000	36000.000000

[a] Weight percents values of individual isotopes are those that generate the largest activity within the allowable ranges presented in Sect. 1.2.3.

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* [Kocher 1981]) creates isotopes that will accumulate enough activity to exceed their respective criteria for limited quantities (*Shippers—General Requirements for Shipments and Packagings* [49 CFR 173.423], Table A-7, "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 (Parks 1984). 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 50^{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.

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 1.0693×10^{-3} TBq (2.890×10^{-2} Ci) in conjunction with the maximum activity-to-A_2 value ratio of 290.26 occurs after about 50 years of decay for the assumed maximum 36 kg of HEU.

Table 2. Mass values of parent and daughter products for 36 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	1.4472e-10	1.1160e-09	8.3520e-09	2.6136e-08	5.7960e-08	1.0584e-07	1.7280e-07	2.5848e-07
Pb-212	0.0000e+00	1.8576e-08	2.0736e-08	1.9296e-08	1.7424e-08	1.5840e-08	1.4314e-08	1.2960e-08	1.1736e-08
Bi-210	0.0000e+00	8.9280e-14	6.8832e-13	5.1192e-12	1.6128e-11	3.5712e-11	6.5376e-11	1.0656e-10	1.5912e-10
Bi-212	0.0000e+00	1.7568e-09	1.9584e-09	1.8288e-09	1.6560e-09	1.4976e-09	1.3579e-09	1.2298e-09	1.1131e-09
Po-210	0.0000e+00	2.4624e-12	1.9008e-11	1.4112e-10	4.4496e-10	9.8640e-10	1.8072e-09	2.9304e-09	4.3920e-09
Rn-222	0.0000e+00	1.4472e-12	5.7888e-12	2.3112e-11	5.1984e-11	9.2160e-11	1.4400e-10	2.0664e-10	2.8152e-10
Ra-223	0.0000e+00	6.9474e-12	2.6310e-11	9.5784e-11	1.9630e-10	3.1860e-10	4.5837e-10	6.1047e-10	7.7080e-10
Ra-224	0.0000e+00	1.6128e-07	1.8000e-07	1.6848e-07	1.5264e-07	1.3795e-07	1.2485e-07	1.1304e-07	1.0238e-07
Ra-225	0.0000e+00	2.1600e-08	4.6656e-08	9.3312e-08	1.3997e-07	1.8641e-07	2.3328e-07	2.7864e-07	3.2616e-07
Ra-226	0.0000e+00	2.2536e-07	9.0000e-07	3.6000e-06	8.0640e-06	1.4328e-05	2.2392e-05	3.2184e-05	4.3776e-05
Ra-228	0.0000e+00	2.1024e-13	7.0560e-13	2.1024e-12	3.7008e-12	5.3568e-12	7.0272e-12	8.7120e-12	1.0397e-11
Ac-225	0.0000e+00	1.7280e-08	3.1536e-08	6.3072e-08	9.4608e-08	1.2593e-07	1.5746e-07	1.8878e-07	2.2032e-07
Ac-227	0.0000e+00	4.9125e-09	1.8684e-08	6.7624e-08	1.3874e-07	2.2610e-07	3.2476e-07	4.3165e-07	5.4470e-07
Ac-228	0.0000e+00	2.5632e-17	8.6112e-17	2.5632e-16	4.5072e-16	6.5376e-16	8.5824e-16	1.0627e-15	1.2686e-15
Th-227	0.0000e+00	1.1408e-11	4.3370e-11	1.5724e-10	3.2271e-10	5.2414e-10	7.5435e-10	1.0031e-09	1.2682e-09
Th-228	0.0000e+00	3.1392e-05	3.4992e-05	3.2688e-05	2.9664e-05	2.6784e-05	2.4336e-05	2.2032e-05	1.9872e-05
Th-229	0.0000e+00	6.4800e-03	9.2448e-03	1.8468e-02	2.7648e-02	3.6936e-02	4.6008e-02	5.5296e-02	6.4584e-02
Th-230	0.0000e+00	1.0008e-02	1.9944e-02	3.9960e-02	5.9904e-02	7.9920e-02	1.0008e-01	1.1952e-01	1.3968e-01
Th-231	0.0000e+00	8.3657e-08	8.3657e-08	8.3657e-08	8.3657e-08	8.3657e-08	8.3657e-08	8.3657e-08	8.3657e-08
Th-232	0.0000e+00	2.0880e-03	4.1904e-03	8.3808e-03	1.2571e-02	1.6704e-02	2.0880e-02	2.5200e-02	2.9376e-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	9.9484e-05	1.9917e-04	3.9876e-04	5.9814e-04	7.9546e-04	9.9484e-04	1.1942e-03	1.3915e-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	1.4400e-03	1.3680e-03	1.3032e-03	1.1808e-03	1.0685e-03	9.6768e-04	8.7696e-04	7.9344e-04	7.1856e-04
U-233	2.1600e+02	2.1599e+02	2.1599e+02	2.1598e+02	2.1597e+02	2.1596e+02	2.1595e+02	2.1594e+02	2.1594e+02
U-234	7.2000e+02	7.1999e+02	7.1998e+02	7.1996e+02	7.1994e+02	7.1992e+02	7.1990e+02	7.1988e+02	7.1986e+02
U-235	2.0555e+04	2.0555e+04	2.0555e+04	2.0555e+04	2.0555e+04	2.0555e+04	2.0555e+04	2.0555e+04	2.0555e+04
U-236	1.4400e+04	1.4400e+04	1.4400e+04	1.4400e+04	1.4400e+04	1.4400e+04	1.4400e+04	1.4400e+04	1.4400e+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.	1.4400e+00	1.4400e+00	1.4400e+00	1.4400e+00	1.4400e+00	1.4400e+00	1.4400e+00	0.0000e+00	0.0000e+00
Np-237	1.0800e+02	1.0800e+02	1.0800e+02	1.0800e+02	1.0800e+02	1.0800e+02	1.0800e+02	0.0000e+00	0.0000e+00
Total	**3.6000e+04**	**3.6000e+04**	**3.6000e+04**	**3.6000e+04**	**3.6000e+04**	**3.6000e+04**	**3.6000e+04**	**3.6000e+04**	**3.6000e+04**

Table 3. A_2 value calculation for 36 kg HEU for fast absorption uranium at 50 years

Isotope	Mass at 50 years (g)	Specific activity (TBq/g)	Activity (TBq)	A_2 (TBq)	f(i) (TBq/TBq)	f(i) / A_2 (1/TBq)
Pb-210	1.0584e-07	2.8000e+00	2.9635e-07	5.0000e-02	9.5477e-07	1.9095e-05
Pb-212	1.4314e-08	5.1000e+04	7.2999e-04	2.0000e-01	2.3519e-03	1.1759e-02
Bi-210	6.5376e-11	4.6000e+03	3.0073e-07	6.0000e-01	9.6887e-07	1.6148e-06
Bi-212	1.3579e-09	5.4000e+05	7.3328e-04	6.0000e-01	2.3624e-03	3.9374e-03
Po-210	1.8072e-09	1.7000e+02	3.0722e-07	2.0000e-02	9.8980e-07	4.9490e-05
Rn-222	1.4400e-10	5.7000e+03	8.2080e-07	4.0000e-03	2.6444e-06	6.6110e-04
Ra-223	4.5837e-10	1.9000e+03	8.7090e-07	7.0000e-03	2.8058e-06	4.0083e-04
Ra-224	1.2485e-07	5.9000e+03	7.3660e-04	2.0000e-02	2.3731e-03	1.1866e-01
Ra-225	2.3328e-07	1.5000e+03	3.4992e-04	4.0000e-03	1.1274e-03	2.8184e-01
Ra-226	2.2392e-05	3.7000e-02	8.2850e-07	3.0000e-03	2.6692e-06	8.8974e-04
Ra-228	7.0272e-12	1.0000e+01	7.0272e-11	2.0000e-02	2.2640e-10	1.1320e-08
Ac-225	1.5746e-07	2.1000e+03	3.3067e-04	6.0000e-03	1.0653e-03	1.7756e-01
Ac-227	3.2476e-07	2.7000e+00	8.7686e-07	9.0000e-05	2.8250e-06	3.1389e-02
Ac-228	8.5824e-16	8.4000e+04	7.2092e-11	5.0000e-01	2.3226e-10	4.6453e-10
Th-227	7.5435e-10	1.1000e+03	8.2979e-07	5.0000e-03	2.6734e-06	5.3467e-04
Th-228	2.4336e-05	3.0000e+01	7.3008e-04	1.0000e-03	2.3521e-03	2.3521e+00
Th-229	4.6008e-02	7.9000e-03	3.6346e-04	5.0000e-04	1.1710e-03	2.3420e+00
Th-230	1.0008e-01	7.6000e-04	7.6061e-05	1.0000e-03	2.4505e-04	2.4505e-01
Th-231	8.3657e-08	2.0000e+04	1.6731e-03	2.0000e-02	5.3904e-03	2.6952e-01
Th-232	2.0880e-02	4.0000e-09	8.3520e-11	1.0000e+75	2.6908e-10	2.6908e-85
Pa-231	9.9484e-04	1.7000e-03	1.6912e-06	4.0000e-04	5.4487e-06	1.3622e-02
U-232	8.7696e-04	8.3000e-01	7.2788e-04	1.0000e-02	2.3450e-03	2.3450e-01
U-233	2.1595e+02	3.6000e-04	7.7743e-02	9.0000e-02	2.5047e-01	2.7830e+00
U-234	7.1990e+02	2.3000e-04	1.6558e-01	9.0000e-02	5.3345e-01	5.9272e+00
U-235	2.0555e+04	8.0000e-08	1.6444e-03	1.0000e+75	5.2977e-03	5.2977e-78
U-236	1.4400e+04	2.4000e-06	3.4560e-02	1.0000e+75	1.1134e-01	1.1134e-76
Transuranic	1.4400e+00	1.5000e-02	2.1600e-02	9.0000e-05	6.9590e-02	7.7322e+02
Np-237	1.0800e+02	2.6000e-05	2.8080e-03	2.0000e-03	9.0467e-03	4.5233e+00
Total Mass =	3.6000e+04	$\sum$ Act. =	3.1039e-01		$\sum$ f(i) / A_2 =	7.9254e+02

$$A_2(\text{mixture}) = \frac{1}{\sum f(i) / A_2} = \frac{1}{7.9254 \times 10^2 \ (1/\text{Tbq})} = 1.2618 \times 10^{-3} \text{ TBq}$$

Table 4. A_2 value calculation for 36 kg HEU for medium absorption uranium at 50 years

Isotope	Mass at 50 years (g)	Specific activity (TBq/g)	Activity (TBq)	A_2' (TBq)	f(i) (TBq/TBq)	f(i) / A_2 (1/TBq)
Pb-210	1.0584e-07	2.8000e+00	2.9635e-07	5.0000e-02	9.5477e-07	1.9095e-05
Pb-212	1.4314e-08	5.1000e+04	7.2999e-04	2.0000e-01	2.3519e-03	1.1759e-02
Bi-210	6.5376e-11	4.6000e+03	3.0073e-07	6.0000e-01	9.6887e-07	1.6148e-06
Bi-212	1.3579e-09	5.4000e+05	7.3328e-04	6.0000e-01	2.3624e-03	3.9374e-03
Po-210	1.8072e-09	1.7000e+02	3.0722e-07	2.0000e-02	9.8980e-07	4.9490e-05
Rn-222	1.4400e-10	5.7000e+03	8.2080e-07	4.0000e-03	2.6444e-06	6.6110e-04
Ra-223	4.5837e-10	1.9000e+03	8.7090e-07	7.0000e-03	2.8058e-06	4.0083e-04
Ra-224	1.2485e-07	5.9000e+03	7.3660e-04	2.0000e-02	2.3731e-03	1.1866e-01
Ra-225	2.3328e-07	1.5000e+03	3.4992e-04	4.0000e-03	1.1274e-03	2.8184e-01
Ra-226	2.2392e-05	3.7000e-02	8.2850e-07	3.0000e-03	2.6692e-06	8.8974e-04
Ra-228	7.0272e-12	1.0000e+01	7.0272e-11	2.0000e-02	2.2640e-10	1.1320e-08
Ac-225	1.5746e-07	2.1000e+03	3.3067e-04	6.0000e-03	1.0653e-03	1.7756e-01
Ac-227	3.2476e-07	2.7000e+00	8.7686e-07	9.0000e-05	2.8250e-06	3.1389e-02
Ac-228	8.5824e-16	8.4000e+04	7.2092e-11	5.0000e-01	2.3226e-10	4.6453e-10
Th-227	7.5435e-10	1.1000e+03	8.2979e-07	5.0000e-03	2.6734e-06	5.3467e-04
Th-228	2.4336e-05	3.0000e+01	7.3008e-04	1.0000e-03	2.3521e-03	2.3521e+00
Th-229	4.6008e-02	7.9000e-03	3.6346e-04	5.0000e-04	1.1710e-03	2.3420e+00
Th-230	1.0008e-01	7.6000e-04	7.6061e-05	1.0000e-03	2.4505e-04	2.4505e-01
Th-231	8.3657e-08	2.0000e+04	1.6731e-03	2.0000e-02	5.3904e-03	2.6952e-01
Th-232	2.0880e-02	4.0000e-09	8.3520e-11	1.0000e+75	2.6908e-10	2.6908e-85
Pa-231	9.9484e-04	1.7000e-03	1.6912e-06	4.0000e-04	5.4487e-06	1.3622e-02
U-232	8.7696e-04	8.3000e-01	7.2788e-04	7.0000e-03	2.3450e-03	3.3500e-01
U-233	2.1595e+02	3.6000e-04	7.7743e-02	2.0000e-02	2.5047e-01	1.2523e+01
U-234	7.1990e+02	2.3000e-04	1.6558e-01	2.0000e-02	5.3345e-01	2.6672e+01
U-235	2.0555e+04	8.0000e-08	1.6444e-03	1.0000e+75	5.2977e-03	5.2977e-78
U-236	1.4400e+04	2.4000e-06	3.4560e-02	2.0000e-02	1.1134e-01	5.5672e+00
Transuranic	1.4400e+00	1.5000e-02	2.1600e-02	9.0000e-05	6.9590e-02	7.7322e+02
Np-237	1.0800e+02	2.6000e-05	2.8080e-03	2.0000e-03	9.0467e-03	4.5233e+00
Total Mass =	3.6000e+04	∑ Act. =	3.1039e-01		∑ f(i) / A_2 =	8.2869e+02

$$A_2(\text{mixture}) = \frac{1}{\sum f(i) / A_2} = \frac{1}{8.2869 \times 10^{2}\ (1/\text{Tbq})} = 1.2067 \times 10^{-3}\ \text{TBq}$$

Table 5. A_2 value calculation for 36 kg HEU for slow absorption uranium at 50 years

Isotope	Mass at 50 years (g)	Specific activity (TBq/g)	Activity (TBq)	A_2 (TBq)	f(i) (TBq/TBq)	f(i) / A_2 (1/TBq)
Pb-210	1.0584e-07	2.8000e+00	2.9635e-07	5.0000e-02	9.5477e-07	1.9095e-05
Pb-212	1.4314e-08	5.1000e+04	7.2999e-04	2.0000e-01	2.3519e-03	1.1759e-02
Bi-210	6.5376e-11	4.6000e+03	3.0073e-07	6.0000e-01	9.6887e-07	1.6148e-06
Bi-212	1.3579e-09	5.4000e+05	7.3328e-04	6.0000e-01	2.3624e-03	3.9374e-03
Po-210	1.8072e-09	1.7000e+02	3.0722e-07	2.0000e-02	9.8980e-07	4.9490e-05
Rn-222	1.4400e-10	5.7000e+03	8.2080e-07	4.0000e-03	2.6444e-06	6.6110e-04
Ra-223	4.5837e-10	1.9000e+03	8.7090e-07	7.0000e-03	2.8058e-06	4.0083e-04
Ra-224	1.2485e-07	5.9000e+03	7.3660e-04	2.0000e-02	2.3731e-03	1.1866e-01
Ra-225	2.3328e-07	1.5000e+03	3.4992e-04	4.0000e-03	1.1274e-03	2.8184e-01
Ra-226	2.2392e-05	3.7000e-02	8.2850e-07	3.0000e-03	2.6692e-06	8.8974e-04
Ra-228	7.0272e-12	1.0000e+01	7.0272e-11	2.0000e-02	2.2640e-10	1.1320e-08
Ac-225	1.5746e-07	2.1000e+03	3.3067e-04	6.0000e-03	1.0653e-03	1.7756e-01
Ac-227	3.2476e-07	2.7000e+00	8.7686e-07	9.0000e-05	2.8250e-06	3.1389e-02
Ac-228	8.5824e-16	8.4000e+04	7.2092e-11	5.0000e-01	2.3226e-10	4.6453e-10
Th-227	7.5435e-10	1.1000e+03	8.2979e-07	5.0000e-03	2.6734e-06	5.3467e-04
Th-228	2.4336e-05	3.0000e+01	7.3008e-04	1.0000e-03	2.3521e-03	2.3521e+00
Th-229	4.6008e-02	7.9000e-03	3.6346e-04	5.0000e-04	1.1710e-03	2.3420e+00
Th-230	1.0008e-01	7.6000e-04	7.6061e-05	1.0000e-03	2.4505e-04	2.4505e-01
Th-231	8.3657e-08	2.0000e+04	1.6731e-03	2.0000e-02	5.3904e-03	2.6952e-01
Th-232	2.0880e-02	4.0000e-09	8.3520e-11	1.0000e+75	2.6908e-10	2.6908e-85
Pa-231	9.9484e-04	1.7000e-03	1.6912e-06	4.0000e-04	5.4487e-06	1.3622e-02
U-232	8.7696e-04	8.3000e-01	7.2788e-04	1.0000e-03	2.3450e-03	2.3450e+00
U-233	2.1595e+02	3.6000e-04	7.7743e-02	6.0000e-03	2.5047e-01	4.1745e+01
U-234	7.1990e+02	2.3000e-04	1.6558e-01	6.0000e-03	5.3345e-01	8.8908e+01
U-235	2.0555e+04	8.0000e-08	1.6444e-03	1.0000e+75	5.2977e-03	5.2977e-78
U-236	1.4400e+04	2.4000e-06	3.4560e-02	6.0000e-03	1.1134e-01	1.8557e+01
Transuranic	1.4400e+00	1.5000e-02	2.1600e-02	9.0000e-05	6.9590e-02	7.7322e+02
Np-237	1.0800e+02	2.6000e-05	2.8080e-03	2.0000e-03	9.0467e-03	4.5233e+00
Total Mass =	3.6000e+04	$\sum$ Act. =	3.1039e-01		$\sum$ f(i) / A_2 =	9.3515e+02

$$A_2(\text{mixture}) = \frac{1}{\sum f(i) / A_2} = \frac{1}{9.3515 \times 10^2 \text{ (1/Tbq)}} = 1.0693 \times 10^{-3} \text{ TBq}$$

Table 6. Activity, A_2 value, and activity-to-A_2 ratio for the enriched uranium contents [a]

Year	Activity (TBq)	A_2-Mixture (TBq)			Activity/A_2		
		Fast	Medium	Slow	Fast	Medium	Slow
0	3.0517e-01	1.2495e-03	1.1945e-03	1.0562e-03	244.23	255.48	288.93
5	3.1069e-01	1.2659e-03	1.2105e-03	1.0711e-03	245.43	256.67	290.07
10	3.1117e-01	1.2670e-03	1.2115e-03	1.0723e-03	245.60	256.85	290.19
20	3.1101e-01	1.2657e-03	1.2104e-03	1.0717e-03	245.71	256.95	290.20
30	3.1076e-01	1.2643e-03	1.2091e-03	1.0708e-03	245.80	257.02	290.21
40	3.1055e-01	1.2630e-03	1.2078e-03	1.0700e-03	245.89	257.12	290.24
50	3.1039e-01	1.2618e-03	1.2067e-03	1.0693e-03	246.00	257.22	290.26
60	3.1026e-01	1.2612e-03	1.2062e-03	1.0692e-03	246.01	257.22	290.19
70	3.1017e-01	1.2606e-03	1.2057e-03	1.0689e-03	246.05	257.26	290.17

[a] The A_2, total activity, and activity-to-A_2 ratio values used in Appendix 4.6.2 are shaded.

APPENDIX 4.6.2

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

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APPENDIX 4.6.2

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 36 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.

$A_2 = 1.0693 \times 10^{-3}$ TBq, (2.8900×10^{-2} Ci). Table 6 (Appendix 4.6.1)

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)
$= 1.0693 \times 10^{-3} \times 2.78 \times 10^{-10}$ TBq/s,
$R_N = 2.9728 \times 10^{-13}$ TBq/s, (8.0346×10^{-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)
$= 1.0693 \times 10^{-3} \times 1.65 \times 10^{-6}$ (TBq/s),
$= 1.7644 \times 10^{-9}$ TBq/s, (4.7687×10^{-8} 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).

For HEU content:

TSA	=	TotA / m,	
TSA	=	3.1039×10^{-1} (TBq) / 36,000 (g),	Table 6 (Appendix 4.6.1)
TSA	=	8.6220×10^{-6} TBq/g.	
ρ_P	=	9×10^{-6} g/cm^3.	The maximum density of powder aerosols in the fill gas

For any packaging arrangement:

C_N	=	activity per unit volume of medium that could escape from the containment system (TBq/cm^3).
C_N	=	TSA $\times \rho_P$,
	=	8.6220×10^{-6} (TBq/g) $\times 9 \times 10^{-6}$ (g/cm^3),
C_N	=	7.7598×10^{-11} 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
C_A	=	7.7598×10^{-11} 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),	
L_N	=	R_N / C_N,	ANSI N14.5-1997 (Eq. 3)
L_N	=	2.9728×10^{-13} (TBq/s) / 7.7598×10^{-11} (TBq/cm^3),	
L_N	=	3.8310×10^{-3} cm^3/s.	

L_A	=	maximum allowable leakage rate for the medium for HAC (TBq/cm^3),
L_A	=	R_A / C_A,
L_A	=	1.7644×10^{-9} (TBq/s) / 7.7598×10^{-11} (TBq/cm^3),
L_A	=	2.2738×10^{1} 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 maximum temperatures and pressure combinations from Table 3.16 and Table 5 in Appendix 3.6.5.

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 36 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 4.6.1). As calculated in Appendix 4.6.1, the A_2 value and the maximum content activity-to-A_2 ratio used to qualify this package occur at about 50 years of decay and are 1.0693×10^{-3} TBq (2.8900×10^{-2} Ci) and 290.26, 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 are sealed inside the containment vessel in an environmentally controlled area. The ES-3100 package has been analyzed thermally in Sect. 3; it was evaluated at a maximum NCT gas temperature of 87.81°C (190.06°F) [100°F with solar insolation] and a maximum adjusted HAC gas temperature of 123.85°C (254.93°F).

The following analysis determines the maximum allowable O-ring seal air reference leakage rate for both NCT and HAC. The ANSI N14.5-1997 recommended method using a straight circular tube to model the leakage path is applied. Using this "standard" leakage hole model permits the calculation of equivalent reference leakage rates from which leak-test requirements can be established.

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

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

Find the maximum pressure and temperature in the containment vessel:

Converting the temperature to degrees Kelvin:

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

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

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

Converting the pressures from psia to atmospheres:

$$P_N = P\ (psia) / 14.696\ (psia/atm),$$ where P is the pressure in Sect. 3.4.2
$$P_N = 17.786\ (psia) / 14.696\ (psia/atm),$$ NCT
$$P_N = 1.2103\ atm.$$

$$P_A = P\ (psia) / 14.696\ (psia/atm),$$ where P is the pressure in Sect. 3.5.3
$$P_A = 44.585\ (psia) / 14.696\ (psia/atm),$$ HAC
$$P_A = 3.0338\ atm.$$

NCT Leakage Hole Diameter for the HEU Content

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

Input data for NCT with air fill gas:

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

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

The average pressure is:

P_a	=	$(P_u + P_d)/2$,	
	=	$(1.2103 + 0.2382) / 2$,	
P_a	=	0.7242 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	=	$(1.2103)(\text{atm})\ (3.8310 \times 10^{-3})(\text{cm}^3/\text{s})$,	
Q	=	4.6366×10^{-3} atm-cm^3/s.	NCT mass-like leakage rate
Q	=	$P_a L_a$,	(Eq. B1)
L_a	=	$Q / P_a = 4.6366 \times 10^{-3}\ (\text{atm-cm}^3/\text{s}) / (0.7242)(\text{atm})$,	
L_a	=	6.4022×10^{-3} 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)
L_a	=	$(F_c + F_m)\ (1.2103 - 0.2382)$,	
L_a	=	$(0.9721)\ (F_c + F_m)$ cm^3/s.	
F_c	=	$(2.49 \times 10^6)\ D^4 / (a\ \mu)\ (\text{cm}^3/\text{atm-s})$,	(Eq. B3)
F_c	=	$(2.49 \times 10^6)\ D^4 / (\ (0.3531)\ (0.02141)\ )$,	
F_c	=	$(3.2943 \times 10^8)\ D^4$ cm^3/atm-s.	
F_m	=	$(3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)\ (\text{cm}^3/\text{atm-s})$,	(Eq. B4)
F_m	=	$(3.81 \times 10^3)\ D^3\ (360.96 / 29)^{.5} / (\ (0.3531)\ (0.7242)\ )$,	
F_m	=	$(5.2571 \times 10^4)\ D^3$ cm^3/atm-s.	

From the mass-like leakage calculation:

L_a	=	6.4022×10^{-3} cm^3/s.	NCT average leakage rate

Find the leakage hole diameter that sets:

$$L_2 = L_a.$$

Using the equations:

L_2	=	$(0.9721)\ (F_c + F_m)$ cm^3/s,
F_c	=	$(3.2943 \times 10^8)\ D^4$ cm^3/atm-s,
F_m	=	$(5.2571 \times 10^4)\ D^3$ 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 $L_a = 6.4022 \times 10^{-3}$ cm³/s. NCT average leakage rate

Diameter	F_c	F_m	L_2	L_a / L_2
1.00000e-03	3.29430e-04	5.25710e-05	3.71343e-04	1.72407e+01
2.04933e-03	5.81044e-03	4.52461e-04	6.08817e-03	1.05158e+00
2.07547e-03	6.11261e-03	4.69996e-04	6.39895e-03	1.00051e+00
2.07573e-03	6.11574e-03	4.70176e-04	6.40217e-03	1.00001e+00
2.07574e-03	6.11577e-03	4.70178e-04	6.40220e-03	1.00000e+00

The NCT leakage hole diameter for the HEU oxide content:

$D = 2.0757 \times 10^{-3}$ 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 $D = 2.0757 \times 10^{-3}$ 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	=	2.0757×10^{-3} 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-mole,	Molecular weight of air
μ	=	0.0185 cP,	Viscosity of air at reference temperature

Calculate P_a:

$$P_a = (P_u + P_d) / 2,$$
$$= (1.0 + 0.01) / 2,$$
$$P_a = 0.505 \text{ atm.}$$ NCT average pressure

F_c = $(2.49 \times 10^6)\ D^4 / (a\ \mu)\ (cm^3/atm\text{-}s)$, (Eq. B3)
F_c = $(2.49 \times 10^6)\ (2.0757 \times 10^{-3})^4 / (\ (0.3531)\ (0.0185)\ )$,
F_c = $(3.8122 \times 10^8)\ (2.0757 \times 10^{-3})^4$,
F_c = $7.0772 \times 10^{-3}\ cm^3/atm\text{-}s$.

F_m = $(3.81 \times 10^3)\ D^3\ (\ T / M\ )^{.5} / (\ a\ P_a\ )\ (cm^3/atm\text{-}s)$, (Eq. B4)
F_m = $(3.81 \times 10^3)\ (2.0757 \times 10^{-3})^3\ (298 / 29)^{.5} / (\ (0.3531)\ (0.505)\ )$,
F_m = $(6.8501 \times 10^4)\ (2.0757 \times 10^{-3})^3$,
F_m = $6.1264 \times 10^{-4}\ cm^3/atm\text{-}s$.

L_u = $(F_c + F_m)\ (P_u - P_d)\ (P_a / P_u)\ (cm^3/s)$, (Eq. B5)
L_u = $(7.0772 \times 10^{-3} + 6.1264 \times 10^{-4})(cm^3/atm\text{-}s)\ (1.0 - 0.01)(atm)\ (0.505 / 1.0)$,
L_u = $(7.6848 \times 10^{-3})(cm^3/atm\text{-}s)\ (0.49995)(atm)$,
L_u = $3.8445 \times 10^{-3}\ cm^3/s$.

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

$L_{RN,Air}$ = 3.8445×10^{-3} 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-mole, Molecular weight of helium
μ = 0.0198 cP. Viscosity of helium at temperature

F_c = $(2.49 \times 10^6)\ D^4 / (a\ \mu\ )\ (cm^3/atm\text{-}s)$, (Eq. B3)
F_c = $(2.49 \times 10^6)\ (2.0757 \times 10^{-3})^4 / (\ (0.3531)\ (0.0198)\ )$,
F_c = $(3.5619 \times 10^8)\ (2.0757 \times 10^{-3})^4$,
F_c = $6.6125 \times 10^{-3}\ cm^3/atm\text{-}s$.

F_m = $(3.81 \times 10^3)\ D^3\ (T / M)^{.5} / (a\ P_a)\ (cm^3/atm\text{-}s)$, (Eq. B4)
F_m = $(3.81 \times 10^3)\ (2.0757 \times 10^{-3})^3\ (\ 298 / 4\ )^{.5} / (\ (0.3531)\ (0.505)\ )$,
F_m = $(1.8444 \times 10^5)\ (1.9674 \times 10^{-3})^3$,
F_m = $1.6496 \times 10^{-3}\ cm^3/atm\text{-}s$.

L_u = $(F_c + F_m)\ (P_u - P_d)\ (P_a / P_u)\ (cm^3/s)$, (Eq. B5)
L_u = $(6.6125 \times 10^{-3} + 1.6496 \times 10^{-3})(cm^3/atm\text{-}s)\ (1.0 - 0.01)(atm)\ (0.505 / 1.0)$,
L_u = $(8.262 \times 10^{-3})(cm^3/atm\text{-}s)\ (0.49995)(atm)$,
L_u = $4.1307 \times 10^{-3}\ cm^3/s$.

The allowable leakage rate using helium for leak testing is:

$L_{RN,He}$ = $4.1307 \times 10^{-3}\ cm^3/s$. 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	=	22.738 cm^3/s,	Maximum exit leakage
P_u	=	3.0338 atm,	Upstream pressure = 44.585 psia
P_d	=	1.0 atm,	Downstream pressure
T	=	397.000 K,	Fill gas temperature = 254.93°F
μ	=	0.02297 cP,	Viscosity of air at temperature
M	=	29 g/g-mole,	Molecular weight of air
a	=	0.3531 cm.	Leak path length, 0.139-in. O-ring section diameter

$P_a = (P_u + P_d) / 2$

$= (3.0701 + 1.0) / 2,$ HAC average pressure

$P_a = 2.0169$ atm.

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

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

$L_u = L_A.$ HAC leakage

$Q = (3.0338)(atm)\ (22.738)(cm^3/s),$

$Q = 68.9825\ atm\text{-}cm^3/s.$ HAC mass-like leakage rate

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

$L_a = Q / P_a$

$= 68.9825\ (atm\text{-}cm^3/s) / (2.0169)(atm),$

$L_a = 34.2022\ cm^3/s.$ HAC average leakage rate

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

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

$L_a = (F_c + F_m)\ (3.0338 - 1.0),$

$L_a = 2.0338\ (F_c + F_m)\ cm^3/s.$

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

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

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

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

$F_m = (3.81 \times 10^3)\ D^3\ (397.00 / 29)^{.5} / ((0.3531)\ (2.0169)),$

$F_m = (1.9796 \times 10^4)\ D^3\ cm^3/atm\text{-}s.$

From the mass-like leakage calculation:

$L_a = 34.2022\ cm^3/s.$ HAC average leakage rate

Find the leakage hole diameter that sets:

$L_2 = L_a.$

Using the equations:

$$L_2 = 2.0338\ (F_c + F_m)\ cm^3/s,$$
$$F_c = (3.0706 \times 10^8)\ D^4\ cm^3/atm\text{-}s,$$
$$F_m = (1.9796 \times 10^4)\ D^3\ cm^3/atm\text{-}s.$$

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 HAC:

D_2 = 0.01 (cm), and solve for L_a = 34.304 (cm^3/s). HAC average leakage rate

Diameter	F_c	F_m	L_2	L_a / L_2
1.0000e-02	3.0706e+00	1.9796e-02	6.2852e+00	5.4417e+00
1.5325e-02	1.6937e+01	7.1251e-02	3.4592e+01	9.8874e-01
1.5281e-02	1.6745e+01	7.0644e-02	3.4200e+01	1.0001e+00
1.5282e-02	1.6746e+01	7.0648e-02	3.4202e+01	1.0000e+00

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

$D = 1.5282 \times 10^{-2}$ cm. HAC diameter

HAC Reference Air Leakage Rate for HEU Content

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

Input data for HAC reference air leakage rate:

D	=	1.5282×10^{-2} cm,	From the HAC of transport
a	=	0.3531 cm,	Leak path length, 0.139-in. O-ring section diameter
P_u	=	1.0 atm,	Upstream pressure
P_d	=	0.01 atm,	Downstream pressure
T	=	298 K,	Fill gas temperature, 77°F
M	=	29 g/g-mole,	Molecular weight of air
μ	=	0.0185 cP.	Viscosity at temperature

Calculate P_a:

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

$$F_c = (2.49 \times 10^6)\, D^4 / (a\, \mu)\ (\text{cm}^3/\text{atm-s}), \qquad \text{(Eq. B3)}$$
$$F_c = (2.49 \times 10^6)(1.5282 \times 10^{-2})^4 / ((0.3531)(0.0185)),$$
$$F_c = (3.8122 \times 10^8)(1.5282 \times 10^{-2})^4,$$
$$F_c = 2.0791 \times 10^1 \text{ cm}^3/\text{atm-s}.$$

$$F_m = (3.81 \times 10^3)\, D^3 (T/M)^{.5} / (a\, P_a)\ (\text{cm}^3/\text{atm-s}), \qquad \text{(Eq. B4)}$$
$$F_m = (3.81 \times 10^3)(1.5282 \times 10^{-2})^3 (298/29)^{.5} / ((0.3531)(0.505)),$$
$$F_m = (6.8501 \times 10^4)(1.5282 \times 10^{-2})^3,$$
$$F_m = 2.4446 \times 10^{-1} \text{ cm}^3/\text{atm-s}.$$

$$L_u = (F_c + F_m)(P_u - P_d)(P_a / P_u)\ (\text{cm}^3/\text{s}), \qquad \text{(Eq. B5)}$$
$$L_u = (2.0791 \times 10^1 + 2.4446 \times 10^{-1})(\text{cm}^3/\text{atm-s})(1.0 - 0.01)(\text{atm})(0.505/1.0),$$
$$L_u = (2.1036 \times 10^1)(\text{cm}^3/\text{atm-s})(0.49995)(\text{atm}),$$
$$L_u = 1.0517 \times 10^1 \text{ cm}^3/\text{s}.$$

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

$$L_{RA,Air} = 1.0517 \times 10^1 \text{ ref-cm}^3/\text{s}. \qquad \text{for HEU oxide content}$$

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

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

$$F_c = (2.49 \times 10^6)\, D^4 / (a\, \mu)\ (\text{cm}^3/\text{atm-s}), \qquad \text{(Eq. B3)}$$
$$F_c = (2.49 \times 10^6)(1.5282 \times 10^{-2})^4 / ((0.3531)(0.0198)),$$
$$F_c = (3.5619 \times 10^8)(1.5282 \times 10^{-2})^4,$$
$$F_c = 1.9426 \times 10^1 \text{ cm}^3/\text{atm-s}.$$

$$F_m = (3.81 \times 10^3)\, D^3 (T/M)^{.5} / (a\, P_a)\ (\text{cm}^3/\text{atm-s}), \qquad \text{(Eq. B4)}$$
$$F_m = (3.81 \times 10^3)(1.5282 \times 10^{-2})^3 (298/4)^{.5} / ((0.3531)(0.505)),$$
$$F_m = (1.8444 \times 10^5)(1.5282 \times 10^{-2})^3,$$
$$F_m = 6.5824 \times 10^{-1} \text{ cm}^3/\text{atm-s}.$$

$$L_u = (F_c + F_m)(P_u - P_d)(P_a / P_u)\ (\text{cm}^3/\text{s}), \qquad \text{(Eq. B5)}$$
$$L_u = (1.9426 \times 10^1 + 6.5824 \times 10^{-1})(\text{cm}^3/\text{atm-s})(1.0 - 0.01)(\text{atm})(0.505/1.0),$$
$$L_u = (2.0084 \times 10^1)(\text{cm}^3/\text{atm-s})(0.49995)(\text{atm}),$$
$$L_u = 1.0041 \times 10^1 \text{ cm}^3/\text{s}.$$

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

$$L_{RA,He} = 1.0041 \times 10^1 \text{ cm}^3/\text{s}. \qquad \text{HAC helium test value}$$

Table 1. Regulatory leakage criteria for 36 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	4.5676e-03	4.8821e-03	1.2495e+01	1.1919e+01
	5	4.5453e-03	4.8590e-03	1.2434e+01	1.1861e+01
	10	4.5421e-03	4.8556e-03	1.2425e+01	1.1853e+01
	20	4.5401e-03	4.8536e-03	1.2420e+01	1.1848e+01
	30	4.5385e-03	4.8519e-03	1.2415e+01	1.1844e+01
	40	4.5367e-03	4.8501e-03	1.2411e+01	1.1839e+01
	50	4.5348e-03	4.8481e-03	1.2405e+01	1.1834e+01
	60	4.5346e-03	4.8479e-03	1.2405e+01	1.1834e+01
	70	4.5337e-03	4.8470e-03	1.2402e+01	1.1831e+01
Medium absorption	0	4.3669e-03	4.6739e-03	1.1946e+01	1.1398e+01
	5	4.3466e-03	4.6528e-03	1.1891e+01	1.1345e+01
	10	4.3437e-03	4.6498e-03	1.1883e+01	1.1338e+01
	20	4.3420e-03	4.6480e-03	1.1878e+01	1.1333e+01
	30	4.3406e-03	4.6465e-03	1.1874e+01	1.1330e+01
	40	4.3391e-03	4.6449e-03	1.1870e+01	1.1326e+01
	50	4.3373e-03	4.6431e-03	1.1865e+01	1.1321e+01
	60	4.3373e-03	4.6431e-03	1.1865e+01	1.1321e+01
	70	4.3366e-03	4.6424e-03	1.1863e+01	1.1319e+01
Slow absorption	0	3.8624e-03	4.1492e-03	1.0565e+01	1.0087e+01
	5	3.8472e-03	4.1334e-03	1.0524e+01	1.0048e+01
	10	3.8455e-03	4.1316e-03	1.0519e+01	1.0044e+01
	20	3.8453e-03	4.1314e-03	1.0519e+01	1.0043e+01
	30	3.8453e-03	4.1314e-03	1.0519e+01	1.0043e+01
	40	3.8450e-03	4.1312e-03	1.0518e+01	1.0042e+01
	50	3.8445e-03	4.1307e-03	1.0517e+01	1.0041e+01
	60	3.8455e-03	4.1316e-03	1.0519e+01	1.0044e+01
	70	3.8458e-03	4.1320e-03	1.0520e+01	1.0044e+01

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) 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 Code of Federal Regulations (CFR) 71 and 49 CFR 173.

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, spacer assemblies to support and position the convenience cans, the ES-3100 containment vessel, and an insulation-filled drum as shown in Appendix 1.4.1. None of the package materials are specifically designed for shielding gamma rays (photons), the primary contributor to external package dose rates. For HAC, it is assumed that the containment vessel and content remain intact, but all exterior packaging materials 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% ^{235}U and is assumed to contain 0.6% ^{233}U, 0.3% ^{237}Np, 40 ppb (parts per billion) ^{232}U, and 40 ppm (parts per million) plutonium.

5.1.2 Summary Table of Maximum Radiation Levels

The results of these shielding model evaluations, summarized in Tables 5.1 and 5.2, are the calculated dose rates at the locations indicated. The uncertainty associated with the results is one standard deviation of the mean (expressed as a percentage of the mean) of the Monte Carlo calculated results. As shown from the dose rates in the tables and the discussion in Sect. 5.3, the shielding evaluation demonstrates that the package meets all dose-rate limits for both NCT and HAC for all proposed contents.

5.2 SOURCE SPECIFICATION

The source for the calculated dose rates is from the decay and fission of the radioactive isotope contents. The isotopic content used in the shielding calculations is shown in Table 5.3. This composition was chosen to represent all proposed package contents. The primary contribution to the dose rates in Tables 5.1 and 5.2 is from decay of the ^{232}U isotope, for any mix of the other isotopes. The photon and neutron source spectra are given in Tables 5.4 and 5.5. In Table 5.4, the group 6 photons are from the decay chain of ^{232}U. Group 18 photons were omitted from the source for the dose rate calculation due to negligible contribution from photons at these energies. 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, rev. 6). The uranium metal source is assumed to be the same as that for the oxides, per unit HEU mass. Spontaneous fission neutrons are included in

Table 5.1. Calculated external dose rates for the ES-3100 package with 36 kg of HEU metal contents (mrem/h)[a]

	Drum surface			One meter from surface[b]		
	Side	Top	Bottom	Side	Top	Bottom
			NCT			
Photon	64.260 ± 0.6%	26.593 ± 4.4%	54.020 ± 3.8%	4.296 ± 0.3%	0.956 ± 0.9%	0.980 ± 0.9%
Neutron[c]	1.647 ± 3.3%	0.135 ± 3.4%	3.441 ± 3.4%	0.060 ± 3.3%	0.025 ± 3.3%	0.074 ± 3.3%
Total	65.907 ± 0.6%	26.728 ± 4.4%	57.461 ± 3.6%	4.356 ± 0.3%[d]	0.981 ± 0.9%	1.054 ± 0.9%
Limit[e]	200	200	200	10	10	10
			HAC			
Photon	NA[f]	NA	NA	7.460 ± 0.3%	1.108 ± 0.8%	1.281 ± 0.9%
Neutron[c]	NA	NA	NA	0.026 ± 3.1%	0.007 ± 3.1%	0.017 ± 3.2%
Total	NA	NA	NA	7.486 ± 0.3%	1.115 ± 0.8%	1.298 ± 0.9%
Limit[g]	NA	NA	NA	1000	1000	1000

[a] MORSE-CGA Monte Carlo code results (ORNL-6174).
[b] Drum for NCT and containment vessel for HAC.
[c] Includes secondary photon dose rate (<1% of neutron dose rates).
[d] The radiation shielding transport index is 4.4.
[e] 10 CFR 71.47 and 49 CFR 173.441.
[f] Not applicable.
[g] 10 CFR 71.51.

Table 5.2. Calculated external dose rates for the ES-3100 package with 24 kg of HEU oxide contents (mrem/h)[a]

	Drum surface			One meter from surface[b]		
	Side	Top	Bottom	Side	Top	Bottom
			NCT			
Photon	54.735 ± 0.5%	10.113 ± 2.0%	38.318 ± 1.5%	3.283 ± 0.3%	0.853 ± 0.7%	1.012 ± 0.7%
Neutron[c]	0.966 ± 1.3%	0.079 ± 2.6%	2.020 ± 3.1%	0.035 ± 1.3%	0.015 ± 1.7%	0.044 ± 1.6%
Total	55.701 ± 0.5%	10.192 ± 2.0%	40.338 ± 1.4%	3.318 ± 0.3%[d]	0.868 ± 0.7%	1.056 ± 0.7%
Limit[e]	200	200	200	10	10	10
			HAC			
Photon	NA[f]	NA	NA	5.583 ± 0.4%	1.004 ± 1.1%	1.123 ± 1.0%
Neutron[c]	NA	NA	NA	0.024 ± 0.7%	0.009 ± 0.9%	0.017 ± 0.9%
Total	NA	NA	NA	5.607 ± 0.4%	1.013 ± 1.1%	1.140 ± 1.0%
Limit[g]	NA	NA	NA	1000	1000	1000

[a] MORSE-CGA Monte Carlo code results (ORNL-6174).
[b] Drum for NCT and containment vessel for HAC.
[c] Includes secondary photon dose rate (<1% of neutron dose rates).
[d] The radiation shielding transport index is 3.4.
[e] 10 CFR 71.47 and 49 CFR 173.441.
[f] Not applicable.
[g] 10 CFR 71.51.

Table 5.5 spectra. Induced fission neutrons and secondary photons are included in the dose rate calculations. Details of the source specifications and use in the dose rate calculations are given in the Sect. 5 appendices.

5.3 DOSE RATE ANALYSIS MODELS

The photon and neutron sources from the radioactive content as described in the previous section, and listed in Tables 5.4 and 5.5, are input into the MORSE Monte Carlo radiation code to calculate the ES-3100 external package dose rates given in Tables 5.1 and 5.2. The packaging component drawings are shown in Appendix 1.4.1. A cylindrical model of this packaging and proposed HEU material content is shown in Fig. 5.1 and Table 5.6. The dose rate detector locations relative to the package model exterior are listed in Table 5.7. The materials and densities used in the calculational model are given in Table 5.8. These models are described in more detail in the input data and other information given in the Sect. 5 appendices. Kaolite is an insulation material, and Cat 277-4 is a criticality control material. Additional information on these two materials can be found in Sects. 1, 2, and 6.

Two proposed package contents have been analyzed: (1) 36 kg of HEU metal and (2) 24 kg of HEU oxide. The analyses of these models have been performed in a manner that covers other proposed contents, not analyzed, in an equivalent or conservative manner. Due to the simple source and packaging geometry, there are no radiation streaming paths from the source toward the package exterior. Each of the two models is analyzed for both photon and neutron sources, and for both NCT and HAC.

In addition to the analyses for the dose rates shown in Tables 5.1 and 5.2, many preliminary and auxiliary calculations were made for each model to ensure that all proposed content loadings in the ES-3100 vessel were covered. These extra analyses are necessary since only a content mass limit is specified for each shipment, and various geometric configurations must be investigated to determine if the maximum external package dose rates have been found. 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, etc. The dose rate values shown in Tables 5.1 and 5.2 are all at or near possible maximum values for the package specifications given in Sect. 1. All package models investigated, including the preliminary and auxiliary models, are conservative.

Table 5.3. Radioisotope specification for all ES-3100 package analysis source calculations with HEU content and other nuclides per HEU unit weight

Isotope	wt %
^{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	0.300000
Pu [a]	0.004000

[a] Nominal weapons-grade at 40 ppm uranium by weight—see Appendix 5.5.1.

Table 5.4. Photon source for one gram of HEU for all contents[a]

Group number	Energy range (MeV)	Source (photons/s)
1	10.00–8.00	4.310×10^{-6}
2	8.00–6.50	2.478×10^{-5}
3	6.50–5.00	1.596×10^{-4}
4	5.00–4.00	4.905×10^{-4}
5	4.00–3.00	2.102×10^{-3}
6	3.00–2.50	1.011×10^{-4}
7	2.50–2.00	1.008×10^{-1}
8	2.00–1.66	$9.761 \times 10^{+1}$
9	1.66–1.33	$1.101 \times 10^{+3}$
10	1.33–1.00	$3.426 \times 10^{+2}$
11	1.00–0.80	$1.595 \times 10^{+3}$
12	0.80–0.60	$4.620 \times 10^{+3}$
13	0.60–0.40	$1.533 \times 10^{+4}$
14	0.40–0.30	$3.075 \times 10^{+4}$
15	0.30–0.20	$2.415 \times 10^{+4}$
16	0.20–0.10	$7.600 \times 10^{+4}$
17	0.10–0.05	$9.066 \times 10^{+4}$
18[b]	0.05–0.01	-
Total		$2.548 \times 10^{+5}$

[a] ORIGEN-S code results at 10½ years decay.
[b] Omitted in the dose rate calculations.

Table 5.5. Neutron source for one gram of HEU for all contents[a]

Group number	Energy range (MeV)	Source in uranium metal and oxide (neutrons/s)
1	$2.00 \times 10^{+1} - 6.43 \times 10^{+0}$	6.614×10^{-5}
2	$6.43 \times 10^{+0} - 3.00 \times 10^{+0}$	2.107×10^{-2}
3	$3.00 \times 10^{+0} - 1.85 \times 10^{+0}$	5.841×10^{-2}
4	$1.85 \times 10^{+0} - 1.40 \times 10^{+0}$	1.593×10^{-2}
5	$1.40 \times 10^{+0} - 9.00 \times 10^{-1}$	9.334×10^{-3}
6	$9.00 \times 10^{-1} - 4.00 \times 10^{-1}$	3.219×10^{-3}
7	$4.00 \times 10^{-1} - 1.00 \times 10^{-1}$	5.304×10^{-4}
8[b]	$1.00 \times 10^{-1} - 1.70 \times 10^{-2}$	0
Total		1.086×10^{-1}

[a] ORIGEN-S results at 15 years decay.
[b] Source is zero for Groups 9–27.

Table 5.6. Geometric data for the shielding analysis models of the ES-3100 shipping package as shown in Fig. 5.1 for NCT. Each item is modeled as a cylinder or cylindrical shell. The content volume not identified (HEU metal photon shell model interior) is modeled as void. All materials interior to the containment vessel except the HEU material content are omitted. Each of the four content models is placed in the packaging to create four separate calculational models. All dimensions are in centimeters. For HAC, all material external to the containment vessel is omitted.

	Material	Outer radius	Base reference height[a]	Height[b] (h)	Side wall thickness	Top thickness	Bottom thickness
Content							
HEU metal shell photon model	HEU	6.35	11.195	76.2	0.6639	-	-
HEU metal neutron model	HEU	6.35	11.195	15.1003	-	-	-
Oxide photon model	UO_2	6.35	11.195	63.5	-	-	-
Oxide neutron model	UO_2	6.35	11.195	17.2864	-	-	-
Packaging (identical for all models)							
Inner vessel gap	void	6.4008	11.195	76.2	0.0508	-	-
ES-3100 containment vessel[c]	SS304[e]	6.6548	10.56	77.47	0.254	0.635	0.635
Outer vessel gap	void	7.9248	10.56	77.47	1.27	-	-
Inner Cat 277-4 liner	SS304	8.0748	10.56	77.47	0.15	-	-
Criticality control material	Cat 277-4	10.9196	10.56	77.47	2.8448	-	-
Outer Cat 277-4 liner	SS304	11.0696	10.26	77.92	0.15	0.15	0.3
Upper insulation	Kaolite[d]	23.0275	88.18	19.385	-	-	-
Base and radial insulation	Kaolite	23.0275	0.26	87.92	11.9579	-	10
Drum	SS304	23.1775	0	107.715	0.15	0.15	0.26

[a] Measured from the lower drum base.
[b] Vessel interior content (and gap) height varies with density to preserve content mass.
[c] Upper flange and lid detail omitted.
[d] Modeled as void.
[e] 304 stainless steel

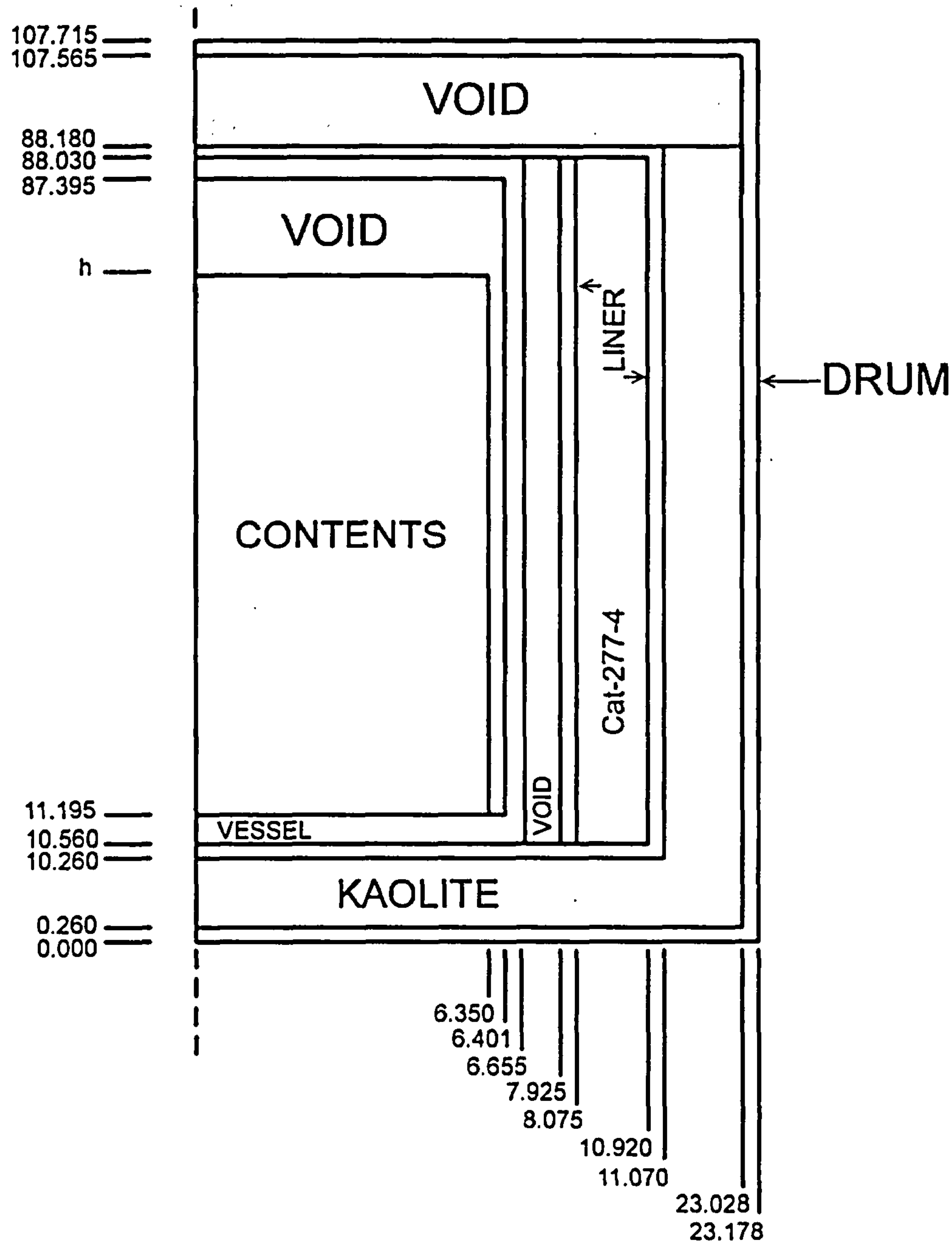


Fig. 5.1. Cylindrical calculational model of the ES-3100 shipping package for NCT. See Tables 5.6–5.8 for data on the contents, materials, and detector locations (not to scale; all dimensions are in centimeters). For HAC, all material external to the containment vessel is omitted.

Table 5.7. Detector locations relative to the drum for NCT and to the containment vessel for HAC

	Radius (cm)	H[a] (cm)
NCT detectors		
Side surface[b]	24.1775	49.2950
Top surface	0.0000	108.7150
Bottom surface	0.0000	-1.0000
Side 1 meter[b]	123.1775	49.2950
Top 1 meter	0.0000	207.7150
Bottom 1 meter	0.0000	-100.0000
HAC detectors		
Side 1 meter[b]	106.6548	49.2950
Top 1 meter	0.0000	188.0300
Bottom 1 meter	0.0000	-89.4400

[a] Height above drum base.
[b] Surface side location is at the axial mid-point of the content; values shown are for the first content in Table 5.6.

5.3.1 Packaging Model Conservative Features

Several conservative features applying to all content models are included in the packaging model. All material dimensions, thicknesses, and densities for the packaging are modeled at or less than specified or nominal values. All non-cylindrical detail has been omitted from the shielding models (see packaging drawings in Appendix 1.4.1). All minor items, such as the silicone rubber pads supporting the ES-3100 containment vessel, have been omitted. It was determined from preliminary analysis that the maximum axial external dose rates would occur relative to the package lower surface. All contents were modeled to contact the containment vessel lower surface, and the upper containment vessel geometry, containment vessel lid, and upper packaging, insulation, lids, covers, etc., were conservatively simplified and/or modeled as void (see Fig. 5.1).

All models of the vessel interior contain HEU material content only. All convenience cans, spacers, content wrappings, covers, supports, etc., are omitted. All contents are modeled as cylinders or cylindrical shells with the base resting on the lower vessel 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. However, the calculated dose rates from the models used will always exceed those from a model where the geometry is expanded so the can mass loadings are not exceeded and the internal vessel hardware is included. All the general, conservative items relative to the ES-3100 package shielding model are applied to each individual content model.

Table 5.8. Shielding model material specifications for the ES-3100 package with HEU content. Only the two principal uranium isotopes are used in the dose rate calculations. The uranium oxide density varies with the geometric model volume to preserve the 24-kg mass.

Material	Density (g/cm^3)	Constitute	Weight percent	Atomic density (atoms/barn-cm)
Uranium metal	18.82	^{235}U	95.00	4.582×10^{-2}
		^{238}U	5.00	2.381×10^{-3}
UO_2	10.960[a]	O	11.98	4.941×10^{-2}
		^{235}U	83.62	2.349×10^{-2}
		^{238}U	4.40	1.221×10^{-3}
Stainless steel	7.92	Cr	19.00	1.743×10^{-2}
		Ni	9.50	7.721×10^{-3}
		Fe	69.50	5.936×10^{-2}
		Mn	2.00	1.736×10^{-3}
Cat 277-4	1.682	H	4.62	4.642×10^{-2}
		^{10}B	0.79	8.002×10^{-4}
		^{11}B	3.44	3.168×10^{-3}
		C	1.51	1.274×10^{-3}
		O	60.00	3.798×10^{-2}
		Mg	0.38	1.584×10^{-4}
		Al	21.16	7.944×10^{-3}
		Si	1.32	4.760×10^{-4}
		S	0.15	4.739×10^{-5}
		Na	0.13	5.728×10^{-5}
		Ca	6.18	1.562×10^{-3}
		Fe	0.32	5.804×10^{-5}
Kaolite	0.321	O	40.43	4.888×10^{-3}
		Na	1.45	1.219×10^{-4}
		Mg	7.86	6.251×10^{-4}
		Al	5.58	3.998×10^{-4}
		Si	16.12	1.110×10^{-3}
		Ca	23.40	1.129×10^{-3}
		Fe	5.16	1.786×10^{-4}

[a] Theoretical density— a density of 2.984 g/cm^3 is used in the Table 5.6 geometric model for photons.

5.3.2 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. Some of these models violate, in a conservative manner, the volume capacity of a convenience can. The cans and spacers are omitted from the models.

The photon model for the dose rates shown in Table 5.1 is that given for the first content item in Table 5.6 (the HEU metal shell). Here, the content is a cylindrical shell the same height as the containment vessel model (76.2 cm). The inner radius of the shell, 5.6861 cm, was used to preserve the 36 kg HEU metal at 18.82 g/cm^3 for an outer radius of 6.35 cm. This case corresponds to a three-can loading configuration with a maximum of 12 kg in each 25.4-cm (10-in.) tall can.

Several 36-kg HEU metal cylindrical shell photon dose rate models were evaluated at lesser heights than the containment vessel inside height (in each case the shell wall thickness was adjusted to preserve the mass). The 1-m side photon dose rate in Table 5.1 is the calculated value for the entire analysis that gave the largest overall fraction of the regulatory limit, 43% of the 10-mrem/h limit. There was some increase in the side surface (not 1-m) photon dose at lesser shell heights. At ~50 cm content height, the maximum side surface dose rate for the shell model was calculated to be 68 mrem/h, 34% of the regulatory limit. This geometry would approximate a 12-kg loading in each of the 8.75-in. cans. The maximum calculated axial surface dose rate of 70 mrem/h was at the bottom drum surface for a shell height of 25 cm and inner radius of 4.0 cm, a gross conservative violation of an actual can loading.

The cylindrical shell representation of the HEU metal content is a convenient, conservative model for multiple possible loading configurations inside the vessel. Some other, more complicated, geometric radial models were also analyzed. The radial geometric cross-sections of these models are shown schematically in Fig. 5.2:

a. The cylindrical shell as described above.

b. A vertical flat plate across the center of the vessel. The maximum calculated photon package surface dose rate for a plate of dimensions 1.9766 cm × 12.7 cm × 76.2 cm was 63 mrem/h.

c. A cylindrical hemi-shell. The maximum calculated package surface photon dose rate was 69 mrem/h for an outer radius of 6.35 cm, an inner radius of 4.0436 cm, and a height of 50.8 cm.

d. A single solid rod placed against the side wall of the vessel. The maximum calculated package surface dose rate for a rod of radius 3.0966 cm and a height of 63.5 cm was 48 mrem/h.

e. A cylindrical segment (the shape a liquid would assume in a horizontal vessel). The maximum calculated package surface dose rate was calculated to be 71 mrem/h for a radius of 6.35 cm, an inner flat surface 11.495 cm across, and a height of 63.5 cm.

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. It may be possible to devise other geometric configurations that could produce slightly higher dose rates. However, it can be said with

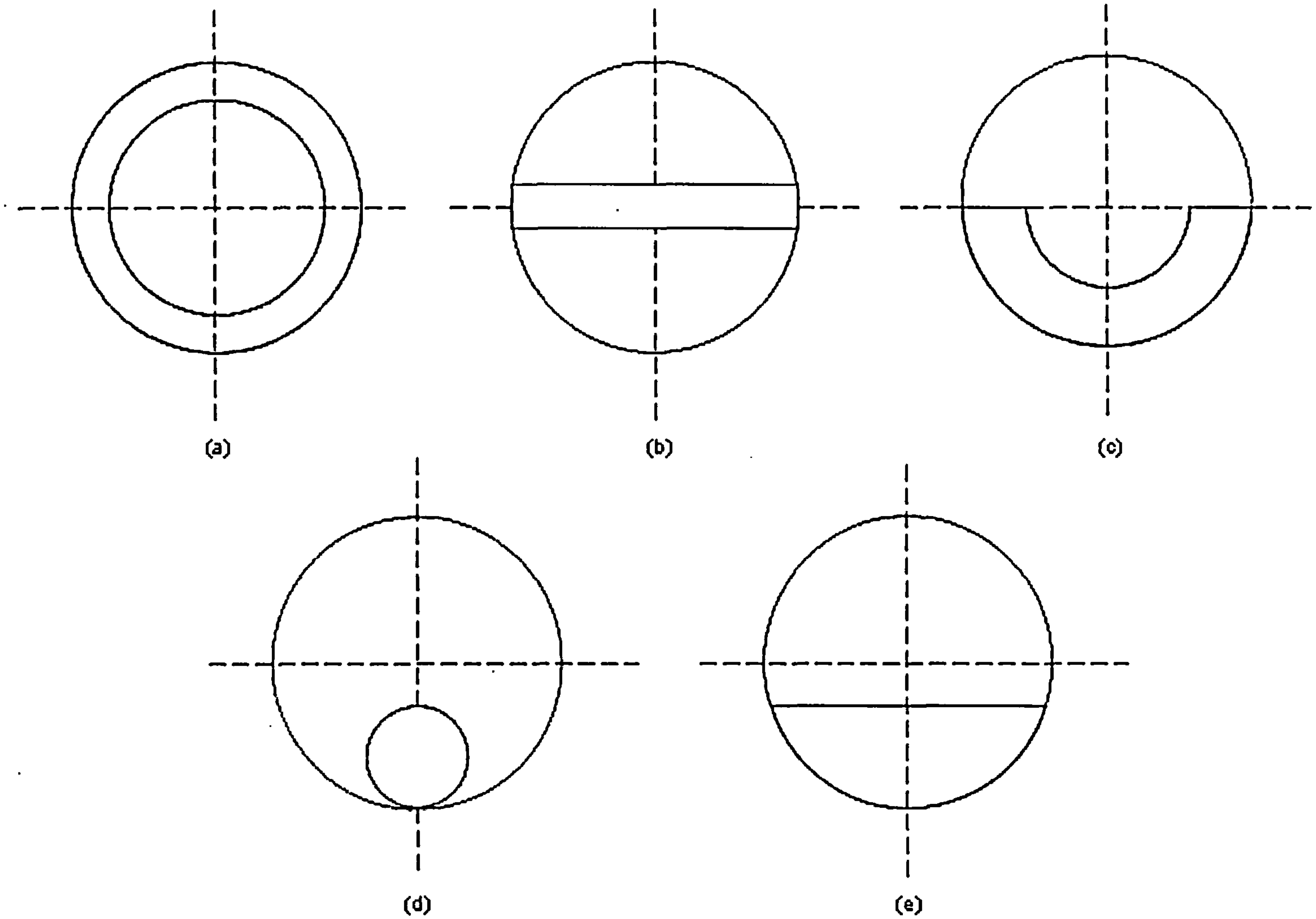


Fig. 5.2. ES-3100 HEU metal content radial (top view) geometric models. The 36-kg mass is conserved for each case. Detector locations were adjusted both vertically and radially from those given in Table 5.7 in the search for maximum external package dose rates for each case.

some certainty that the calculated photon dose rates for 36-kg HEU metal content defined in Table 5.3 should never exceed 75 mrem/h on the package surface, 5 mrem/h at one meter, and 10 mrem/h for HAC.

5.3.3 Neutron model for 36-kg HEU metal content

In the model for the neutron dose rates for the 36-kg HEU contents, it was assumed that all the uranium was a solid cylinder at the bottom of the vessel. The neutron results in Table 5.1 are from this configuration. This is a gross, conservative violation of a convenience can capacity, and no further investigation was made due to the low neutron dose rates obtained from this conservative model relative to the photon results.

5.3.4 Photon model for 24-kg HEU oxide content

A package photon dose rate calculation model was created to apply to 24 kg HEU oxide for all three common uranium oxides—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 spacers and it is represented by a solid cylinder of oxide resting on the vessel 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. In the dose rate calculations, the partial density of oxygen was set to zero, so that the analysis conservatively applies to all three oxides without regard to variations in the oxygen density. The photon dose rates in Table 5.2 are for a cylinder height of 63.5 cm. The 1-m dose rates are slightly higher for 76.2 cm height, and the surface values are slightly higher for a 50.8 cm height. The bottom dose rates approach the side values in Table 5.2 when the cylinder is compressed to the UO_2 theoretical density at the vessel bottom. From the various analyses, it can be stated that no calculated HEU oxide photon dose rates should exceed 60 mrem/h on the package surface, 4 mrem/h at one meter, and 8 mrem/h for HAC.

5.3.5 Neutron model for 24-kg HEU oxide content

The neutron model for the calculated values shown in Table 5.2 was for a solid cylinder of UO_2 at the containment vessel bottom. The density was 10.96 g/cm^3 and the height was 17.286 cm.

5.4 SHIELDING EVALUATION

Several computer programs were used in the shielding evaluation. These included the ORIGEN-S computer code, the CSASN analysis module, the ICE-S computer code, and the MORSE-CGA computer code. ORIGEN-S, CSASN, and ICE-S are parts of the SCALE code. MORSE-CGA is a stand-alone code. Brief descriptions of the programs are presented below.

1. ORIGEN-S 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. CSASN is a sequence of codes for performing resonance processing of neutron cross sections using the SCALE modules BONAMI-S and NITAWL-S.

3. ICE-S is a SCALE module used to format a cross-section library for MORSE-CGA.

4. MORSE-CGA is a general-purpose Monte Carlo code that treats multidimensional neutron, photon, and coupled problems in either a forward or an adjoint mode. Sources and detectors may be defined through user-supplied subroutines. Model definition is facilitated by combinatorial array geometry. Dose rates are calculated by the SAMBO analysis module.

Dose rates were calculated at the detector locations in Table 5.7 by converting the calculated photon and neutron fluxes using the American National Standards Institute (ANSI) 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.

The results of these shielding model evaluations, summarized in Tables 5.1 and 5.2, are the calculated dose rates at the locations indicated. As shown from the dose rates in the tables and the discussion in Sect. 5.3, the shielding evaluation demonstrates that the package meets all dose-rate limits for both NCT and HAC. The shielding analyses were done in a conservative manner applicable to all proposed ES-3100 package contents listed in Sect. 1.2.3.

Table 5.9. ANSI standard photon flux-to-dose-rate conversion factors

Group number	Energy (MeV)	Factor (mrem/h)/(photons/s/cm^2)
1	10.00–8.00	8.771×10^{-3}
2	8.00–6.50	7.478×10^{-3}
3	6.50–5.00	6.374×10^{-3}
4	5.00–4.00	5.413×10^{-3}
5	4.00–3.00	4.622×10^{-3}
6	3.00–2.50	3.959×10^{-3}
7	2.50–2.00	3.468×10^{-3}
8	2.00–1.66	3.019×10^{-3}
9	1.66–1.33	2.627×10^{-3}
10	1.33–1.00	2.205×10^{-3}
11	1.00–0.80	1.832×10^{-3}
12	0.80–0.60	1.522×10^{-3}
13	0.60–0.40	1.172×10^{-3}
14	0.40–0.30	8.759×10^{-4}
15	0.30–0.20	6.306×10^{-4}
16	0.20–0.10	3.833×10^{-4}
17	0.10–0.05	2.669×10^{-4}
18	0.05–0.01	9.347×10^{-4}

Table 5.10. ANSI standard neutron flux-to-dose-rate conversion factors

Group number	Energy (MeV)	Factor (mrem/h)/(neutrons/s/cm²)
1	$2.00 \times 10^{+1} - 6.43 \times 10^{+0}$	1.4916×10^{-1}
2	$6.43 \times 10^{+0} - 3.00 \times 10^{+0}$	1.4464×10^{-1}
3	$3.00 \times 10^{+0} - 1.85 \times 10^{+0}$	1.2701×10^{-1}
4	$1.85 \times 10^{+0} - 1.40 \times 10^{+0}$	1.2811×10^{-1}
5	$1.40 \times 10^{-0} - 9.00 \times 10^{-1}$	1.2977×10^{-1}
6	$9.00 \times 10^{-1} - 4.00 \times 10^{-1}$	1.0281×10^{-1}
7	$4.00 \times 10^{-1} - 1.00 \times 10^{-1}$	5.1183×10^{-2}
8	$1.00 \times 10^{-1} - 1.70 \times 10^{-2}$	1.2319×10^{-2}
9	$1.70 \times 10^{-2} - 3.00 \times 10^{-3}$	3.8365×10^{-3}
10	$3.00 \times 10^{-3} - 5.50 \times 10^{-4}$	3.7247×10^{-3}
11	$5.50 \times 10^{-4} - 1.00 \times 10^{-4}$	4.0150×10^{-3}
12	$1.00 \times 10^{-4} - 3.00 \times 10^{-5}$	4.2926×10^{-3}
13	$3.00 \times 10^{-5} - 1.00 \times 10^{-5}$	4.4744×10^{-3}
14	$1.00 \times 10^{-5} - 3.05 \times 10^{-6}$	4.5676×10^{-3}
15	$3.05 \times 10^{-6} - 1.77 \times 10^{-6}$	4.5581×10^{-3}
16	$1.77 \times 10^{-6} - 1.30 \times 10^{-6}$	4.5185×10^{-3}
17	$1.30 \times 10^{-6} - 1.13 \times 10^{-6}$	4.4879×10^{-3}
18	$1.13 \times 10^{-6} - 1.00 \times 10^{-6}$	4.4665×10^{-3}
19	$1.00 \times 10^{-6} - 8.00 \times 10^{-7}$	4.4345×10^{-3}
20	$8.00 \times 10^{-7} - 4.00 \times 10^{-7}$	4.3271×10^{-3}
21	$4.00 \times 10^{-7} - 3.25 \times 10^{-7}$	4.1975×10^{-3}
22	$3.25 \times 10^{-7} - 2.25 \times 10^{-7}$	4.0976×10^{-3}
23	$2.25 \times 10^{-7} - 1.00 \times 10^{-7}$	3.8390×10^{-3}
24	$1.00 \times 10^{-7} - 5.00 \times 10^{-8}$	3.6748×10^{-3}
25	$5.00 \times 10^{-8} - 3.00 \times 10^{-8}$	3.6748×10^{-3}
26	$3.00 \times 10^{-8} - 1.00 \times 10^{-8}$	3.6748×10^{-3}
27	$1.00 \times 10^{-8} - 1.00 \times 10^{-11}$	3.6748×10^{-3}

5.5 APPENDICES

Appendix	Descriptions
5.5.1	ORIGEN INPUT DATA FROM TABLE 5.3
5.5.2	CSASN AND ICE INPUT FROM TABLE 5.8
5.5.3	MORSE ROUTINES AND INPUT DATA

APPENDIX 5.5.1

ORIGEN INPUT DATA FROM TABLE 5.3

APPENDIX 5.5.1

ORIGEN INPUT DATA FROM TABLE 5.3

This file is for generation of the photon spectra in Table 5.4 and the metal and oxide neutron data in Table 5.5. The concentration for each isotope is given based on 1 g of HEU.

```
#origen
0$$ 6 13 a8 26 e
1$$ 1 t
master photon
3$$ 21 0 1 -88 6 a16 2 a33 18
4** a4 1-70 t
35$$ 0 t
56$$ 0 10 a13 13 5 3 a17 2 e
57** 0 e t
es3100 uranium metal and oxides
one gram HEU
60** 8 9 10 10.5 11 12 15 20 40 50
65$$ a7 1 a25 1 a28 1 a31 1 a49 1 e
73$$ 922320 922340 922350 922360 922380
     922330 942380 942390 932370
     942400 942410 942420 952410
74** 0.4000-07 .020000 0.92000 .010000 0.04399996
     6.00-03 8.00-09 3.7032-05 0.003
     2.60-06 2.24-07 1.60-08 1.20-07
75$$ 2 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 0 0
83** 10+6 8+6 6.5+6 5+6 4+6 3+6 2.5+6 2+6 1.66+6 1.33+6 1+6 .8+6
     .6+6 .4+6 .3+6 .2+6 .1+6 .05+6 .01+6 t
               8
               9
              10
              10.5
              11
              12
              15
              20
56$$ f0 t
end
```

APPENDIX 5.5.2

CSASN AND ICE INPUT FROM TABLE 5.8

APPENDIX 5.5.2

CSASN AND ICE INPUT FROM TABLE 5.8

This file is the input data for the generation and preparation (format) of the cross-section data used in the MORSE code. The data generated from this input file can be used for all MORSE media input cases. Oxygen is omitted from the oxide models, and HEU is assumed to be all U-235 in the neutron models in the MORSE data. The atomic densities for all dose rate calculations in Appendix 5.5.3 cases are given, or indicated, in Table 5.8.

```
=csasn
es3100: morse-cg cross section library
27n-18couple
multiregion
  arbmu02      10.9600  3  0  0  0    8016  11.9800
                                     92235  83.6200
                                     92238   4.4000   1 1.0000 293.0 end
  arbmsst       7.9200  4  0  0  0   26304  69.5000
                                     24304  19.0000
                                     28304   9.5000
                                     25055   2.0000   2 1.0000 293.0 end
  arbmcat       1.6820 12  0  0  0    1001   4.6200
                                      5010   0.7900
                                      5011   3.4400
                                      6012   1.5100
                                      8016  60.0000
                                     12000   0.3800
                                     13027  21.1600
                                     14000   1.3200
                                     16000   0.1500
                                     11023   0.1300
                                     20000   6.1800
                                     26304   0.3200  3 1.0000 293.0 end
  arbmkoa       0.3210  7  0  0  0    8016  40.4300
                                     11023   1.4500
                                     12000   7.8600
                                     13027   5.5800
                                     14000  16.1200
                                     20000  23.4000
                                     26304   5.1600   4 1.0000 293.0 end
end comp
spherical end
  1  1.0     noextermod
end zone
end
=ice
es31 ice : morse cross section library
-1$$ a3 2200 e
1$$ 26 26 0 10 0 0 1 1t
2$$ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
       25 26
3$$ 1008016 1092235 1092238
    2024304 2025055 2026304 2028304
    3001001 3005010 3005011 3006012 3008016 3012000 3013027
    3014000 3016000 3011023 3020000 3026304
    4008016 4011023 4012000 4013027 4014000 4020000 4026304
4** 26r1.0
5$$ 26r10
7$$ 3 16 60 0 0 0 e 2t
9$$ 258I1 260
10$$ 1 1452 27 3t
end
```

APPENDIX 5.5.3

MORSE ROUTINES AND INPUT DATA

APPENDIX 5.5.3

MORSE ROUTINES AND INPUT DATA

Included here are the routines and input files used for the dose rate calculations for the results in Tables 5.1 and 5.2. For each case, there are two routines, INSCOR and SOURCE, followed by the NCT and the HAC input. The normalization is given in INSCOR, which is the appropriate Total value in Tables 5.4 or 5.5 times the content mass. The spatial and energy distributions for the photon and neutron sources from Tables 5.4 and 5.5 are in the data statements in the SOURCE routine. Induced fission and secondary photons are included in the MORSE calculation. It is assumed that the energy group distribution of induced fissions is the same as for the spectra in Table 5.5. The photon source is biased, and weight corrected, so that half of all primary photons are selected in group 6 from Table 5.4.

For each case, the input data for NCT and HAC follow the two routines. For the HAC cases, all material external to the containment vessel is set to void and the detectors (now three) are set one meter from the external vessel surface. The 24-kg oxide neutron case, similar to the 36-kg metal neutron case, is not shown.

```
      subroutine inscor
       common /pdet/   nd,     nne,    ne,     nt,     na,     nresp,
      1                nex,    nexnd,  nend,   ndnr,   ntnr,   ntne,
      2                nane,   ntndnr, ntnend, nanend, locrsp, locxd,
      3                locib,  locco,  loct,   locud,  locsd,  locqe,
      4                locqt,  locqte, locqae, lmax,   efirst, egtop
       common bc(1)
       do 100 i = 1,nd
         bc(locxd + 5*nd + i) = 9.173e+09
100    continue
       return
       end
       subroutine source( ig,u,v,w,x,y,z,
      1                   wate,med,ag,isour,itstr,ngpqt3,ddf,
      2                   isbias,nmtg )
       dimension spect(1,18)
       data xst,yst,zst /0.000,0.0,11.195/
       data cyl_ht/76.200/
c40ppb u232
       data (spect(1,k),k=1,18) /
      1  4.310e-6,2.478e-5,1.596e-4,4.905e-4, 2.102e-3,2.447e+5,
      2  1.008e-1,9.761e+1,1.101e+3,
      3  3.426e+2,1.595e+3, 4.620e+03,
      4  1.533e+04,3.075e+4,2.415e+4,7.600e+4,9.066e+4,0.000e-00/
       data icall / 1 /
       if (icall) 10,10,5
5      icall = 0
       r02 = 5.6861**2
       r12 = 6.3500**2
        i=1
        sum=0.0
         do 92 j = 1,nmtg
92         sum = sum + spect(i,j)
         spect(i,1) = spect(i,1) / sum
         do 93 j = 2,nmtg
93         spect(i,j) = spect(i,j-1) + spect(i,j) / sum
10     continue
       r1 = fltrnf( 0 )
       call azirn( sinang,cosang )
       rad = sqrt( r1 * r12 + ( 1.0 - r1 ) * r02 )
       x = rad * sinang + xst
       y = rad * cosang + yst
       z = zst + fltrnf( 0 ) * cyl_ht
       i=1
       rn = fltrnf( 0 )
       do 94 j = 1,nmtg
         if ( rn .le. spect(i,j) ) goto 95
94     continue
       j = nmtg
95     ig = j
c40ppb u232
       if(ig.ne.6)wate=wate*1.9207
       if(ig.eq.6)wate=wate*0.079356
       return
       end
```

```
es3100 package nct 36kg u metal 40 ppb u232
 $$ 500 850 500    1    0   17   18   18    0    0  99.    4    0
 $$  0     0     0     0  **   1.0 1.0000e-5 1.0000e+4        1.0 2.2000e+5
 **    0.0        0.0        0.0        0.0        0.0        0.0        0.0
 **
 10.000e+6 8.0000e+6 6.5000e+6 5.0000e+6 4.0000e+6 3.0000e+6 2.5000e+6
 2.0000e+6 1.6600e+6 1.3300e+6 1.0000e+6 0.8000e+6 0.6000e+6 0.4000e+6
 0.3000e+6 0.2000e+6 0.1000e+6 0.0500e+6
 b1a303a31a34
 $$   1     1     0     0     0     1    18
 $$   1     1    10     1     1     1 **    0.1     .001         .010  5.000e-01
 $$  11     1    14     1     1     1 **    1.0     .010         .100  5.000e-01
 $$  15     1    18     1     1     1 **    10.     .100         1.00  5.000e-01
 $$  -1    9r0
    0     0     0     0
    0     0                  heu in es-3100 36kg cylinder model
    0     0     1     0
  rcc     1    0.000    0.0   11.1950   0.00    0.0  76.2000    5.6861
  rcc     2    0.000    0.0   11.1950   0.00    0.0  76.2000    6.3500
  rcc     3    0.000    0.0   11.1950   0.00    0.0  76.2000    6.4008
  rcc     4    0.000    0.0   10.5600   0.00    0.0  77.4700    6.6548
  rcc     5    0.000    0.0   10.5600   0.00    0.0  77.4700    7.9248
  rcc     6    0.000    0.0   10.5600   0.00    0.0  77.4700    8.0748
  rcc     7    0.000    0.0   10.5600   0.00    0.0  77.4700   10.9196
  rcc     8    0.000    0.0   10.2600   0.00    0.0  77.9200   11.0696
  rcc     9    0.000    0.0    0.2600   0.00    0.0  87.9200   23.0275
  rcc    10    0.000    0.0    0.2600   0.00    0.0 107.3050   23.0275
  rcc    11    0.000    0.0    0.0000   0.00    0.0 107.7150   23.1775
  sph    12      0.0       0.0       0.0        1000.
  sph    13      0.0       0.0       0.0        2000.
  end
  vid           1
  con           2      -1
  vid           3      -2
  sst           4      -3
  vid           5      -4
  sst           6      -5
  bor           7      -6
  sst           8      -7
  kao           9      -8
  vid          10      -9
  sst          11     -10
  vid          12     -11
  vix          13     -12
  end
    1     1     1     1     1     1     1     1     1     1     1     1     1
  13z
 1000     1 1000     2 1000     2     3     2     4 1000     2 1000     0
    0
27N18P LIBRARY (P5)
 $$ 0     0    18    18    45    60    16     4    26   26     6     3     1     3
    0     0     0     0     0     0     0    20     0     0     0
    1     2     3     4     5     6    11    12    13    14    15    16    21    22
   23    24    25    26    31    32    33    34    35    36    41    42    43    44
   45    46    51    52    53    54    55    56    61    62    63    64    65    66
   71    72    73    74    75    76    81    82    83    84    85    86    91    92
   93    94    95    96   101   102   103   104   105   106   111   112   113   114
  115   116   121   122   123   124   125   126   131   132   133   134   135   136
  141   142   143   144   145   146   151   152   153   154   155   156   161   162
  163   164   165   166   171   172   173   174   175   176   181   182   183   184
  185   186   191   192   193   194   195   196   201   202   203   204   205   206
  211   212   213   214   215   216   221   222   223   224   225   226   231   232
  233   234   235   236   241   242   243   244   245   246   251   252   253   254
  255   256
 $$ 1    12 ** 1.0000e-9
 $$ 1     2 ** 4.5820e-2
```

```
$$ 1   -3 ** 2.3810e-3
$$ 2    5 ** 1.7360e-3
$$ 2    6 ** 5.9360e-2
$$ 2    7 ** 7.7210e-3
$$ 2   -4 ** 1.7430e-2
$$ 3    8 ** 4.6420e-2
$$ 3    9 ** 8.0020e-4
$$ 3   10 ** 3.1680e-3
$$ 3   11 ** 1.2740e-3
$$ 3   12 ** 3.7980e-2
$$ 3   13 ** 1.5840e-4
$$ 3   14 ** 7.9440e-3
$$ 3   15 ** 4.7600e-4
$$ 3   16 ** 4.7390e-5
$$ 3   17 ** 5.7280e-5
$$ 3   18 ** 1.5620e-3
$$ 3  -19 ** 5.8040e-5
$$ 4   20 ** 4.8880e-3
$$ 4   21 ** 1.2190e-4
$$ 4   22 ** 6.2510e-4
$$ 4   23 ** 3.9980e-4
$$ 4   24 ** 1.1100e-3
$$ 4   25 ** 1.1290e-3
$$ 4  -26 ** 1.7860e-4
SAMBO ANALYSIS INPUT DATA
$$   6    0    0    0    0    1    1    2
**
  24.1775 0.0 49.295
  0.0 0.0  -1.00
  0.0 0.0  108.715
  123.1775 0.0 49.295
  0.0 0.0 -100.00
  0.0 0.0  207.7150
UNCOLLIDED AND TOTAL PHOTON DOSE RATES
ANSI STANDARD GAMMA DOSE RATES
**
8.7716e-3 7.4785e-3 6.3748e-3 5.4136e-3 4.6221e-3 3.9596e-3 3.4686e-3
3.0192e-3 2.6276e-3 2.2051e-3 1.8326e-3 1.5228e-3 1.1725e-3 8.7594e-4
6.3061e-4 3.8338e-4 2.6693e-4 9.3472e-4
```

```
es3100 package hac 36kg u metal 40 ppb u232
 $$ 500 850 500    1   0   17   18   18    0    0  99.    4    0
 $$  0    0    0    0  **  1.0 1.0000e-5 1.0000e+4        1.0 2.2000e+5
 **    0.0       0.0       0.0       0.0       0.0       0.0       0.0
 **
 10.000e+6 8.0000e+6 6.5000e+6 5.0000e+6 4.0000e+6 3.0000e+6 2.5000e+6
 2.0000e+6 1.6600e+6 1.3300e+6 1.0000e+6 0.8000e+6 0.6000e+6 0.4000e+6
 0.3000e+6 0.2000e+6 0.1000e+6 0.0500e+6
 b1a303a31a34
 $$   1    1    0    0    0    1   18
 $$   1    1   10    1    1    1 **   0.1    .001         .010  5.000e-01
 $$  11    1   14    1    1    1 **   1.0    .010         .100  5.000e-01
 $$  15    1   18    1    1    1 **   10.    .100         1.00  5.000e-01
 $$  -1    9r0
    0    0    0    0
    0    0                heu in es-3100 36kg cylinder model
    0    0    1    0
  rcc    1    0.000   0.0   11.1950   0.00   0.0  76.2000    5.6861
  rcc    2    0.000   0.0   11.1950   0.00   0.0  76.2000    6.3500
  rcc    3    0.000   0.0   11.1950   0.00   0.0  76.2000    6.4008
  rcc    4    0.000   0.0   10.5600   0.00   0.0  77.4700    6.6548
  rcc    5    0.000   0.0   10.5600   0.00   0.0  77.4700    7.9248
  rcc    6    0.000   0.0   10.5600   0.00   0.0  77.4700    8.0748
  rcc    7    0.000   0.0   10.5600   0.00   0.0  77.4700   10.9196
  rcc    8    0.000   0.0   10.2600   0.00   0.0  77.9200   11.0696
  rcc    9    0.000   0.0    0.2600   0.00   0.0  87.9200   23.0275
  rcc   10    0.000   0.0    0.2600   0.00   0.0 107.3050   23.0275
  rcc   11    0.000   0.0    0.0000   0.00   0.0 107.7150   23.1775
  sph   12      0.0      0.0      0.0       1000.
  sph   13      0.0      0.0      0.0       2000.
  end
  vid             1
  con             2     -1
  vid             3     -2
  sst             4     -3
  vid             5     -4
  sst             6     -5
  bor             7     -6
  sst             8     -7
  kao             9     -8
  vid            10     -9
  sst            11    -10
  vid            12    -11
  vix            13    -12
  end
    1    1    1    1    1    1    1    1    1    1    1    1    1
  13z
 1000    1 1000    2 1000 1000 1000 1000 1000 1000 1000 1000    0
    0
27N18P LIBRARY (P5)
 $$ 0    0   18   18   45   60   16    4   26   26    6    3    1    3
    0    0    0    0    0    0    0   20    0    0    0
    1    2    3    4    5    6   11   12   13   14   15   16   21   22
   23   24   25   26   31   32   33   34   35   36   41   42   43   44
   45   46   51   52   53   54   55   56   61   62   63   64   65   66
   71   72   73   74   75   76   81   82   83   84   85   86   91   92
   93   94   95   96  101  102  103  104  105  106  111  112  113  114
  115  116  121  122  123  124  125  126  131  132  133  134  135  136
  141  142  143  144  145  146  151  152  153  154  155  156  161  162
  163  164  165  166  171  172  173  174  175  176  181  182  183  184
  185  186  191  192  193  194  195  196  201  202  203  204  205  206
  211  212  213  214  215  216  221  222  223  224  225  226  231  232
  233  234  235  236  241  242  243  244  245  246  251  252  253  254
  255  256
 $$ 1   12 ** 1.0000e-9
 $$ 1    2 ** 4.5820e-2
```

```
 $$ 1   -3 ** 2.3810e-3
 $$ 2    5 ** 1.7360e-3
 $$ 2    6 ** 5.9360e-2
 $$ 2    7 ** 7.7210e-3
 $$ 2   -4 ** 1.7430e-2
 $$ 3    8 ** 4.6420e-2
 $$ 3    9 ** 8.0020e-4
 $$ 3   10 ** 3.1680e-3
 $$ 3   11 ** 1.2740e-3
 $$ 3   12 ** 3.7980e-2
 $$ 3   13 ** 1.5840e-4
 $$ 3   14 ** 7.9440e-3
 $$ 3   15 ** 4.7600e-4
 $$ 3   16 ** 4.7390e-5
 $$ 3   17 ** 5.7280e-5
 $$ 3   18 ** 1.5620e-3
 $$ 3  -19 ** 5.8040e-5
 $$ 4   20 ** 4.8880e-3
 $$ 4   21 ** 1.2190e-4
 $$ 4   22 ** 6.2510e-4
 $$ 4   23 ** 3.9980e-4
 $$ 4   24 ** 1.1100e-3
 $$ 4   25 ** 1.1290e-3
 $$ 4  -26 ** 1.7860e-4
SAMBO ANALYSIS INPUT DATA
 $$   3    0    0    0    0    1    1    2
 **
   106.6548 0.0 49.295
   0.0 0.0 -89.440
   0.0 0.0 188.03
UNCOLLIDED AND TOTAL PHOTON DOSE RATES
ANSI STANDARD GAMMA DOSE RATES
 **
 8.7716e-3 7.4785e-3 6.3748e-3 5.4136e-3 4.6221e-3 3.9596e-3 3.4686e-3
 3.0192e-3 2.6276e-3 2.2051e-3 1.8326e-3 1.5228e-3 1.1725e-3 8.7594e-4
 6.3061e-4 3.8338e-4 2.6693e-4 9.3472e-4
```

```
      subroutine inscor
      common /pdet/   nd,     nne,     ne,     nt,     na,     nresp,
     1                nex,    nexnd,   nend,   ndnr,   ntnr,   ntne,
     2                nane,   ntndnr,  ntnend, nanend, locrsp, locxd,
     3                locib,  locco,   loct,   locud,  locsd,  locqe,
     4                locqt,  locqte,  locqae, lmax,   efirst, egtop
      common bc(1)
      do 100 i = 1,nd
        bc(locxd + 5*nd + i) = 3.9100e+03
100   continue
      return
      end
      subroutine source( ig,u,v,w,x,y,z,
     1                 wate,med,ag,isour,itstr,ngpqt3,ddf,
     2                 isbias,nmtg )
     dimension spect(1,8)
      data xst,yst,zst /0.000,0.0, 11.1950/
      data cyl_ht/15.1003/
      data (spect(1,k),k=1,8) /
     1 6.614e-5,2.107e-2,5.841e-2,1.593e-2,9.334e-3,3.219e-3,
     2 5.304e-4,0.000e+0/
      data icall / 1 /
      if (icall) 10,10,5
5     icall = 0
      r11 = 6.3500
       i=1
       sum=0.0
        do 92 j = 1,8
92        sum = sum + spect(i,j)
        spect(i,1) = spect(i,1) / sum
        do 93 j = 2,8
93        spect(i,j) = spect(i,j-1) + spect(i,j) / sum
10    continue
      r1 = fltrnf( 0 )
      call azirn( sinang,cosang )
      rad = sqrt( r1)* r11
      x = rad * sinang + xst
      y = rad * cosang + yst
      z = zst + fltrnf( 0 ) * cyl_ht
      i=1
      rn = fltrnf( 0 )
      do 94 j = 1,8
        if ( rn .le. spect(i,j) ) goto 95
94    continue
      j = 8
95    ig = j
      return
      end
```

```
es3100 package nct 36kg u metal neutrons
 $$ 200  850  200   1   27   18   27   45    0    0  60.    4    0
 $$   0    0    0    0  **    1.0 1.0000e-5 1.0000e+4       1.0 2.2000e+5
 $$    0.0       0.0       0.0       0.0       0.0       0.0       0.0
 **
 2.0000e+7 6.4300e+6 3.0000e+6 1.8500e+6 1.4000e+6 9.0000e+5 4.0000e+5
 1.0000e+5 1.7000e+4 3.0000e+3 5.5000e+2 1.0000e+2 3.0000e+1 1.0000e+1
 3.0500e+0 1.7700e+0 1.3000e+0 1.1300e+0 1.0000e+0 8.0000e-1 4.0000e-1
 3.2500e-1 2.2500e-1 9.9999e-2 5.0000e-2 3.0000e-2 1.0000e-2 1.0000e+7
 8.0000e+6 6.5000e+6 5.0000e+6 4.0000e+6 3.0000e+6 2.5000e+6 2.0000e+6
 1.6600e+6 1.3300e+6 1.0000e+6 0.8000e+6 0.6000e+6 0.4000e+6 0.3000e+6
 0.2000e+6 0.1000e+6 0.0500e+6
 b3a343b203a1
 $$   1    1    0    0    0    1   45
 $$   1    1    9    1    1    1 **    50.     .050         .500  5.000e-01
 $$  10    1   27    1    1    1 **    50.     1.00         10.0  5.000e-01
 $$  28    1   45    1    1    1 **    20.     .500         2.00  5.000e-01
 $$  -1     9r0
 $$ 0    1    0    0
 ** 1.0
 **
 6.6140e-5 2.107e-2 5.841e-2 1.593e-2 9.334e-3 3.219e-3 5.304e-4
 0.0000e-0 19z
 **   27z
 **   27z
 **   27z
 ** 27r.01
    0    0            heu in es-3100 36kg cylinder model
    0    0    1    0
  rcc    1    0.000    0.0    11.1950    0.00    0.0  15.1003    0.0001
  rcc    2    0.000    0.0    11.1950    0.00    0.0  15.1003    6.3500
  rcc    3    0.000    0.0    11.1950    0.00    0.0  76.2000    6.4008
  rcc    4    0.000    0.0    10.5600    0.00    0.0  77.4700    6.6548
  rcc    5    0.000    0.0    10.5600    0.00    0.0  77.4700    7.9248
  rcc    6    0.000    0.0    10.5600    0.00    0.0  77.4700    8.0748
  rcc    7    0.000    0.0    10.5600    0.00    0.0  77.4700   10.9196
  rcc    8    0.000    0.0    10.2600    0.00    0.0  77.9200   11.0696
  rcc    9    0.000    0.0     0.2600    0.00    0.0  87.9200   23.0275
  rcc   10    0.000    0.0     0.2600    0.00    0.0 107.3050   23.0275
  rcc   11    0.000    0.0     0.0000    0.00    0.0 107.7150   23.1775
  sph   12      0.0       0.0       0.0        1000.
  sph   13      0.0       0.0       0.0        2000.
  end
  vid          1
  con          2     -1
  vid          3     -2
  sst          4     -3
  vid          5     -4
  sst          6     -5
  bor          7     -6
  sst          8     -7
  kao          9     -8
  vid         10     -9
  sst         11    -10
  vid         12    -11
  vix         13    -12
  end
    1    1    1    1    1    1    1    1    1    1    1    1    1
  13z
 1000    1 1000    2 1000    2    3    2    4 1000    2 1000    0
    0
27N18P LIBRARY (P5)
 $$ 27    27   18   18   45   60   16    4   26   26    6    3    1    3
    0    0    0    0    0    0    0   20    0    0    0
    1    2    3    4    5    6   11   12   13   14   15   16   21   22
   23   24   25   26   31   32   33   34   35   36   41   42   43   44
```

```
  45   46   51   52   53   54   55   56   61   62   63   64   65   66
  71   72   73   74   75   76   81   82   83   84   85   86   91   92
  93   94   95   96  101  102  103  104  105  106  111  112  113  114
 115  116  121  122  123  124  125  126  131  132  133  134  135  136
 141  142  143  144  145  146  151  152  153  154  155  156  161  162
 163  164  165  166  171  172  173  174  175  176  181  182  183  184
 185  186  191  192  193  194  195  196  201  202  203  204  205  206
 211  212  213  214  215  216  221  222  223  224  225  226  231  232
 233  234  235  236  241  242  243  244  245  246  251  252  253  254
 255  256
$$ 1   12 ** 1.0000e-9
$$ 1    2 ** 4.8240e-2
$$ 1   -3 ** 1.2210e-9
$$ 2    5 ** 1.7360e-3
$$ 2    6 ** 5.9360e-2
$$ 2    7 ** 7.7210e-3
$$ 2   -4 ** 1.7430e-2
$$ 3    8 ** 4.6420e-2
$$ 3    9 ** 8.0020e-4
$$ 3   10 ** 3.1680e-3
$$ 3   11 ** 1.2740e-3
$$ 3   12 ** 3.7980e-2
$$ 3   13 ** 1.5840e-4
$$ 3   14 ** 7.9440e-3
$$ 3   15 ** 4.7600e-4
$$ 3   16 ** 4.7390e-5
$$ 3   17 ** 5.7280e-5
$$ 3   18 ** 1.5620e-3
$$ 3  -19 ** 5.8040e-5
$$ 4   20 ** 4.8880e-3
$$ 4   21 ** 1.2190e-4
$$ 4   22 ** 6.2510e-4
$$ 4   23 ** 3.9980e-4
$$ 4   24 ** 1.1100e-3
$$ 4   25 ** 1.1290e-3
$$ 4  -26 ** 1.7860e-4
SAMBO ANALYSIS INPUT DATA
$$   6    0    0    0    0    3    1    2
**
   24.1775 0.0  18.745
   0.0 0.0 -1.000
   0.0 0.0  108.715
   123.1775 0.0  18.745
   0.0 0.0 -100.00
   0.0 0.0  207.7150
uncollided and total photon dose rates
ansi standard neutron dose rates :
**
 1.4916e-1 1.4464e-1 1.2701e-1 1.2811e-1 1.2977e-1 1.0281e-1 5.1183e-2
 1.2319e-2 3.8365e-3 3.7247e-3 4.0150e-3 4.2926e-3 4.4744e-3 4.5676e-3
 4.5581e-3 4.5185e-3 4.4879e-3 4.4665e-3 4.4345e-3 4.3271e-3 4.1975e-3
 4.0976e-3 3.8390e-3 3.6748e-3 3.6748e-3 3.6748e-3 3.6748e-3
 18r0.0
ansi standard photon dose rates :
**
 27r0.0
 8.7716e-3 7.4785e-3 6.3748e-3 5.4136e-3 4.6221e-3 3.9596e-3 3.4686e-3
 3.0192e-3 2.6276e-3 2.2051e-3 1.8326e-3 1.5228e-3 1.1725e-3 8.7594e-4
 6.3061e-4 3.8338e-4 2.6693e-4 9.3472e-4
ansi standard total dose rates :
**
 1.4916e-1 1.4464e-1 1.2701e-1 1.2811e-1 1.2977e-1 1.0281e-1 5.1183e-2
 1.2319e-2 3.8365e-3 3.7247e-3 4.0150e-3 4.2926e-3 4.4744e-3 4.5676e-3
 4.5581e-3 4.5185e-3 4.4879e-3 4.4665e-3 4.4345e-3 4.3271e-3 4.1975e-3
 4.0976e-3 3.8390e-3 3.6748e-3 3.6748e-3 3.6748e-3 3.6748e-3
 8.7716e-3 7.4785e-3 6.3748e-3 5.4136e-3 4.6221e-3 3.9596e-3 3.4686e-3
```

```
3.0192e-3 2.6276e-3 2.2051e-3 1.8326e-3 1.5228e-3 1.1725e-3 8.7594e-4
6.3061e-4 3.8338e-4 2.6693e-4 9.3472e-4


es3100 package hac 36kg u metal neutrons
$$ 200   850   200    1    27    18    27    45     0     0   60.     4     0
$$    0     0     0     0   **    1.0 1.0000e-5 1.0000e+4        1.0 2.2000e+5
$$     0.0        0.0        0.0        0.0        0.0        0.0        0.0
**
2.0000e+7 6.4300e+6 3.0000e+6 1.8500e+6 1.4000e+6 9.0000e+5 4.0000e+5
1.0000e+5 1.7000e+4 3.0000e+3 5.5000e+2 1.0000e+2 3.0000e+1 1.0000e+1
3.0500e+0 1.7700e+0 1.3000e+0 1.1300e+0 1.0000e+0 8.0000e-1 4.0000e-1
3.2500e-1 2.2500e-1 9.9999e-2 5.0000e-2 3.0000e-2 1.0000e-2 1.0000e+7
8.0000e+6 6.5000e+6 5.0000e+6 4.0000e+6 3.0000e+6 2.5000e+6 2.0000e+6
1.6600e+6 1.3300e+6 1.0000e+6 0.8000e+6 0.6000e+6 0.4000e+6 0.3000e+6
0.2000e+6 0.1000e+6 0.0500e+6
b3a343b203a1
$$    1     1     0     0     0     1    45
$$    1     1     9     1     1     1 **    50.     .050        .500  5.000e-01
$$   10     1    27     1     1     1 **    50.     1.00        10.0  5.000e-01
$$   28     1    45     1     1     1 **    20.     .500        2.00  5.000e-01
$$   -1     9r0
$$ 0     1     0     0
** 1.0
**
6.6140e-5 2.107e-2 5.841e-2 1.593e-2 9.334e-3 3.219e-3 5.304e-4
0.0000e-0 19z
**    27z
**    27z
**    27z
** 27r.01
   0     0              heu in es-3100 36kg cylinder model
   0     0     1     0
  rcc    1     0.000   0.0   11.1950   0.00    0.0  15.1003    0.0001
  rcc    2     0.000   0.0   11.1950   0.00    0.0  15.1003    6.3500
  rcc    3     0.000   0.0   11.1950   0.00    0.0  76.2000    6.4008
  rcc    4     0.000   0.0   10.5600   0.00    0.0  77.4700    6.6548
  rcc    5     0.000   0.0   10.5600   0.00    0.0  77.4700    7.9248
  rcc    6     0.000   0.0   10.5600   0.00    0.0  77.4700    8.0748
  rcc    7     0.000   0.0   10.5600   0.00    0.0  77.4700   10.9196
  rcc    8     0.000   0.0   10.2600   0.00    0.0  77.9200   11.0696
  rcc    9     0.000   0.0    0.2600   0.00    0.0  87.9200   23.0275
  rcc   10     0.000   0.0    0.2600   0.00    0.0 107.3050   23.0275
  rcc   11     0.000   0.0    0.0000   0.00    0.0 107.7150   23.1775
  sph   12       0.0       0.0      0.0        1000.
  sph   13       0.0       0.0      0.0        2000.
  end
  vid            1
  con            2      -1
  vid            3      -2
  sst            4      -3
  vid            5      -4
  sst            6      -5
  bor            7      -6
  sst            8      -7
  kao            9      -8
  vid           10      -9
  sst           11     -10
  vid           12     -11
  vix           13     -12
  end
   1     1     1     1     1     1     1     1     1     1     1     1     1
  13z
 1000     1 1000     2 1000 1000 1000 1000 1000 1000 1000 1000       0
   0
```

```
27N18P LIBRARY (P5)
 $$ 27   27   18   18   45   60   16    4   26   26    6    3    1    3
     0    0    0    0    0    0    0   20    0    0    0
     1    2    3    4    5    6   11   12   13   14   15   16   21   22
    23   24   25   26   31   32   33   34   35   36   41   42   43   44
    45   46   51   52   53   54   55   56   61   62   63   64   65   66
    71   72   73   74   75   76   81   82   83   84   85   86   91   92
    93   94   95   96  101  102  103  104  105  106  111  112  113  114
   115  116  121  122  123  124  125  126  131  132  133  134  135  136
   141  142  143  144  145  146  151  152  153  154  155  156  161  162
   163  164  165  166  171  172  173  174  175  176  181  182  183  184
   185  186  191  192  193  194  195  196  201  202  203  204  205  206
   211  212  213  214  215  216  221  222  223  224  225  226  231  232
   233  234  235  236  241  242  243  244  245  246  251  252  253  254
   255  256
 $$ 1   12 ** 1.0000e-9
 $$ 1    2 ** 4.8240e-2
 $$ 1   -3 ** 1.2210e-9
 $$ 2    5 ** 1.7360e-3
 $$ 2    6 ** 5.9360e-2
 $$ 2    7 ** 7.7210e-3
 $$ 2   -4 ** 1.7430e-2
 $$ 3    8 ** 4.6420e-2
 $$ 3    9 ** 8.0020e-4
 $$ 3   10 ** 3.1680e-3
 $$ 3   11 ** 1.2740e-3
 $$ 3   12 ** 3.7980e-2
 $$ 3   13 ** 1.5840e-4
 $$ 3   14 ** 7.9440e-3
 $$ 3   15 ** 4.7600e-4
 $$ 3   16 ** 4.7390e-5
 $$ 3   17 ** 5.7280e-5
 $$ 3   18 ** 1.5620e-3
 $$ 3  -19 ** 5.8040e-5
 $$ 4   20 ** 4.8880e-3
 $$ 4   21 ** 1.2190e-4
 $$ 4   22 ** 6.2510e-4
 $$ 4   23 ** 3.9980e-4
 $$ 4   24 ** 1.1100e-3
 $$ 4   25 ** 1.1290e-3
 $$ 4  -26 ** 1.7860e-4
SAMBO ANALYSIS INPUT DATA
 $$   3   0    0    0    0    3    1    2
 **
   106.6548 0.0  18.745
   0.0 0.0 -89.44
   0.0 0.0 188.03
uncollided and total photon dose rates
ansi standard neutron dose rates :
 **
 1.4916e-1 1.4464e-1 1.2701e-1 1.2811e-1 1.2977e-1 1.0281e-1 5.1183e-2
 1.2319e-2 3.8365e-3 3.7247e-3 4.0150e-3 4.2926e-3 4.4744e-3 4.5676e-3
 4.5581e-3 4.5185e-3 4.4879e-3 4.4665e-3 4.4345e-3 4.3271e-3 4.1975e-3
 4.0976e-3 3.8390e-3 3.6748e-3 3.6748e-3 3.6748e-3 3.6748e-3
 18r0.0
ansi standard photon dose rates :
 **
 27r0.0
 8.7716e-3 7.4785e-3 6.3748e-3 5.4136e-3 4.6221e-3 3.9596e-3 3.4686e-3
 3.0192e-3 2.6276e-3 2.2051e-3 1.8326e-3 1.5228e-3 1.1725e-3 8.7594e-4
 6.3061e-4 3.8338e-4 2.6693e-4 9.3472e-4
ansi standard total dose rates :
 **
 1.4916e-1 1.4464e-1 1.2701e-1 1.2811e-1 1.2977e-1 1.0281e-1 5.1183e-2
 1.2319e-2 3.8365e-3 3.7247e-3 4.0150e-3 4.2926e-3 4.4744e-3 4.5676e-3
 4.5581e-3 4.5185e-3 4.4879e-3 4.4665e-3 4.4345e-3 4.3271e-3 4.1975e-3
```

4.0976e-3 3.8390e-3 3.6748e-3 3.6748e-3 3.6748e-3 3.6748e-3
8.7716e-3 7.4785e-3 6.3748e-3 5.4136e-3 4.6221e-3 3.9596e-3 3.4686e-3
3.0192e-3 2.6276e-3 2.2051e-3 1.8326e-3 1.5228e-3 1.1725e-3 8.7594e-4
6.3061e-4 3.8338e-4 2.6693e-4 9.3472e-4

```
      subroutine inscor
       common /pdet/   nd,     nne,     ne,      nt,      na,      nresp,
      1                nex,    nexnd,   nend,    ndnr,    ntnr,    ntne,
      2                nane,   ntndnr,  ntnend,  nanend,  locrsp,  locxd,
      3                locib,  locco,   loct,    locud,   locsd,   locqe,
      4                locqt,  locqte,  locqae,  lmax,    efirst,  egtop
       common bc(1)
       do 100 i = 1,nd
         bc(locxd + 5*nd + i) = 9.1730e+09*24./36.*0.88024
100    continue
       return
       end
       subroutine source( ig,u,v,w,x,y,z,
      1                   wate,med,ag,isour,itstr,ngpqt3,ddf,
      2                   isbias,nmtg )
       dimension spect(1,18)
       data xst,yst,zst /0.000,0.0,11.195/
        data cyl_ht/63.500/
c40ppb u232
       data (spect(1,k),k=1,18) /
      1  4.310e-6,2.478e-5,1.596e-4,4.905e-4, 2.102e-3,2.447e+5,
      2  1.008e-1,9.761e+1,1.101e+3,
      3  3.426e+2,1.595e+3, 4.620e+03,
      4  1.533e+04,3.075e+4,2.415e+4,7.600e+4,9.066e+4,0.000e-00/
       data icall / 1 /
       if (icall) 10,10,5
5      icall = 0
c      r02 = 5.6861**2
       r02 = 0.0001**2
       r12 = 6.3500**2
        i=1
        sum=0.0
         do 92 j = 1,nmtg
92         sum = sum + spect(i,j)
         spect(i,1) = spect(i,1) / sum
         do 93 j = 2,nmtg
93         spect(i,j) = spect(i,j-1) + spect(i,j) / sum
10     continue
       r1 = fltrnf( 0 )
       call azirn( sinang,cosang )
       rad = sqrt( r1 * r12 + ( 1.0 - r1 ) * r02 )
       x = rad * sinang + xst
       y = rad * cosang + yst
       z = zst + fltrnf( 0 ) * cyl_ht
       i=1
       rn = fltrnf( 0 )
       do 94 j = 1,nmtg
         if ( rn .le. spect(i,j) ) goto 95
94     continue
       j = nmtg
95     ig = j
c40ppb u232
       if(ig.ne.6)wate=wate*1.9207
       if(ig.eq.6)wate=wate*0.079356
       return
       end
```

```
es3100 package photon nct 24kg u oxide 40 ppb u232
$$ 500 850 500   1    0   17   18   18    0    0  99.    4    0
$$  0    0    0    0  **  1.0 1.0000e-5 1.0000e+4      1.0 2.2000e+5
**    0.0        0.0        0.0        0.0        0.0        0.0        0.0
**
10.000e+6 8.0000e+6 6.5000e+6 5.0000e+6 4.0000e+6 3.0000e+6 2.5000e+6
2.0000e+6 1.6600e+6 1.3300e+6 1.0000e+6 0.8000e+6 0.6000e+6 0.4000e+6
0.3000e+6 0.2000e+6 0.1000e+6 0.0500e+6
b1a303a31a34
$$   1    1    0    0    0    1   18
$$   1    1   10    1    1    1 **   0.1    .001        .010  5.000e-01
$$  11    1   14    1    1    1 **   1.0    .010        .100  5.000e-01
$$  15    1   18    1    1    1 **   10.    .100        1.00  5.000e-01
$$  -1      9r0
   0    0    0    0
   0    0              oxide in es-3100 24kg cylinder model
   0    0    1    0
  rcc   1    0.000   0.0   11.1950   0.00   0.0  63.5000   0.0001
  rcc   2    0.000   0.0   11.1950   0.00   0.0  63.5000   6.3500
  rcc   3    0.000   0.0   11.1950   0.00   0.0  76.2000   6.4008
  rcc   4    0.000   0.0   10.5600   0.00   0.0  77.4700   6.6548
  rcc   5    0.000   0.0   10.5600   0.00   0.0  77.4700   7.9248
  rcc   6    0.000   0.0   10.5600   0.00   0.0  77.4700   8.0748
  rcc   7    0.000   0.0   10.5600   0.00   0.0  77.4700  10.9196
  rcc   8    0.000   0.0   10.2600   0.00   0.0  77.9200  11.0696
  rcc   9    0.000   0.0    0.2600   0.00   0.0  87.9200  23.0275
  rcc  10    0.000   0.0    0.2600   0.00   0.0 107.3050  23.0275
  rcc  11    0.000   0.0    0.0000   0.00   0.0 107.7150  23.1775
  sph  12      0.0      0.0      0.0        1000.
  sph  13      0.0      0.0      0.0        2000.
  end
  vid          1
  con          2    -1
  vid          3    -2
  sst          4    -3
  vid          5    -4
  sst          6    -5
  bor          7    -6
  sst          8    -7
  kao          9    -8
  vid         10    -9
  sst         11   -10
  vid         12   -11
  vix         13   -12
  end
   1    1    1    1    1    1    1    1    1    1    1    1    1
  13z
 1000    1 1000    2 1000    2    3    2    4 1000    2 1000    0
   0
27N18P LIBRARY (P5)
 $$ 0    0   18   18   45   60   16    4   26   26    6    3    1    3
   0    0    0    0    0    0    0   20    0    0    0
   1    2    3    4    5    6   11   12   13   14   15   16   21   22
  23   24   25   26   31   32   33   34   35   36   41   42   43   44
  45   46   51   52   53   54   55   56   61   62   63   64   65   66
  71   72   73   74   75   76   81   82   83   84   85   86   91   92
  93   94   95   96  101  102  103  104  105  106  111  112  113  114
 115  116  121  122  123  124  125  126  131  132  133  134  135  136
 141  142  143  144  145  146  151  152  153  154  155  156  161  162
 163  164  165  166  171  172  173  174  175  176  181  182  183  184
 185  186  191  192  193  194  195  196  201  202  203  204  205  206
 211  212  213  214  215  216  221  222  223  224  225  226  231  232
 233  234  235  236  241  242  243  244  245  246  251  252  253  254
 255  256
 $$ 1   12 ** 1.0000e-9
 $$ 1    2 ** 6.3940e-3
```

```
 $$ 1   -3 ** 3.3220e-4
 $$ 2    5 ** 1.7360e-3
 $$ 2    6 ** 5.9360e-2
 $$ 2    7 ** 7.7210e-3
 $$ 2   -4 ** 1.7430e-2
 $$ 3    8 ** 4.6420e-2
 $$ 3    9 ** 8.0020e-4
 $$ 3   10 ** 3.1680e-3
 $$ 3   11 ** 1.2740e-3
 $$ 3   12 ** 3.7980e-2
 $$ 3   13 ** 1.5840e-4
 $$ 3   14 ** 7.9440e-3
 $$ 3   15 ** 4.7600e-4
 $$ 3   16 ** 4.7390e-5
 $$ 3   17 ** 5.7280e-5
 $$ 3   18 ** 1.5620e-3
 $$ 3  -19 ** 5.8040e-5
 $$ 4   20 ** 4.8880e-3
 $$ 4   21 ** 1.2190e-4
 $$ 4   22 ** 6.2510e-4
 $$ 4   23 ** 3.9980e-4
 $$ 4   24 ** 1.1100e-3
 $$ 4   25 ** 1.1290e-3
 $$ 4  -26 ** 1.7860e-4
SAMBO ANALYSIS INPUT DATA
 $$    6    0    0    0    0    1    1    2
 **
   24.1775 0.0 42.945
   0.0 0.0  -1.00
   0.0 0.0  108.715
   123.1775 0.0 42.945
   0.0 0.0 -100.00
   0.0 0.0  207.715
UNCOLLIDED AND TOTAL PHOTON DOSE RATES
ANSI STANDARD GAMMA DOSE RATES
 **
 8.7716e-3 7.4785e-3 6.3748e-3 5.4136e-3 4.6221e-3 3.9596e-3 3.4686e-3
 3.0192e-3 2.6276e-3 2.2051e-3 1.8326e-3 1.5228e-3 1.1725e-3 8.7594e-4
 6.3061e-4 3.8338e-4 2.6693e-4 9.3472e-4
```

```
es3100 package photon hac 24kg u oxide 40 ppb u232
$$ 500 850 500    1    0   17   18   18    0    0  99.    4    0
$$  0    0    0    0  **  1.0 1.0000e-5 1.0000e+4       1.0 2.2000e+5
**    0.0        0.0        0.0        0.0        0.0        0.0        0.0
**
10.000e+6 8.0000e+6 6.5000e+6 5.0000e+6 4.0000e+6 3.0000e+6 2.5000e+6
2.0000e+6 1.6600e+6 1.3300e+6 1.0000e+6 0.8000e+6 0.6000e+6 0.4000e+6
0.3000e+6 0.2000e+6 0.1000e+6 0.0500e+6
b1a303a31a34
$$   1    1    0    0    0    1   18
$$   1    1   10    1    1    1 **   0.1     .001        .010  5.000e-01
$$  11    1   14    1    1    1 **   1.0     .010        .100  5.000e-01
$$  15    1   18    1    1    1 **   10.     .100        1.00  5.000e-01
$$  -1    9r0
   0.   0    0    0
   0    0                oxide in es-3100 24kg cylinder model
   0    0    1    0
 rcc    1    0.000   0.0   11.1950   0.00   0.0  63.5000    0.0001
 rcc    2    0.000   0.0   11.1950   0.00   0.0  63.5000    6.3500
 rcc    3    0.000   0.0   11.1950   0.00   0.0  76.2000    6.4008
 rcc    4    0.000   0.0   10.5600   0.00   0.0  77.4700    6.6548
 rcc    5    0.000   0.0   10.5600   0.00   0.0  77.4700    7.9248
 rcc    6    0.000   0.0   10.5600   0.00   0.0  77.4700    8.0748
 rcc    7    0.000   0.0   10.5600   0.00   0.0  77.4700   10.9196
 rcc    8    0.000   0.0   10.2600   0.00   0.0  77.9200   11.0696
 rcc    9    0.000   0.0    0.2600   0.00   0.0  87.9200   23.0275
 rcc   10    0.000   0.0    0.2600   0.00   0.0 107.3050   23.0275
 rcc   11    0.000   0.0    0.0000   0.00   0.0 107.7150   23.1775
 sph   12      0.0      0.0      0.0       1000.
 sph   13      0.0      0.0      0.0       2000.
 end
 vid          1
 con          2     -1
 vid          3     -2
 sst          4     -3
 vid          5     -4
 sst          6     -5
 bor          7     -6
 sst          8     -7
 kao          9     -8
 vid         10     -9
 sst         11    -10
 vid         12    -11
 vix         13    -12
 end
   1    1    1    1    1    1    1    1    1    1    1    1    1
 13z
 1000    1 1000    2 1000 1000 1000 1000 1000 1000 1000 1000    0
   0
27N18P LIBRARY (P5)
 $$ 0    0   18   18   45   60   16    4   26   26    6    3    1    3
   0    0    0    0    0    0    0   20    0    0    0
   1    2    3    4    5    6   11   12   13   14   15   16   21   22
  23   24   25   26   31   32   33   34   35   36   41   42   43   44
  45   46   51   52   53   54   55   56   61   62   63   64   65   66
  71   72   73   74   75   76   81   82   83   84   85   86   91   92
  93   94   95   96  101  102  103  104  105  106  111  112  113  114
 115  116  121  122  123  124  125  126  131  132  133  134  135  136
 141  142  143  144  145  146  151  152  153  154  155  156  161  162
 163  164  165  166  171  172  173  174  175  176  181  182  183  184
 185  186  191  192  193  194  195  196  201  202  203  204  205  206
 211  212  213  214  215  216  221  222  223  224  225  226  231  232
 233  234  235  236  241  242  243  244  245  246  251  252  253  254
```

```
  255  256
 $$ 1   12 ** 1.0000e-9
 $$ 1    2 ** 6.3940e-3
 $$ 1   -3 ** 3.3220e-4
 $$ 2    5 ** 1.7360e-3
 $$ 2    6 ** 5.9360e-2
 $$ 2    7 ** 7.7210e-3
 $$ 2   -4 ** 1.7430e-2
 $$ 3    8 ** 4.6420e-2
 $$ 3    9 ** 8.0020e-4
 $$ 3   10 ** 3.1680e-3
 $$ 3   11 ** 1.2740e-3
 $$ 3   12 ** 3.7980e-2
 $$ 3   13 ** 1.5840e-4
 $$ 3   14 ** 7.9440e-3
 $$ 3   15 ** 4.7600e-4
 $$ 3   16 ** 4.7390e-5
 $$ 3   17 ** 5.7280e-5
 $$ 3   18 ** 1.5620e-3
 $$ 3  -19 ** 5.8040e-5
 $$ 4   20 ** 4.8880e-3
 $$ 4   21 ** 1.2190e-4
 $$ 4   22 ** 6.2510e-4
 $$ 4   23 ** 3.9980e-4
 $$ 4   24 ** 1.1100e-3
 $$ 4   25 ** 1.1290e-3
 $$ 4  -26 ** 1.7860e-4
SAMBO ANALYSIS INPUT DATA
 $$   3    0    0    0    0    1    1    2
 **
  106.6548 0.0 42.945
   0.0 0.0 -89.440
   0.0 0.0 188.03
UNCOLLIDED AND TOTAL PHOTON DOSE RATES
ANSI STANDARD GAMMA DOSE RATES
 **
 8.7716e-3 7.4785e-3 6.3748e-3 5.4136e-3 4.6221e-3 3.9596e-3 3.4686e-3
 3.0192e-3 2.6276e-3 2.2051e-3 1.8326e-3 1.5228e-3 1.1725e-3 8.7594e-4
 6.3061e-4 3.8338e-4 2.6693e-4 9.3472e-4
```

SECTION 5 REFERENCES

10 CFR 71, *Packaging and Transportation of Radioactive Material*, Jan. 1, 2005.

49 CFR 173, *Transportation*, Oct. 1, 2004.

ANSI/ANS-6.1.1, *Neutron and Gamma Ray Flux-to-Dose-Rate Factors,* American Natl. Standards Institute, American Nuclear Society, La Grange, Ill., 1977.

MORSE-CGA, *Monte Carlo Radiation Transport Code with Array Geometry Capability,* ORNL-6174, M. B. Emmett, Oak Ridge Natl. Lab., April 1985.

SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, C. V. Parks, ed., NUREG/CR-0200, rev. 6, ORNL/NUREG/CSD-2/R6, May 2000.

6. CRITICALITY EVALUATION

This section describes the criticality safety evaluation of the Y-12 National Security Complex Model ES-3100 package with highly enriched uranium (HEU) oxide, HEU metal, or highly enriched uranyl nitrate hexahydrate (UNH) crystals. HEU oxide may be in the form of UO_2, U_3O_8, or UO_3. HEU metal may be solid shapes (spheres, cylinders, bars, slugs) or broken metal pieces of unspecified geometric shape. Physical testing of Type-B fissile material packages 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."

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 No. M2E801580A031, Appendix 1.4.1). The ES-3100 package uses a single containment system (Drawing No. M2E801580A011, Appendix 1.4.1) to contain the HEU contents. The containment is a high-integrity, watertight, post-load leak-testable, stainless-steel vessel (Fig. 1.2). The outer drum system (Drawing No. M2E801580A001, Appendix 1.4.1) 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 for protecting the containment vessel from thermal absorption, shock and impact. The body weldment liner inner cavity contains a neutron poison, Thermo Electron Corp. (formerly "Thermo ReaX") Catalog 277-4 (Cat 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)].

Three 4.25-in. diameter × 10.0-in. tall convenience cans physically fit inside an ES-3100 containment vessel. Other can arrangements (Drawing No. M2E801580A035) fit inside the containment vessel, such as three 4.25 in. × 8.75 in. convenience cans or five 4.25 in. × 4.88 in. convenience cans. Both can arrangements include can pads and Cat 277-4 canned spacers which are ~4.0-in. in diameter × 1-5/16 in. in thickness. Credit is not taken in this criticality analysis for fissile material spacing provided by convenience cans inside the containment vessel because these cans are not manufactured to the ASME Boiler and Pressure Vessel Code, Sect. III, Subsection NG, or better. (B&PVC, Sect. III, Subsection NG) Thus, other configurations of convenience cans up to 5.0-in. diameter are permissible provided Cat 277-4 canned spacers are used as needed for criticality control.

6.1.2 Summary of the Criticality Evaluation

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. However, 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. (Meeting, Docket 71-93150)

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 which 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 with the exception of the containment vessel well. UNH solution resides inside both the containment vessel well and the containment vessel, including the sealed convenience cans. For this evaluation, 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,d).

Credit for the high-integrity, watertight containment is not taken either in the single package analysis [10 CFR 71.55(d, e)] or in the array analysis [10 CFR 71.59(a)(1)] of undamaged packages. In the evaluation of undamaged packages under 10 CFR 71.59(a)(1) and the evaluation of damaged packages under 10 CFR 71.59(a)(2), the containment vessel is flooded with water providing moderation to such an extent as to cause maximum reactivity of the content consistent with the chemical and physical form of the material present. Solid HEU not solution HEU is being shipped in the ES-3100. Consequently in the evaluation of 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 HAC, based on results for tests specified in 10 CFR 71.73. Given that credit for the high-integrity, watertight containment is not fully taken in this criticality evaluation, the fissile material mass loading limits are very conservative as a result.

The sources of hydrogen contained in packing materials are not distinguished from the sources of hydrogen inherent in the fissile content as a constituent such as the bonded water in the UNH crystals or impurity in the HEU oxide. Normally, the hydrogen-to-fissile isotope (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. Given that a flooded containment vessel is assumed for both NCT and HAC calculations, the restriction on hydrogen moderation is specified in terms of hydrogen density instead of the H/X ratio. The total amount of hydrogen contained in the package content (including absorbed moisture and/or hydration molecules of the fissile content) and the water if the containment vessel were to flood; shall not exceed an average density of 0.1117 g/cm^3 inside the voided volume of the containment vessel that is not occupied by dry package content. This limit corresponds to the flooded condition assumed in the calculations where the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents.

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.

The following criticality safety evaluation shows that the Model ES-3100 package with convenience can loading of HEU metal shapes, with loadings of HEU broken metal contents of unspecified geometric shape, with loadings of HEU oxide, or with loadings of UNH crystals, satisfies the requirements of 10 CFR 71.55 and 71.59. Tables 6.1a–6.1c summarize the results of the evaluation for solid HEU metal, for HEU broken metal, and for HEU oxide and UNH crystals, respectively. In Table 6.1b, the fissile or uranium masses for broken metal listed in the content headings indicate the evaluation limits of the criticality calculations. These mass loading limits may be reduced as determined by the NCT and HAC array analysis where fissile material loadings remain below the subcritical safety limit. The reduced loading limits are identified in the "CSI" rows in bold font.

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 Table 6.2 (reproduced in Table 1.3) under the conditions identified in Sect. 6.2.4.

6.1.3 Criticality Safety Index

A CSI is assigned to the Model ES-3100 package on the basis of a an adequate margin of subcriticality for the single package and arrays of packages for both NCT and HAC. Values for the CSI given in Table 6.2 (Table 1.3) are based on the uranium and the ^{235}U mass of the content and on the presence of Cat 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. (SCALE, Vol. 2, Sect. F11) 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, and 5×5×2, 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 = 0.4; N = 64, CSI = 0.8; N = 29, CSI = 1.7; and N = 10, CSI = 5.0. 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 = 0.3; N = 74, CSI = 0.7; and N = 25, CSI = 2.0. 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–6.1c:

- infinite arrays evaluated for NCT and HAC 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) = (64,74) for a CSI = 0.8, and
- 7×7×3 evaluted for NCT and 5×5×2 evaluated for HAC where N(1,2) = (29,25) for a CSI = 2.0.

An appropriate HAC array size for determination of limits for CSI = 5.0 is not available; therefore, limits for CSI =5.0 are not provided.

Table 6.1a. Summary of criticality evaluation for solid HEU metal of specified geometric shapes

Conditions	spheres	cylinders, no can spacers	cylinders, with can spacers	bars	slugs 80% < enr. ≤ 100%	slugs enr. ≤ 80%
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")	$k_{eff} + 2\sigma \leq 0.8841$ cvrsp_06_01_06_15	$k_{eff} + 2\sigma \leq 0.9019$ cvrcy_09_01_06_15	$k_{eff} + 2\sigma \leq 0.9054$ cvrcy_12_03_06_15	$k_{eff} + 2\sigma \leq 0.8813$ cvrsq_12_01_06_15	$k_{eff} + 2\sigma \leq 0.8939$ cvr5slg0p0_02_03_06_15	
(1) the most reactive credible configuration consistent with the chemical and physical form of the material,	6 stacked spheres (d = 3.24 in.) 2 spheres per convenience can, no can spacers, 32,938g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, can spacers, 18,000g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 36,000g ^{235}U	3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000g ^{235}U	pentagonal rings of slugs (d=1.5 in., h=2.0 in.) stacked 2 high per convenience can, can spacers, 32,680g ^{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 of specified geometric shapes (cont.)

Conditions	spheres	cylinders, no can spacers	cylinders, with can spacers	bars	slugs 80% < enr. ≤ 100%	slugs enr. ≤ 80%
"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,	$k_{eff} + 2\sigma \le 0.8691$ nbsrsp_06_01_15	$k_{eff} + 2\sigma \le 0.8858$ nbsrcy_09_01_15	$k_{eff} + 2\sigma \le 0.8922$ nbsrcy_12_03_15	$k_{eff} + 2\sigma \le 0.8635$ nbsrsq_12_01_15	$k_{eff} + 2\sigma \le 0.8785$ nbsr5slg_02_03_15	
(2) the geometric form of the package contents would not be substantially altered,	6 stacked spheres (d = 3.24 in.) 2 spheres per convenience can, no can spacers, 32938g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, can spacers, 18,000g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 36,000g ^{235}U	3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000g ^{235}U	pentagonal rings of slugs (d = 1.5 in., h = 2.0 in.) stacked 2 high per convenience can, can spacers, 32,680g ^{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 of specified geometric shapes (cont.)

Conditions	spheres	cylinders, no can spacers	cylinders, with can spacers	bars	slugs 80% < enr. ≤ 100%	slugs enr. ≤ 80%
"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")	$k_{eff} + 2\sigma \leq 0.8687$ hbsrsp_06_01_15	$k_{eff} + 2\sigma \leq 0.8855$ hbsrcy_09_01_15	$k_{eff} + 2\sigma \leq 0.8887$ hbsrcy_12_03_15	$k_{eff} + 2\sigma \leq 0.8662$ hbsrsq_12_01_15	$k_{eff} + 2\sigma \leq 0.8744$ hbsr5slg_02_03_15	
(1) the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents,	6 stacked spheres (d = 3.24 in.) 2 spheres per convenience can, no can spacers, 32,938g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, can spacers, 18,000g ^{235}U	3 stacked cylinders (d = 3.24 in.) 1 cylinder per convenience can, no can spacers, 36,000g ^{235}U	3 stacked bars (l,w = 2.29 in.) 1 bar per convenience can, no can spacers, 36,000g ^{235}U	6 stacked pentagonal rings of slugs (d=1.5 in., h=2.0 in.) 2 rings per convenience can, can spacers, 32,680g ^{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 of specified geometric shapes (cont.)

Conditions	spheres	cylinders, no can spacers	cylinders, with can spacers	bars	slugs 80% < enr. ≤ 100%	slugs enr. ≤ 80%
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 16,946g ^{235}U no can spacers**	**load-limited to 12,000g ^{235}U no can spacers**		**load-limited to 18,000g ^{235}U no can spacers**	**can spacers are required**	**can spacers are required**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	$k_{eff} + 2\sigma \le 0.8376$ nbiasp_03_01_06_03	$k_{eff} + 2\sigma \le 0.8358$ nbiacy_07_01_06_03		$k_{eff} + 2\sigma \le 0.8483$ nbiasq_09_01_06_03	Not applicable	Not applicable
(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,	$k_{eff} + 2\sigma \le 0.8419$ hbiasp_03_01_06_03	$k_{eff} + 2\sigma \le 0.8403$ hbiacy_07_01_06_03		$k_{eff} + 2\sigma \le 0.8524$ hbiasq_09_01_06_03	Not applicable	Not applicable
(3) the value of "N" not less than 0.5.	N(1,2) = ∞	same		same	same	same

Table 6.1a. Summary of criticality evaluation for solid HEU metal of specified geometric shapes (cont.)

Conditions	spheres	cylinders, no can spacers	cylinders, with can spacers	bars	slugs 80% < enr. ≤ 100%	slugs enr. ≤ 80%
Transport index based on nuclear criticality control, CSI = 0.0	**load-limited to 32,983g ^{235}U can spacers**	**load-limited to 18,000g ^{235}U can spacers**		**load-limited to 30,000g ^{235}U can spacers**	**load-limited to 16,342g ^{235}U can spacers**	**load-limit to 26,213g ^{235}U can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \le 0.8511$ nbiasp_06_03_06_03	$k_{eff} + 2\sigma \le 0.8181$ nbiacy_09_03_06_03		$k_{eff} + 2\sigma \le 0.8434$ nbiasq_11_03_06_03	$k_{eff} + 2\sigma \le 0.7859$ nbia5slg_01_03_09_03	$k_{eff} + 2\sigma \le 0.8477$ nbia5slg_02_03_05_03
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \le 0.8583$ hbiasp_06_03_06_03	$k_{eff} + 2\sigma \le 0.8222$ hbiacy_09_03_06_03		$k_{eff} + 2\sigma \le 0.8505$ hbiasq_11_03_06_03	$k_{eff} + 2\sigma \le 0.7962$ hbia5slg_01_03_09_03	$k_{eff} + 2\sigma \le 0.8546$ hbia5slg_02_03_05_03
(3) the value of "N"	N(1,2) = ∞	same		same	same	same
Transport index based on nuclear criticality control, CSI = 0.4	**load-limited to 16,946g ^{235}U no can spacers**	**load-limited to 12,000g ^{235}U no can spacers**		**load-limited to 18,000g ^{235}U no can spacers**	**can spacers are required**	**can spacers are required**
(1) five times "N" undamaged packages	bounded by CSI=0	bounded by CSI=0		bounded by CSI=0	Not applicable	Not applicable
(2) two times "N" damaged packages, ...	bounded by CSI=0	bounded by CSI=0		bounded by CSI=0	Not applicable	Not applicable
(3) the value of "N"	N(1,2) = 202/162	same		same	same	same
Transport index based on nuclear criticality control, CSI = 0.4	**load-limited to 32,983g ^{235}U can spacers**	**load-limited to 18,000g ^{235}U can spacers**		**load-limited to 30,000g ^{235}U can spacers**	**80% < enr. ≤ 100%, limited 16,342g ^{235}U can spacers**	**enr. ≤ 80%, limited 26,213g ^{235}U can spacxers**
(1) five times "N" undamaged packages	bounded by CSI=0	bounded by CSI=0		bounded by CSI=0	$k_{eff} + 2\sigma \le 0.7619$ nbf15slg_01_03_09_03	$k_{eff} + 2\sigma \le 0.8228$ nbf15slg_02_03_05_03
(2) two times "N" damaged packages, ...	bounded by CSI=0	bounded by CSI=0		bounded by CSI=0	$k_{eff} + 2\sigma \le 0.7596$ hbf25slg_01_03_09_03	$k_{eff} + 2\sigma \le 0.8602$ hbf25slg_02_03_06_03
(3) the value of "N"	N(1,2) = 202/162	same		same	same	same

Table 6.1b. Summary of criticality evaluation for solid HEU metal of unspecified geometric shape characterized as broken metal

Conditions	95% < enr. ≤ 100% ≤ 35,141g ^{235}U	90% < enr. ≤95% ≤ 33,405g ^{235}U	80% < enr. ≤90% ≤ 31,667g ^{235}U	70% < enr. ≤80% ≤ 28,184g ^{235}U	60% < enr. ≤70% ≤ 24,692g ^{235}U	enr. ≤60% ≤ 35,320g Uranium
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")	$k_{eff} + 2\sigma \le 0.8930$ cvr3lha_12_03_09_15	$k_{eff} + 2\sigma \le 0.8788$ cvr3lha_12_03_07_15	$k_{eff} + 2\sigma \le 0.8641$ cvr3lha_12_03_06_15	$k_{eff} + 2\sigma \le 0.8904$ cvr3lha_12_01_05_15	$k_{eff} + 2\sigma \le 0.8636$ cvr3lha_12_01_04_15	$k_{eff} + 2\sigma \le 0.8304$ cvr3lha_12_01_03_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 can pads, spacer can and convenience can steel is replaced with water. See Appendix 6.9.3, Sect. 6.9.3.1, for justification of the content model.					
	each can location separated by one can spacer			can spacers not used		
(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 6.1b. Summary of criticality evaluation for solid HEU metal of unspecified geometric shape characterized as broken metal (cont.)

Conditions	95% < enr. ≤ 100% ≤ 35,141g ^{235}U	90% < enr. ≤95% ≤ 33,405g ^{235}U	80% < enr. ≤90% ≤ 31,667g ^{235}U	70% < enr. ≤80% ≤ 28,184g ^{235}U	60% < enr. ≤70% ≤ 24,692g ^{235}U	enr. ≤60% ≤ 35,320g Uranium
"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,	$k_{eff} + 2\sigma \leq 0.8954$ (nbsrbm_12_01_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 6.1b. Summary of criticality evaluation for solid HEU metal of unspecified geometric shape characterized as broken metal (cont.)

Conditions	95% < enr. ≤ 100% ≤ 35,141g ^{235}U	90% < enr. ≤95% ≤ 33,405g ^{235}U	80% < enr. ≤90% ≤ 31,667g ^{235}U	70% < enr. ≤80% ≤ 28,184g ^{235}U	60% < enr. ≤70% ≤ 24,692g ^{235}U	enr. ≤60% ≤ 35,320g Uranium
"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")	$k_{eff} + 2\sigma \leq 0.8957$ (hbsrbm_12_01_.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 6.1b. Summary of criticality evaluation for solid HEU metal of unspecified geometric shape characterized as broken metal (cont.)

Conditions	95% < enr. ≤ 100% ≤ 35,141g ^{235}U	90% < enr. ≤95% ≤ 33,405g ^{235}U	80% < enr. ≤90% ≤ 31,667g ^{235}U	70% < enr. ≤80% ≤ 28,184g ^{235}U	60% < enr. ≤70% ≤ 24,692g ^{235}U	enr. ≤60% ≤ 35,320g Uranium
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 are required**	**can spacers are required**	**can spacers are required**	**load-limited to 2,225g ^{235}U no can spacers**	**load-limited to 1,949g ^{235}U no can spacers**	**load-limited to 5,576g Uranium no can spacers**
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.8153$ nbiabm_04_01_05_03	$k_{eff} + 2\sigma \leq 0.8524$ nbiabm_05_01_04_03	$k_{eff} + 2\sigma \leq 0.8555$ nbiabm_06_01_03_03
(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	$k_{eff} + 2\sigma \leq 0.8297$ hbiabm_04_01_05_03	$k_{eff} + 2\sigma \leq 0.8090$ hbiabm_04_01_04_03	$k_{eff} + 2\sigma \leq 0.8472$ hbiabm_05_01_03_03
(3) the value of "N" cannot be less than 0.5.	Not applicable	Not applicable	Not applicable	$N(1,2) = \infty$	same	same

Table 6.1b. Summary of criticality evaluation for solid HEU metal of unspecified geometric shape characterized as broken metal (cont.)

Conditions	95% < enr. ≤ 100% ≤ 35,141g ^{235}U	90% < enr. ≤95% ≤ 33,405g ^{235}U	80% < enr. ≤90% ≤ 31,667g ^{235}U	70% < enr. ≤80% ≤ 28,184g ^{235}U	60% < enr. ≤70% ≤ 24,692g ^{235}U	enr. ≤60% ≤ 35,320g Uranium
Transport index based on nuclear criticality control, CSI = 0.0	**load-limited to 2,774g ^{235}U can spacers**	**load-limited to 2,637g ^{235}U can spacers**	**load-limited to 2,500g ^{235}U can spacers**	**load-limited to 2,225g ^{235}U can spacers**	**load-limited to 5,848g ^{235}U can spacers**	**load-limited to 11,153g Uranium can spacers**
(1) five times "N" undamaged packages ...	$k_{eff} + 2\sigma \leq 0.8336$ nbiabm_04_03_09_03	$k_{eff} + 2\sigma \leq 0.8254$ nbiabm_04_03_07_03	$k_{eff} + 2\sigma \leq 0.8160$ nbiabm_04_03_06_03	$k_{eff} + 2\sigma \leq 0.8496$ nbiabm_05_03_05_03	$k_{eff} + 2\sigma \leq 0.8501$ nbiabm_06_03_04_03	$k_{eff} + 2\sigma \leq 0.8589$ nbiabm_09_03_03_03
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.8488$ hbiabm_04_03_09_03	$k_{eff} + 2\sigma \leq 0.8387$ hbiabm_04_03_07_03	$k_{eff} + 2\sigma \leq 0.8296$ hbiabm_04_03_06_03	$k_{eff} + 2\sigma \leq 0.8090$ hbiabm_04_03_05_03	$k_{eff} + 2\sigma \leq 0.8641$ hbiabm_06_03_04_03	$k_{eff} + 2\sigma \leq 0.8580$ hbiabm_07_03_03_03
(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 are required**	**can spacers are required**	**can spacers are required**	**load-limited to 4,450g ^{235}U no can spacers**	**load-limited to 7,797g ^{235}U no can spacers**	**load-limited to 17,660g Uranium no can spacers**
(1) five times "N" undamaged packages	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.8451$ nbf1bm_05_01_05_03	$k_{eff} + 2\sigma \leq 0.8631$ nbf1bm_07_01_04_03	$k_{eff} + 2\sigma \leq 0.8610$ nbf1bm_09_01_03_03
(2) two times "N" damaged packages, ...	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.8717$ hbf2bm_08_01_05_03	$k_{eff} + 2\sigma \leq 0.8740$ hbf2bm_10_01_04_03	$k_{eff} + 2\sigma \leq 0.8739$ hbf2bm_12_01_03_03
(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 5,548g ^{235}U can spacers**	**load-limited to 5,274g ^{235}U can spacers**	**load-limited to 7,500g ^{235}U can spacers**	**load-limited to 8,900g ^{235}U can spacers**	**load-limited to 12,346g ^{235}U can spacers**	**load-limited to 29,743g Uranium can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.8646$ nbf1bm_05_03_09_03	$k_{eff} + 2\sigma \leq 0.8538$ nbf1bm_05_03_07_03	$k_{eff} + 2\sigma \leq 0.8644$ nbf1bm_06_03_06_03	$k_{eff} + 2\sigma \leq 0.8587$ nbf1bm_07_03_05_03	$k_{eff} + 2\sigma \leq 0.8601$ nbf1bm_09_03_04_03	$k_{eff} + 2\sigma \leq 0.8622$ nbf1bm_11_03_03_03
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.8592$ hbf2bm_05_03_09_03	$k_{eff} + 2\sigma \leq 0.8673$ hbf2bm_06_03_07_03	$k_{eff} + 2\sigma \leq 0.8727$ hbf2bm_07_03_06_03	$k_{eff} + 2\sigma \leq 0.8697$ hbf2bm_09_03_05_03	$k_{eff} + 2\sigma \leq 0.8661$ hbf2bm_10_03_04_03	$k_{eff} + 2\sigma \leq 0.8625$ hbf2bm_12_03_03_03
(3) the value of "N"	N(1,2) = 202/162	same	same	same	same	same

Table 6.1b. Summary of criticality evaluation for solid HEU metal of unspecified geometric shape characterized as broken metal (cont.)

Conditions	95% < enr. ≤ 100% ≤ 35,141g ^{235}U	90% < enr. ≤95% ≤ 33,405g ^{235}U	80% < enr. ≤90% ≤ 31,667g ^{235}U	70% < enr. ≤80% ≤ 28,184g ^{235}U	60% < enr. ≤70% ≤ 24,692g ^{235}U	enr. ≤60% ≤ 35,320g Uranium
Transport index based on nuclear criticality control, CSI = 0.8	**can spacers are required**	**can spacers are required**	**can spacers are required**	**load-limited to 23,734g ^{235}U no can spacers**	**load-limited to 16,245g ^{235}U no can spacers**	load-limited to 35,320g Uranium no can spacers
(1) five times "N" undamaged packages	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.8717$ nbf2bm_08_01_05_03	$k_{eff} + 2\sigma \leq 0.8740$ nbf2bm_10_01_04_03	$k_{eff} + 2\sigma \leq 0.8739$ nbf2bm_12_01_03_03
(2) two times "N" damaged packages, ...	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.8732$ hbf3bm_09_01_05_03	$k_{eff} + 2\sigma \leq 0.8824$ hbf3bm_11_01_04_03	$k_{eff} + 2\sigma \leq 0.8662$ hbf3bm_12_01_03_03
(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 8,323g ^{235}U can spacers**	**load-limited to 10,549g ^{235}U can spacers**	**load-limited to 10,000g ^{235}U can spacers**	**load-limited to 14,092g ^{235}U can spacers**	**load-limited to 20,793g ^{235}U can spacers**	load-limited to 35,320g Uranium can spacers
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.8679$ nbf2bm_06_03_09_03	$k_{eff} + 2\sigma \leq 0.8705$ nbf2bm_07_03_07_03	$k_{eff} + 2\sigma \leq 0.8619$ nbf2bm_07_03_06_03	$k_{eff} + 2\sigma \leq 0.8604$ nbf2bm_09_03_05_03	$k_{eff} + 2\sigma \leq 0.8694$ nbf2bm_11_03_04_03	$k_{eff} + 2\sigma \leq 0.8534$ nbf2bm_12_03_03_03
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.8774$ hbf3bm_07_03_09_03	$k_{eff} + 2\sigma \leq 0.8799$ hbf3bm_08_03_07_03	$k_{eff} + 2\sigma \leq 0.8741$ hbf3bm_09_03_06_03	$k_{eff} + 2\sigma \leq 0.8693$ hbf3bm_10_03_05_03	$k_{eff} + 2\sigma \leq 0.8724$ hbf3bm_12_03_04_03	$k_{eff} + 2\sigma \leq 0.8441$ hbf3bm_12_03_03_03
(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 *	**can spacers are required**	**can spacers are required**	**can spacers are required**	**load-limited to 18,542g ^{235}U no can spacers**	load-limited to 24,692g ^{235}U no can spacers	load-limited to 35,320g Uranium no can spacers
(1) five times "N" undamaged packages	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.8775$ nbf3bm_10_01_05_03	$k_{eff} + 2\sigma \leq 0.8791$ nbf3bm_12_01_04_03	$k_{eff} + 2\sigma \leq 0.8549$ nbf3bm_12_01_03_03
(2) two times "N" damaged packages, ...	Not applicable	Not applicable	Not applicable	$k_{eff} + 2\sigma \leq 0.8836$ hbf4bm_12_01_05_03	$k_{eff} + 2\sigma \leq 0.8575$ hbf4bm_12_01_04_03	$k_{eff} + 2\sigma \leq 0.8314$ hbf4bm_12_01_03_03
(3) the value of "N"	Not applicable	Not applicable	Not applicable	N(1,2) = 29/25	same	same

Table 6.1b. Summary of criticality evaluation for solid HEU metal of unspecified geometric shape characterized as broken metal (cont.)

Conditions	95% < enr. ≤ 100% ≤ 35,141g ^{235}U	90% < enr. ≤95% ≤ 33,405g ^{235}U	80% < enr. ≤90% ≤ 31,667g ^{235}U	70% < enr. ≤80% ≤ 28,184g ^{235}U	60% < enr. ≤70% ≤ 24,692g ^{235}U	enr. ≤60% ≤ 35,320g Uranium
Transport index based on nuclear criticality control, CSI = 2.0 *	**load-limited to 11,097g ^{235}U can spacers**	**load-limited to 16,703g ^{235}U can spacers**	**load-limited to 15,834g ^{235}U can spacers**	**load-limited to 23,734g ^{235}U can spacers**	**load-limited to 24,692g ^{235}U can spacers**	**load-limited to 35,320g Uranium can spacers**
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.8667$ nbf3bm_07_03_09_03	$k_{eff} + 2\sigma \leq 0.8737$ nbf3bm_09_03_07_03	$k_{eff} + 2\sigma \leq 0.8626$ nbf3bm_09_03_06_03	$k_{eff} + 2\sigma \leq 0.8761$ nbf3bm_11_03_05_03	$k_{eff} + 2\sigma \leq 0.8634$ nbf3bm_12_03_04_03	$k_{eff} + 2\sigma \leq 0.8335$ nbf3bm_12_03_03_03
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.8696$ hbf4bm_09_03_09_03	$k_{eff} + 2\sigma \leq 0.8715$ hbf4bm_10_03_07_03	$k_{eff} + 2\sigma \leq 0.8729$ hbf4bm_11_03_06_03	$k_{eff} + 2\sigma \leq 0.8618$ hbf4bm_12_03_05_03	$k_{eff} + 2\sigma \leq 0.8378$ hbf4bm_12_03_04_03	$k_{eff} + 2\sigma \leq 0.8093$ hbf4bm_12_03_03_03
(3) the value of "N"	N(1,2) = 29/25	same	same	same	same	same

* Neutron multiplication factors and "N" are shown for an NCT array size of 7x7x3 and an HAC array size of 5x5x2; both arrays are nearly cubic arrangements. An HAC array size is not available for CSI=1.7; therefore, CSI for NCT at 1.7 is rounded up as shown.

Table 6.1c. Summary of criticality evaluation for HEU oxide and UNH crystals

Conditions	HEU oxide ≤ 21,124g ^{235}U	UNH crystals ≤ 11,303g ^{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")	$k_{eff} + 2\sigma \leq 0.8728$ (cvrox_01_11_01_15)	$k_{eff} + 2\sigma \leq 0.8572$ (cvrunhc_06_01_15)
(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 Appendix 6.9.3, Sect. 6.9.3.1, for justification of the content model.	UNH crystals are homogenized with water over the internal volume of the containment vessel consistent with the high solubility properties of UNH. Maximum reactivity occurs at 414 gU/l solution concentration. Amount of water calculated for the flooded containment vessel 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.
(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 6.1c. Summary of criticality evaluation for HEU oxide and UNH crystals (cont.)

Conditions	HEU oxide ≤ 21,124g ^{235}U	UNH crystals ≤ 11,303g ^{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,	$k_{eff} + 2\sigma \le 0.7911$ (nbsrox_01_11_01_15)	$k_{eff} + 2\sigma \le 0.7510$ (nbsrunhc_07_01_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.	UNH crystals are homogenized with water over the internal volume of the containment vessel consistent with the high solubility properties of UNH. Maximum reactivity occurs at 415 gU/l solution concentration. Amount of water calculated for the flooded containment vessel 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.
(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 6.1c. **Summary of criticality evaluation for HEU oxide and UNH crystals (cont.)**

Conditions	HEU oxide ≤ 21,124g ^{235}U	UNH crystals ≤ 11,303g ^{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")	$k_{eff} + 2\sigma \leq 0.7907$ (hbsrox_01_11_01_15)	$k_{eff} + 2\sigma \leq 0.8120$ (ibsrunhc_09_01_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.	Consistent with the high solubility properties of UNH, crystals and water are homogenized over the internal volume of the containment vessel and void space of the containment vessel well. Amount of water calculated for the flooded containment vessel 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.
(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 6.1c. Summary of criticality evaluation for HEU oxide and UNH crystals (cont.)

Conditions	HEU oxide ≤ 21,124g ^{235}U	UNH crystals ≤ 11,303g ^{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 21,124g ^{235}U no can spacers	load-limited to 11,303g ^{235}U no can spacers
(1) five times "N" undamaged packages with nothing between the packages would be subcritical,	$k_{eff} + 2\sigma \leq 0.8457$ nbiaox_01_11_01_03	$k_{eff} + 2\sigma \leq 0.8192$ nbiaunhc_10_11_01_03
(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,	$k_{eff} + 2\sigma \leq 0.8606$ hbiaox_01_11_01_03	$k_{eff} + 2\sigma \leq 0.8345$ hbiaunhc_10_11_01_03
(3) the value of "N" cannot be less than 0.5.	N(1,2) = ∞	same
Transport index based on nuclear criticality control, CSI = 0.0	load-limited to 21,124g ^{235}U can spacers	load-limited to 11,303g ^{235}U can spacers
(1) five times "N" undamaged packages	$k_{eff} + 2\sigma \leq 0.8012$ nbiaox_01_11_03_15	$k_{eff} + 2\sigma \leq 0.7952$ nbiaunhc_10_11_03_03
(2) two times "N" damaged packages, ...	$k_{eff} + 2\sigma \leq 0.8591$ hbiaox_01_11_03_03	$k_{eff} + 2\sigma \leq 0.8133$ hbiaunhc_10_11_03_03
(3) the value of "N"	N(1,2) = ∞	same

Table 6.2. Fissile material mass loading limits for HEU

Solid HEU metal of specified geometric shapes						
Transport index based on nuclear criticality control	**spheres**	**cylinders**	**bars**	**slugs 80% < enr. ≤ 100%**	**slugs enr. ≤ 80%**	
No can spacers						
CSI = 0.0	16,946g ^{235}U	12,000g ^{235}U	18,000g ^{235}U	can spacers required	can spacers required	
With can spacers						
CSI = 0.0	32,983g ^{235}U	18,000g ^{235}U	30,000g ^{235}U	16,342g ^{235}U	26,213g ^{235}U	
Solid HEU metal of unspecified geometric shape characterized as broken metal						
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	2,225g ^{235}U	1,949g ^{235}U	5,576g Uranium
CSI = 0.4	can spacers required	can spacers required	can spacers required	4,450g ^{235}U	7,797g ^{235}U	17,660g Uranium
CSI = 0.8	can spacers required	can spacers required	can spacers required	14,092g ^{235}U	16,245g ^{235}U	35,320g Uranium
CSI = 2.0	can spacers required	can spacers required	can spacers required	18,542g ^{235}U	24,692g ^{235}U	35,320g Uranium
With can spacers						
CSI = 0.0	2,774g ^{235}U	2,637g ^{235}U	2,500g ^{235}U	2,225g ^{235}U	5,848g ^{235}U	11,153g Uranium
CSI = 0.4	5,548g ^{235}U	5,274g ^{235}U	7,500g ^{235}U	8,900g ^{235}U	12,346g ^{235}U	29,743g Uranium
CSI = 0.8	8,323g ^{235}U	10,549g ^{235}U	10,000g ^{235}U	18,542g ^{235}U	20,793g ^{235}U	35,320g Uranium
CSI = 2.0	11,097g ^{235}U	16,703g ^{235}U	15,834g ^{235}U	23,734g ^{235}U	24,692g ^{235}U	35,320g Uranium
HEU oxide and UNH crystals						
Transport index based on nuclear criticality control	**HEU oxide, no can spacers**	**UNH crystals, no can spacers**				
CSI = 0.0	21,124g ^{235}U	11,303g ^{235}U				

6.2 PACKAGE CONTENTS

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.

6.2.1 Fissile Material Contents

The 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 UNH crystals. The HEU mass may include nonradioactive contaminants and trace elements/materials in the HEU.

The bounding types of HEU content evaluated in this criticality analysis are: 3.24-in. diameter spheres and cylinders; 2.29-in. square bars; 1.5-in. diameter × 2-in. tall slugs; cubes ranging from 0.25 to 1 in. on a side; broken metal pieces of unspecified geometric shapes; uranium oxide; and UNH crystals.

The term "broken metal pieces" is 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 20 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.

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 20 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, oxide bulk densities are typically on the order of 6.54 g/cm^3; therefore, only "less-than-theoretical" mass loadings would actually be achieved. Water-saturation of the HEU oxide and crystallization is not expected in the HAC given that UO_2 and UO_3 are non-hygroscopic, while U_3O_8 is only mildly hygroscopic. The density of UNH crystals varies depending on the degree of hydration. The most reactive form of $UO_2(NO_3) \cdot xH_2O$ is with 6 molecules of hydration, having a density of 2.79 g/cm^3. UNH crystals are highly soluble in nitric acid and mildly soluble in water. Dissolution of UNH crystals in water is assumed in this criticality evaluation. The content geometry envelope encompasses both regular, uniform clumps and densities as well as irregular clumps and densities.

Although HEU enrichment ranges from 20 to 97.7 wt % ^{235}U, a maximum enrichment of 100 wt % is used for HEU oxide and UNH crystals in this criticality evaluation, strictly for the purpose of maximizing reactivity. 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/ 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 reduced into HEU oxide and meet the additional content requirements identified in Sect. 6.2.4 can be shipped in this package.

6.2.2 Convenience Cans and Cat 277-4 Canned Spacers

Convenience cans 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 oxide or metal content may be bagged or wrapped in polyethylene, and the convenience cans may also be wrapped in polyethylene and/or nylon to further reduce the possibility of contamination. Masses of the convenience cans and packing materials are in addition to the fissile material mass.

Three 4.25-in. diameter × 10.0-in. tall convenience cans physically fit inside an ES-3100 containment vessel. Other can arrangements (Drawing No. M2E801580A035, Appendix 1.4.1) fit inside the containment vessel. Convenience cans are separated by can pads and Cat 277-4 canned spacers approximately 4.0-in. in diameter × 1-5/16 in. in thickness. Credit for fissile material spacing provided by convenience cans inside the containment vessel is not taken in this criticality analysis because these cans are not manufactured to the *ASME Boiler and Pressure Vessel Code*, Sect. III, Subsection NG, or better. Thus, other configurations of convenience cans up to 5.0-in. diameter are permissible provided Cat 277-4 canned spacers are used as needed for criticality control.

6.2.3 Packing Materials

The amount of hydrogenous packing material used in the Model ES-3100 package is expected to be much less than 1 kg. Polyethylene bags may be used for contamination control. Realistically, the number of polyethylene bags used to wrap a convenience can would be three bags at most. Given that each bag weighs ~33 g, this results in a maximum of ~297 g of polyethylene per ES-3100 package. An equivalent H/X ratio is calculated and displayed for informational purposes, designated as the "wrapped can H/X ratio" in the calculation results tables of Sects. 6.4, 6.5, and 6.6. These H/X values are much less than the assumed H/X in the criticality calculations.

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, the 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 UNH crystals or impurities in the oxide.)

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 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.) Given that a flooded containment vessel is assumed for both NCT and HAC calculations, the restriction on hydrogen moderator is specified instead in terms of hydrogen density. The total amount of hydrogen contained in the package content, in the absorbed moisture or hydration molecules of the fissile content, and the water of a flooded containment vessel shall not exceed an average density of 0.1117 g/cm^3 inside the volume of the containment vessel not occupied by the fissile material. This limit corresponds to the flooded condition assumed in the calculations where the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents.

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 shall be placed in stainless steel, aluminum, tin-plated carbon steel, or nickel-plated carbon steel convenience cans. The can lid types may be welded, press fit, slip lid, crimp seal, or screw cap.

(2) The ES-3100 package may carry up to six loaded convenience cans as shown on Drawing No. M2E801580A035. Configurations of convenience cans up to 5.0-in. diameter are permissible provided Cat 277-4 canned spacers are used as needed for criticality control.

(3) A shipping package may be loaded with "x" number of content-bearing 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, the heavier cans will be loaded into the bottom of the upright shipping container, and the empty cans will be placed above them.

(4) The presence of uranium isotopes is limited on a weight-percent basis as follows: $^{232}U \leq 40$ ppb U, $^{234}U \leq 2.0$ wt % U, $^{235}U \leq 100.0$ wt % U, and $^{236}U \leq 40.0$ wt % U.

(5) For pyrophoric considerations, HEU loading is further restricted to broken metal piece sizes to a specific surface area not greater than 1.00 cm^2/g or a piece weight not less than 50 g, whichever is more restrictive. Furthermore, foils, turnings, and wires, which can easily have much higher specific surface areas, are not permitted for shipment. (Y/LB-15,920/Rev.1)

(6) The content shall not exceed the "per package" fissile material mass loading limits specified in Table 6.2 based on the CSI. Where can spacers are required for a "per package" mass loading, the quantity of fissile material located between any two Cat 277-4 canned spacers shall not exceed one-third of the mass loading limit. The content mass loading may be further restricted based on structural, mechanical, and practical considerations (see Sects. 1 and 2).

(7) HEU bulk metal or alloy content not covered by the specified geometric shapes (HEU sphere, stacked spheres, cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited. However, billets, buttons, or large irregular pieces of solid HEU metal may be approved under limits for specified geometric shapes evaluated in this SAR, provided that a facility criticality safety evaluation/approval demonstrates these content loadings are bounded by the results of this SAR evaluation for specified geometric shapes.

(8) The total amount of hydrogen contained in both the package content (including absorbed moisture and/or hydration molecules of the fissile content) and the water if the containment vessel were to flood, shall not exceed an average density of 0.1117 g/cm^3 inside the free volume of the containment vessel not occupied by dry package content. 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.

(9) The CSI is determined on the basis of the uranium enrichment and total ^{235}U mass in the package and content shape or form.

6.3 GENERAL CONSIDERATIONS

The ES-3100 packaging configuration is shown on Drawing No. M2E801580A031 (Appendix 1.4.1). 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–6.1c). Key input listings are provided in Appendix 6.9.7.

The HEU content of a package is in one of the following forms: metal of a specified geometric shape, metal of an unspecified shape characterized as broken metal, uranium oxide, or UNH crystals. The bounding types of HEU content evaluated in this criticality analysis are: 3.24-in. diameter spheres and cylinders; 2.29-in. square bars; 1.5-in. diameter × 2-in. tall slugs; cubes ranging from 0.25 to 1 in. on a side; broken metal pieces of unspecified geometric shape; uranium oxide; and UNH crystals.

HEU metal shapes are distributed in a 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 uranyl nitrate 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, in 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.

The Cat 277-4 material inside the spacer can is not less than 3.95-in. in diameter by 1.06-in. in thickness. Can spacers are used as indicated in Table 6.2 for the purpose of reducing neutronic interaction between the contents of the package, aiding in maintaining $k_{eff} + 2\sigma$ for the ES-3100 package below the USL.

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), and the HAC calculation models (Sect. 6.3.1.3). 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, and 5×5×2 arrangements with full water reflection at the array boundary.

The geometry of the ES-3100 package is depicted in Drawing No. M2E801580A001 (Appendix 1.4.1). 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 No. M2E801580A001 (Appendix 1.4.1) 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, Cat 277-4 canned spacers, the containment vessel, the stainless-steel liner, the inner-liner cavity filled with Cat 277-4, the outer-liner cavity filled with Kaolite, the Kaolite top plug and steel shell, the silicone 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 a package with three loaded convenience cans inside the containment vessel; the fissile material contents are represented as spheres. Appendix 6.9.1 provides wire-frame schematic diagrams depicting the contents considered in this criticality calculation.

As illustrated in Fig. 6.1, credit is not taken for fissile material spacing provided by convenience cans inside the containment vessel. 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 is 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 a reflected system with 30 cm (1 ft) of water surrounding the package for effectively infinite water reflection.

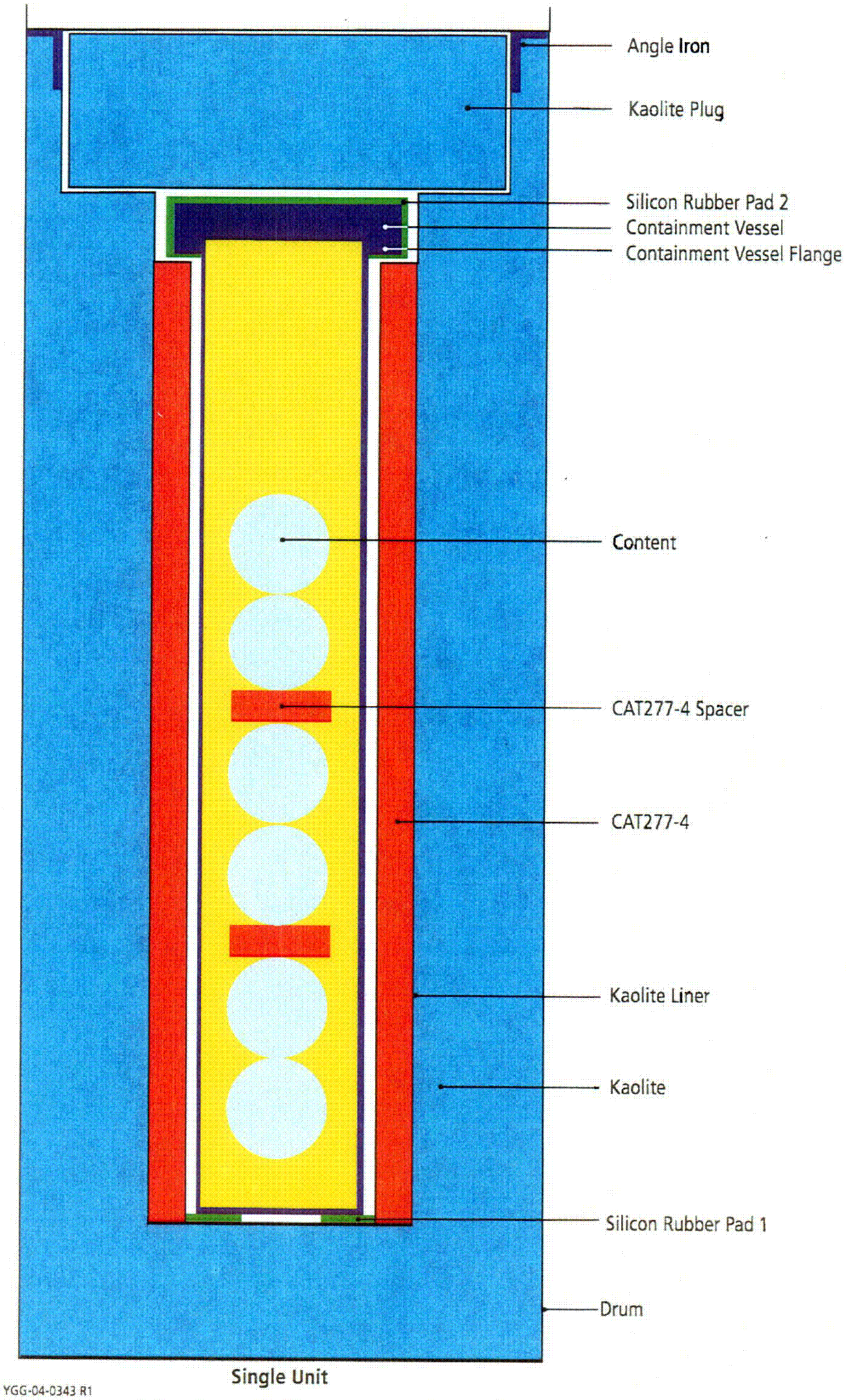


Fig. 6.1. R/Z section view of ES-3100 package.

C58

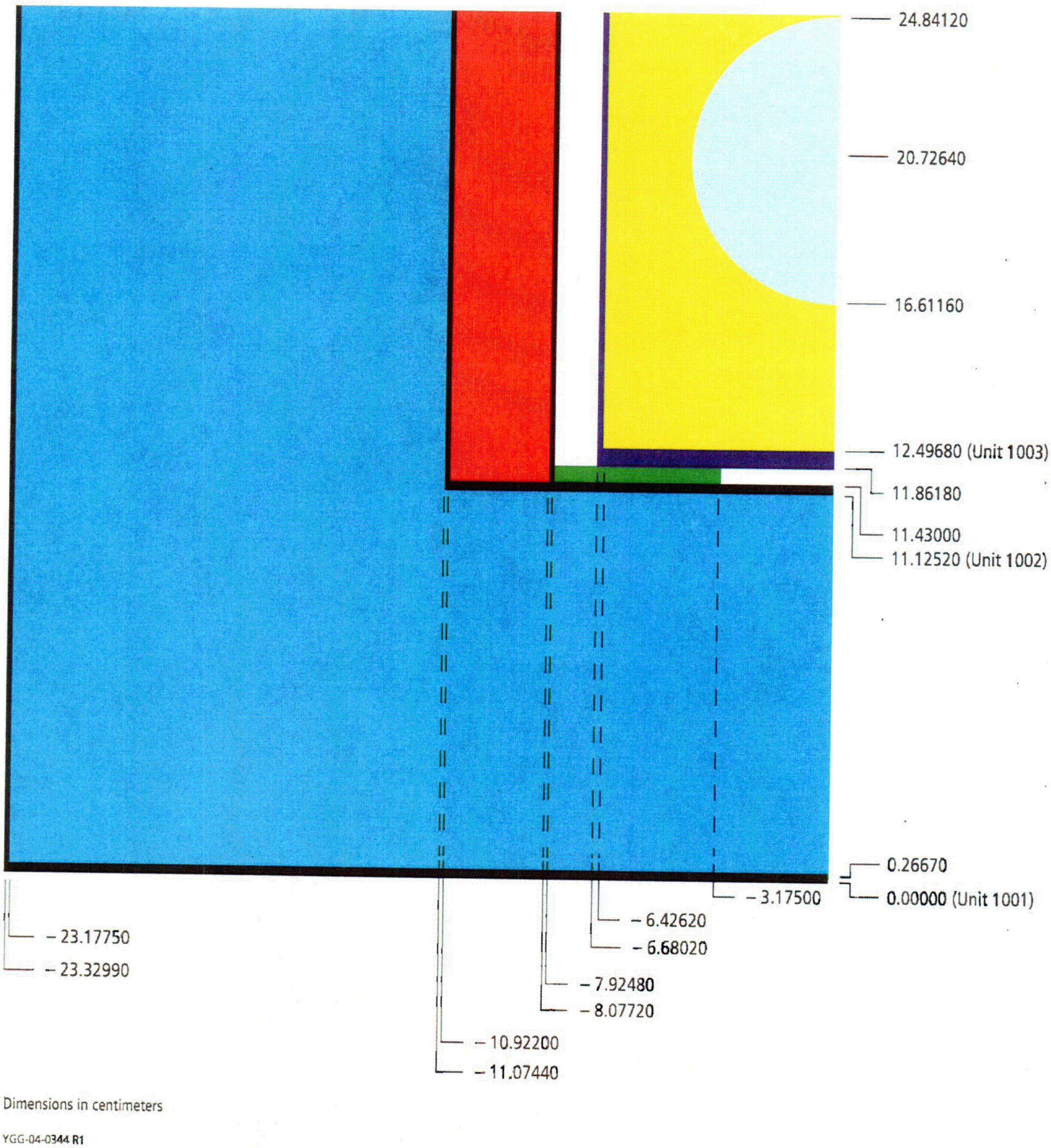
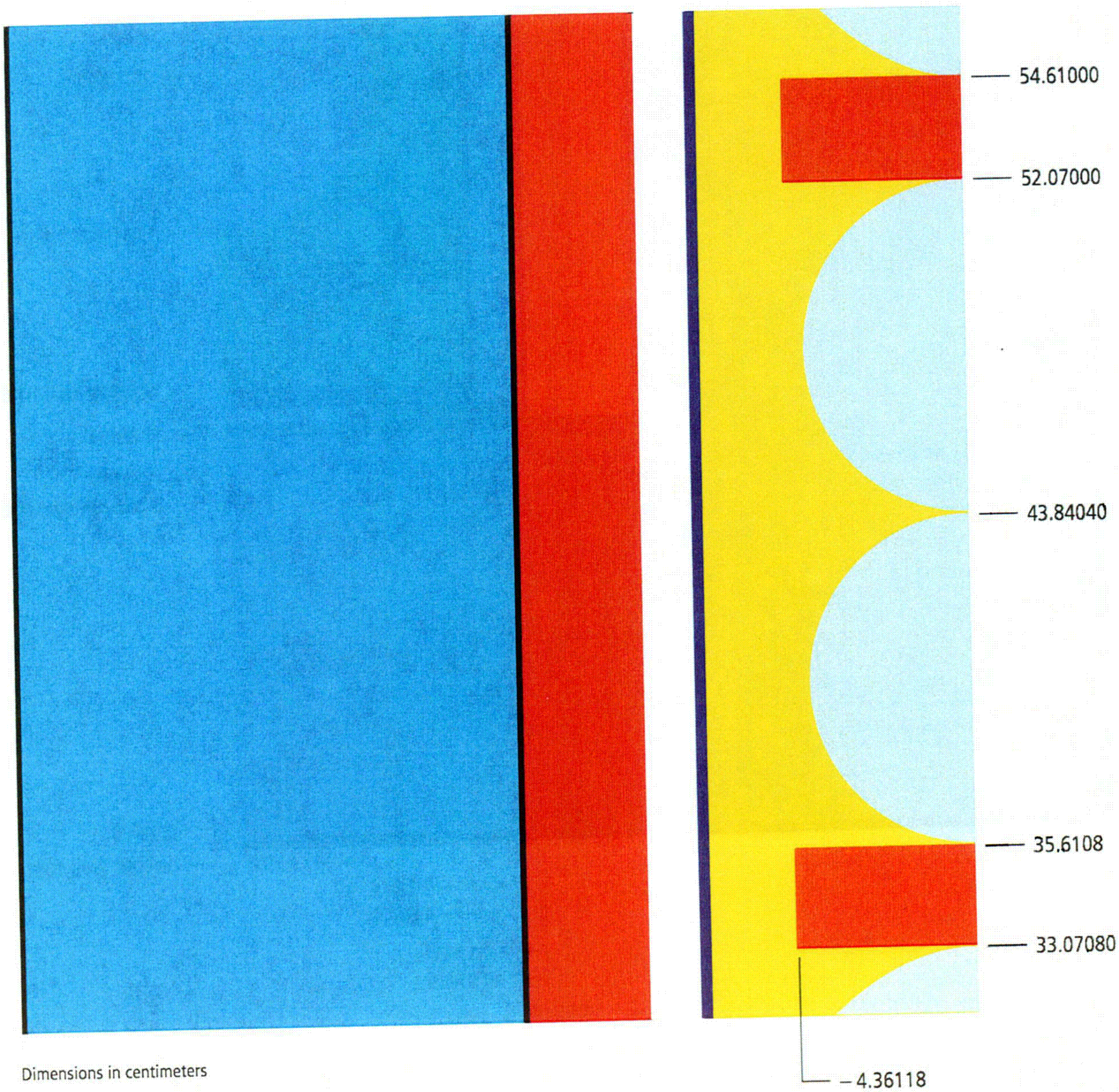


Fig. 6.2. R/Z section view at bottom of ES-3100 package showing KENO V.a geometry units 1001, 1002, and 1003 (partial).

C59



Dimensions in centimeters

YGG-04-0345 R1

Fig. 6.3. R/Z section view at center of the ES-3100 package showing KENO V.a geometry unit 1003 (partial).

CGO

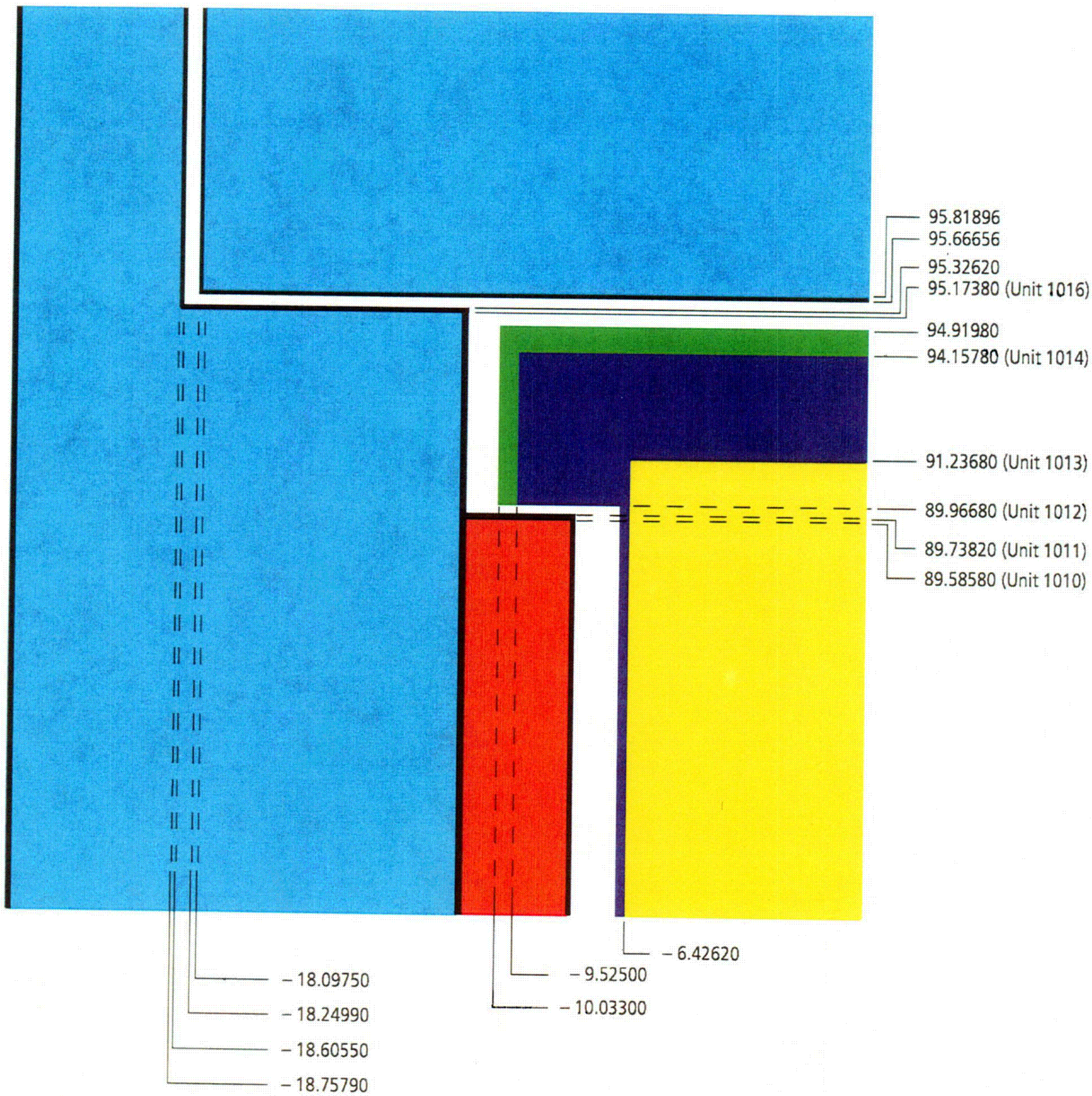


Fig 6.4. R/Z section view of near top of the ES-3100 package showing KENO V.a geometry units 1003 (partial) and 1010–1016.

CGl

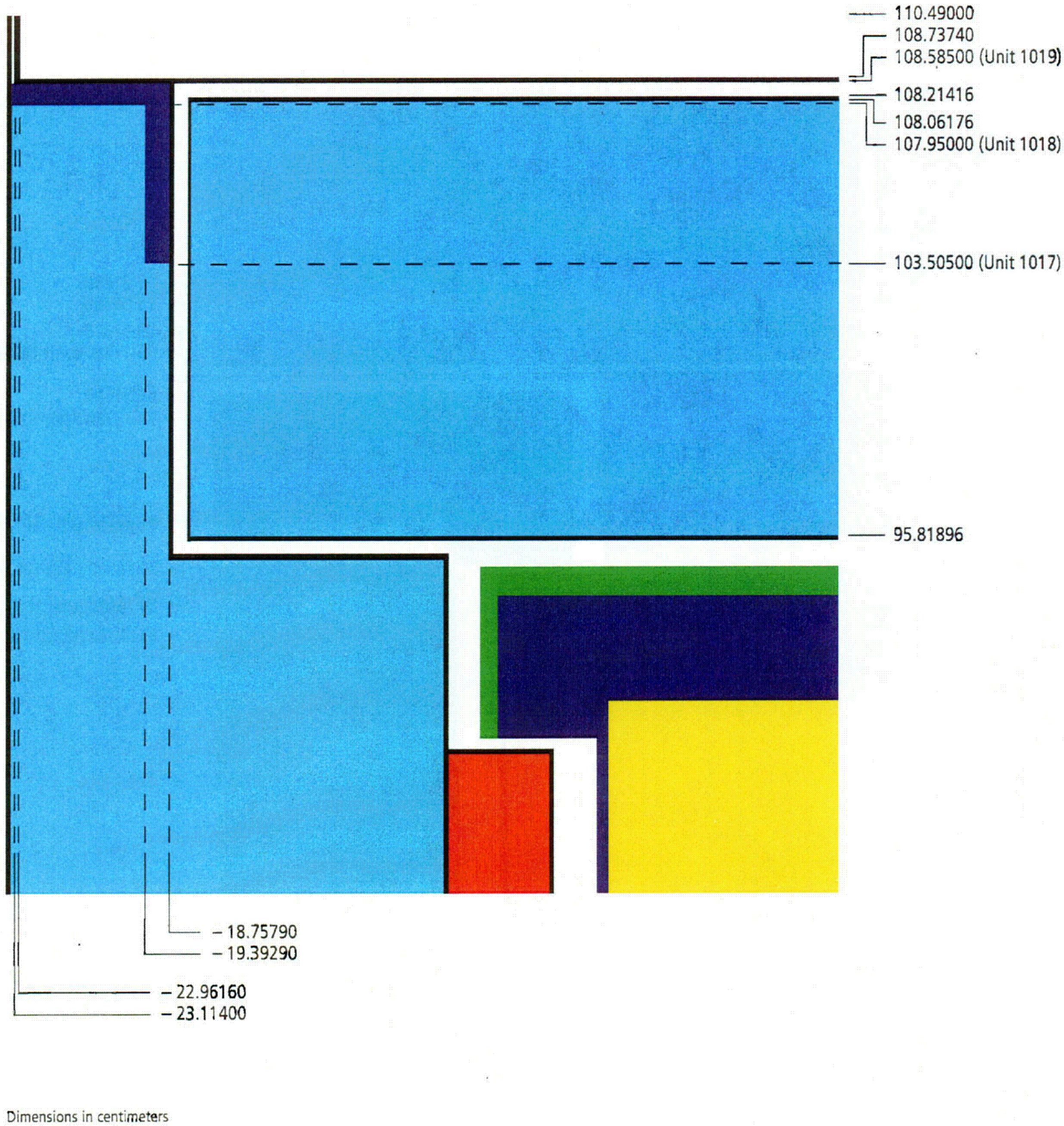


Fig. 6.5. R/Z section view at top of the ES-3100 package showing KENO V.a geometry units 1016–1019.

CG2

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. (Odell and Schlesser 1991) 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.

As seen in Drawing No. M2E801580A002 (Appendix 1.4.1), a 7.0% reduction of the inside diameter of the ES-3100 drum affects the masses of the drum, the inner liner's internal flange, 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 array packaging calculation model, the drum's outside diameter, the density of the steel in the internal flange, 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 array geometry 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, and the drum outer diameter is modified to maintain drum mass. The internal flange outside diameter is identical to the drum inside diameter. To maintain mass, the internal flange 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 internal flange 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.

Odell 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 internal flange is slightly less than 0.9306. Given that the array packages are closer than required by Odell 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 array 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, wide and depth.

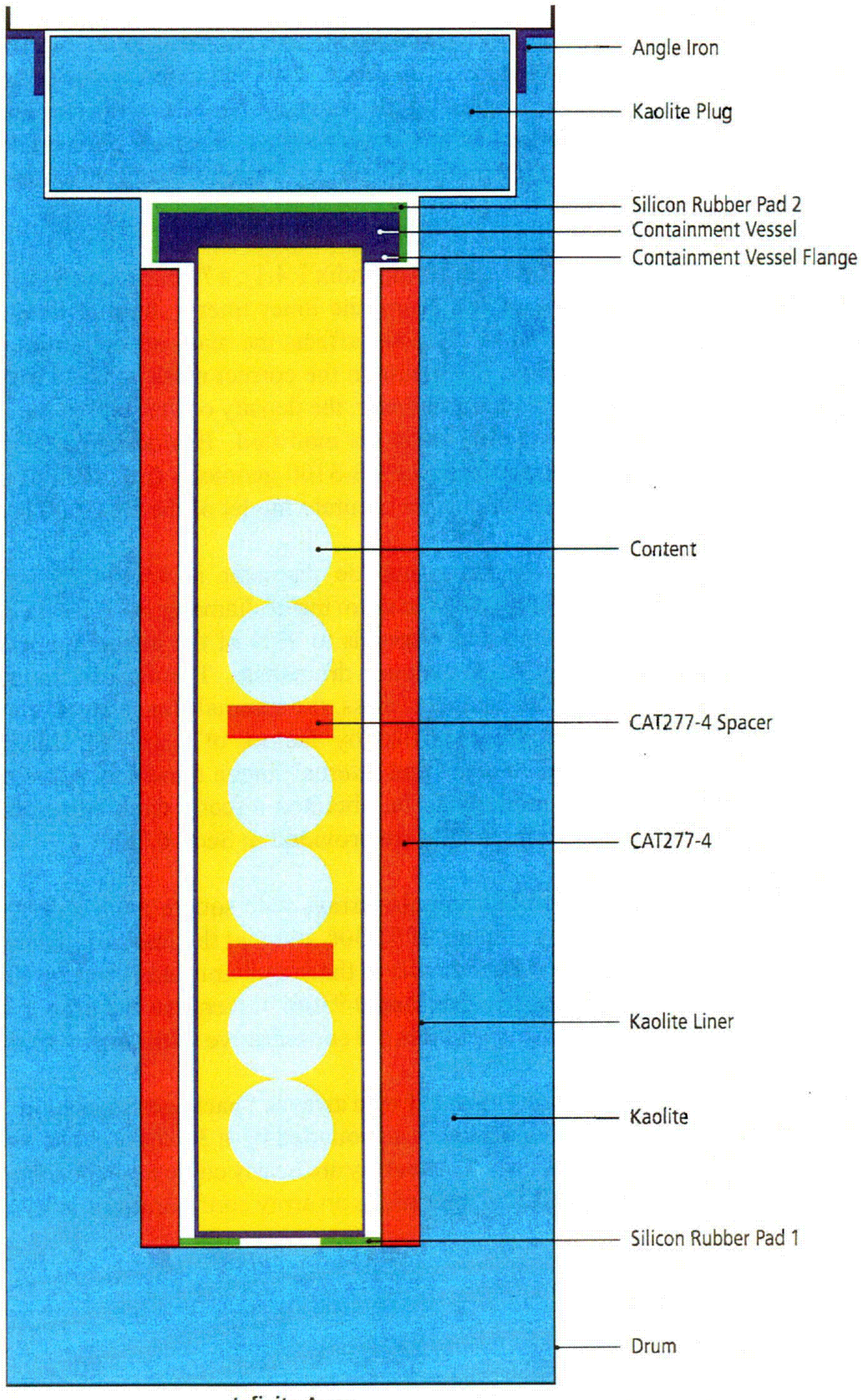


Fig. 6.6 R/Z section view of ES-3100 package.

C63

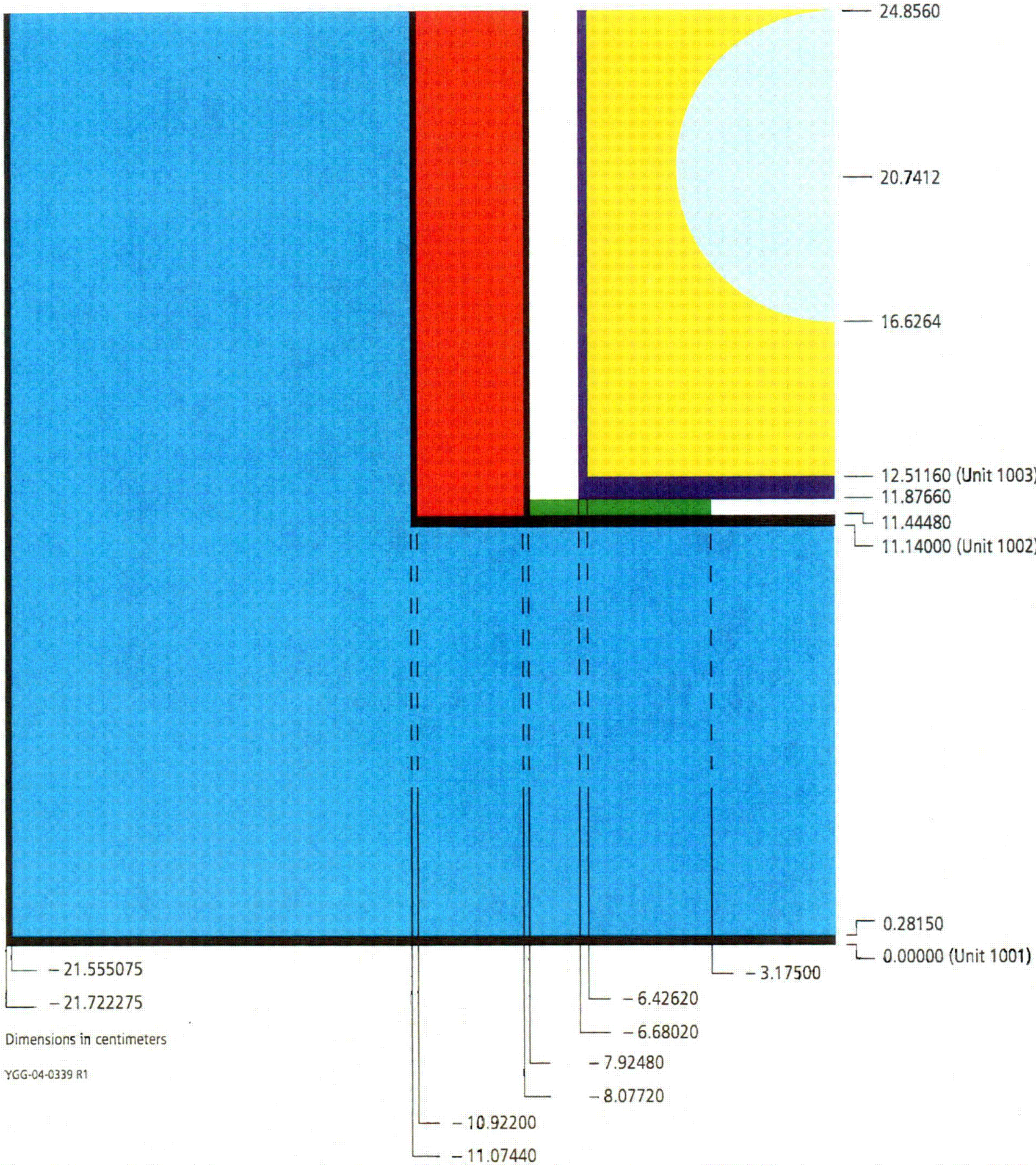
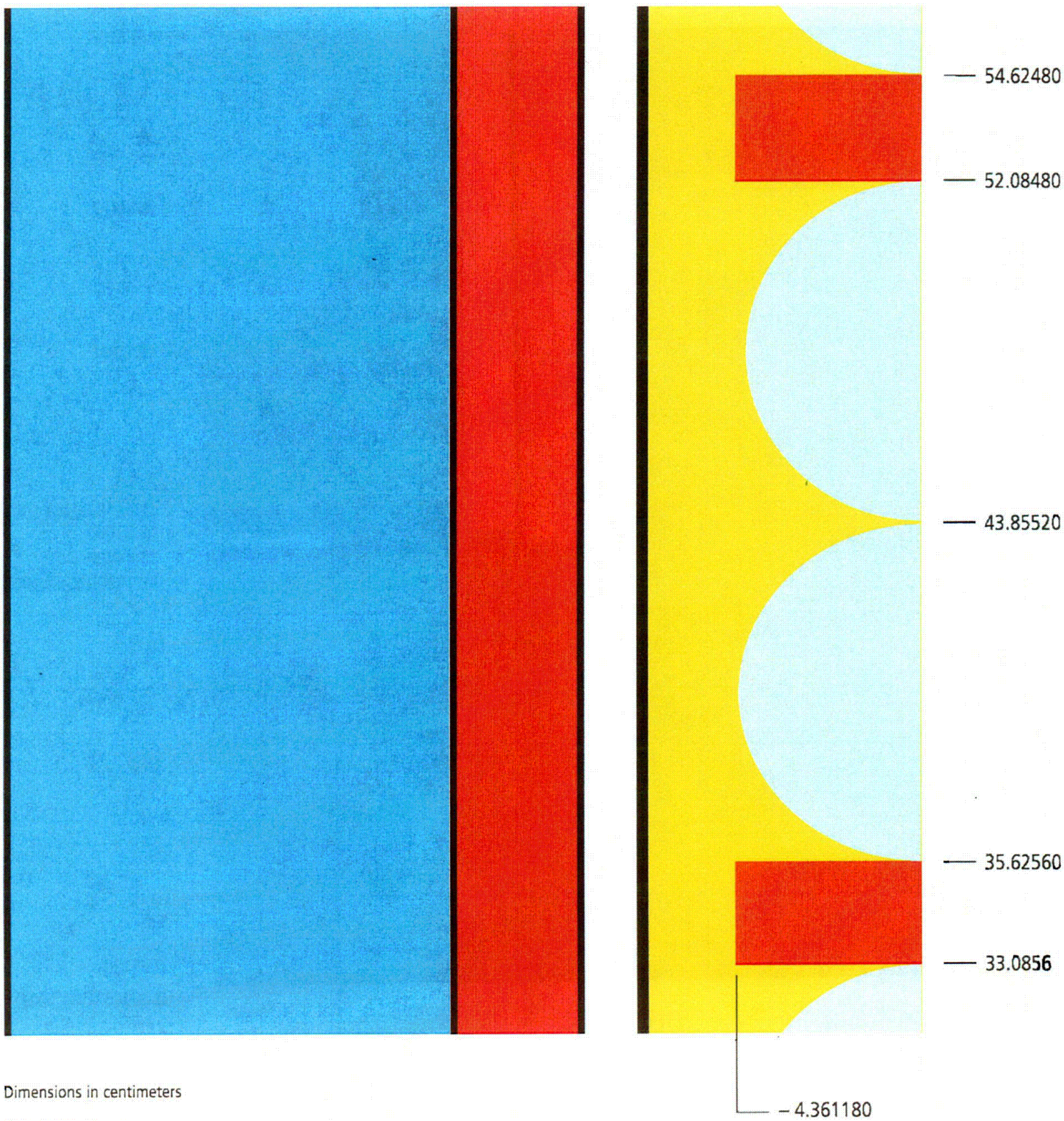


Fig. 6.7. R/Z section view at bottom of ES-3100 package showing KENO V.a geometry units 1001, 1002, and 1003 (partial) of the array model.

C64



Dimensions in centimeters

YGG-04-0340 R1

Fig. 6.8. R/Z section view at center of the ES-3100 package showing KENO V.a geometry unit 1003 (partial) of the array model.

C65

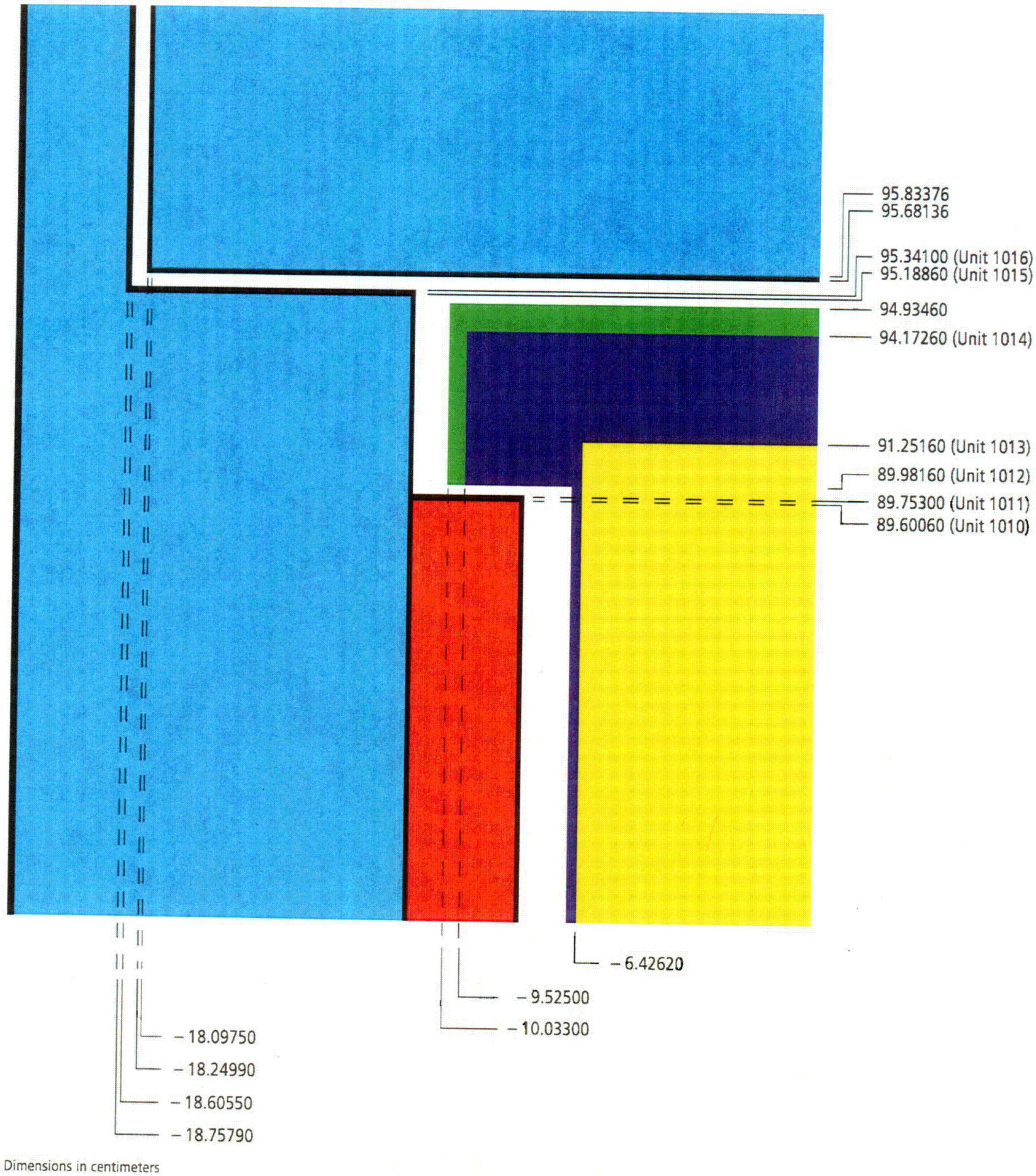


Fig 6.9. R/Z section view of near top of the ES-3100 package showing KENO V.a geometry units 1003 (partial), and 1010 through 1016 of the array model.

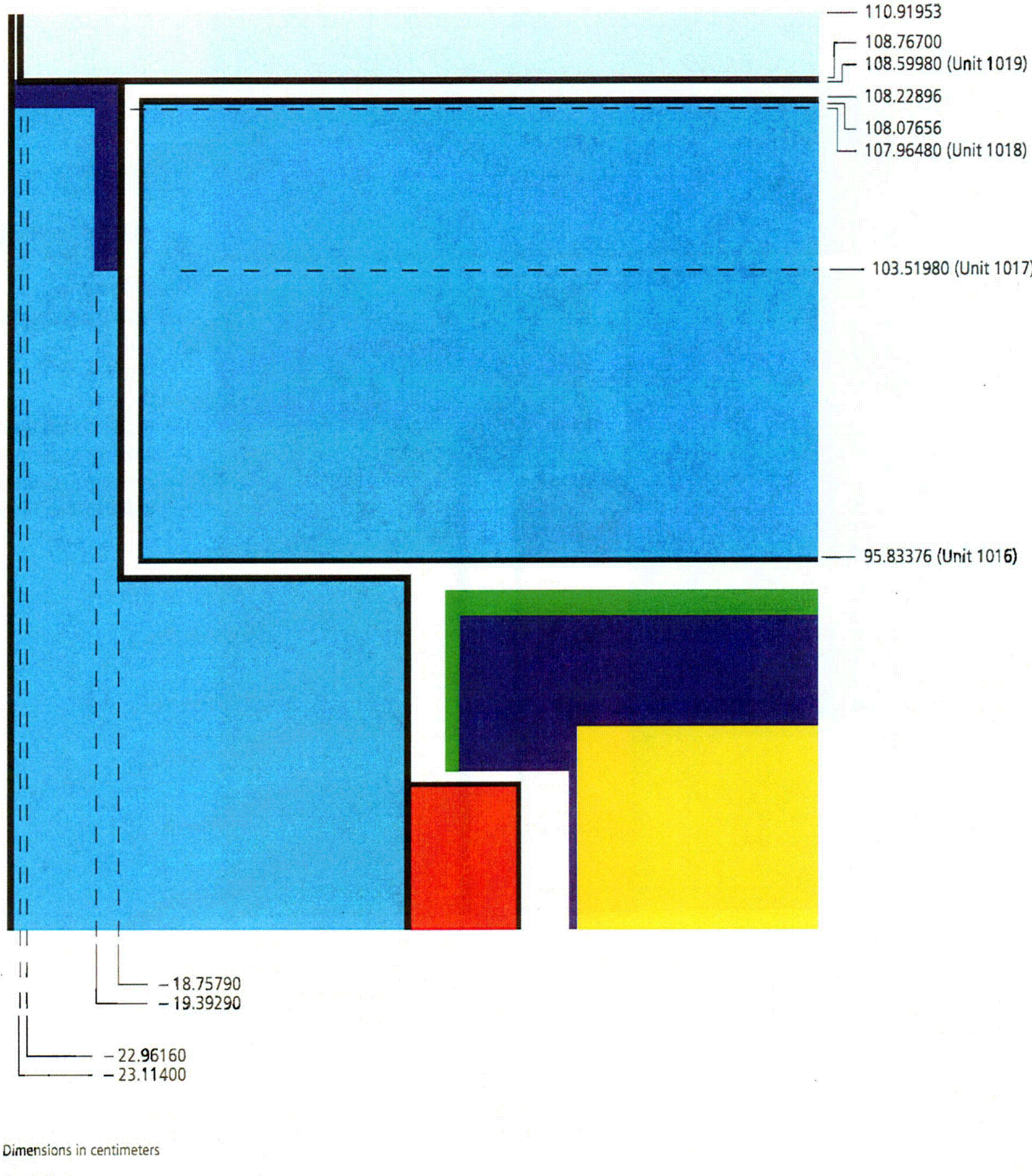


Fig. 6.10 **R/Z section view at top of the ES-3100 package showing KENO V.a geometry units 1016 through 1019 of the array model.**

C67

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, 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 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 are presented in Table 6.3. These diameters measured along the 9–270° 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.

The package water contents of the void spaces external to the containment vessel and the interstital space between drums are 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. This assumption is a reasonable one and the model is conservative given both the irregular shape of deformed drums and that the overall (maximum) dimensions rather than a mean or minimum dimension for a damaged package would establish array spacing.

The neutron poison, Kaolite refractory material, and stainless-steel components of the ES-3100 package are 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.

Table 6.3. Deformation of 18.37 in. diameter 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

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 package during these conditions are HEU uranium metal, oxide or UNH crystals, stainless steel, Cat 277-4, Kaolite, silicone rubber, 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 may significantly affect the reactivity of the package. 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. Appendix 6.9.3 provides the rationale, justification, or both for using the basic data for computing atomic densities listed in Table 6.4.

Cat 277-4, a shielding composite material, is designed to maximize the hydrogen content necessary for thermalizing fast neutrons for capture in the boron constituent. Cat 277-4 is a modified version of Cat 277 in which the boron content is increased from 1.56 wt % to 4.23 wt % for application to the ES-3100. The additive is boron carbide with small amount of a frit-like compound and trace amounts of unaccounted elements (0.17 wt %). The average density of Cat 277-4 in the Model ES-3100 package is 1.6818 g/cm^3; the boron constituent is 0.0711 g/cm^3; the residual base is 0.9165 g/cm^3; and the water component is 0.6942 g/cm^3 (Appendix 6.9.3, Sect. 6.9.3.3).

Cat 277 is capable of retaining a significant portion of its shielding properties up to 230 °C (450 °F). Vendor-supplied test data reveal that Cat. No. 277 retains ~90% of the hydrogen (water) content at an operating temperature of ~280 °F and 70% at the recommended operating limit of 350 °F. The latter temperature is well above the HAC temperatures expected inside the body weldment liner inner cavity. The full amount of hydrogen, attributed as water, is used in the material specification of Cat 277-4 for NCT and 90% is used in HAC. 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 nominal weight of Cat 277-4 in the liner inner cavity of the calculation models is 22.08 kg (48.6 lb) for NCT and 21.2 kg (46.7 lb) for HAC, determined from the input density and the volume of the region, calculated by KENO V.a. The actual mass of the Cat 277-4 in the body weldment liner inner cavity is 22.27 kg (49.1 lb) for NCT.

Table 6.4. Material compositions used in the ES-3100 calculation models

Material	Mix. No.	Theoretical density (g/cm^3)	Volume fraction	Constituent	Atomic weight	Weight percent	Atomic density (atoms/b-cm)
			Fissile material contents				
Uranium (solid metal)	1	18.8111	1.0	^{235}U	235.0441	100.0	4.8197e-02
				^{238}U	238.0510	0.0	0.0000e+00
Uranium (solid metal)	1	18.8166	1.0	^{235}U	235.0441	97.7	4.71016e-02
				^{238}U	238.0510	2.3	1.09483e-03
Uranium (solid metal)	1	18.8230	1.0	^{235}U	235.0441	95.0	4.58156e-02
				^{238}U	238.0510	5.0	2.38089e-03
Uranium (solid metal)	1	18.8349	1.0	^{235}U	235.0441	90.0	4.34317e-02
				^{238}U	238.0510	10.0	4.76479e-03
Uranium (solid metal)	1	18.9547	1.0	^{235}U	235.0441	40.0	1.94258e-02
				^{238}U	238.0510	60.0	2.87707e-02
Uranium (solid metal)	1	19.0031	1.0	^{235}U	235.0441	20.0	9.73769e-03
				^{238}U	238.0510	80.0	3.84590e-02
Uranium oxide (UO_2)	1	6.9425	1.0	H	1.0077	0.6488	2.69208e-02
				O	15.9904	16.4344	4.29699e-02
				^{235}U	235.0441	82.9168	1.47490e-02
Uranium oxide (U_3O_8)	1	6.7517	1.0	H	1.0077	0.3508	1.41552e-02
				O	15.9904	17.6621	4.49101e-02
				^{235}U	235.0441	81.9871	1.41826e-02
Uranium oxide (UO_3)	1	6.6427	1.0	H	1.0077	0.1730	6.86795e-03
				O	15.9904	18.0647	4.51925e-02
				^{235}U	235.0441	81.7623	1.39155e-02
UNH crystals (999.0 g) $[UO_2(NO_3)]$	1	1.0610	1.0	H	1.0077	10.3820	6.58323e-02
				N	14.0033	0.5172	2.36005e-04
				O	15.9904	84.7600	3.38691e-02
				^{235}U	235.0441	4.3408	1.18004e-04
UNH crystals (1500.0 g) $[UO_2(NO_3)]$	1	1.0925	1.0	H	1.0077	10.0117	6.53709e-02
				N	14.0033	0.7542	3.54378e-04
				O	15.9904	82.9041	3.41120e-02
				^{235}U	235.0441	6.3300	1.77191e-04
UNH crystals (1998.0 g) $[UO_2(NO_3)]$	1	1.1239	1.0	H	1.0077	9.6643	6.49118e-02
				N	14.0033	0.9766	4.72010e-04
				O	15.9904	81.1630	3.43530e-02
				^{235}U	235.0441	8.1961	2.36007e-04
UNH crystals (3000.0 g) $[UO_2(NO_3)]$	1	1.1869	1.0	H	1.0077	9.0207	6.39877e-02
				N	14.0033	1.3885	7.08757e-04
				O	15.9904	77.9373	3.48381e-02
				^{235}U	235.0441	11.6534	3.54382e-04
UNH crystals (6000.0 g) $[UO_2(NO_3)]$	1	1.3756	1.0	H	1.0077	7.4468	6.12221e-02
				N	14.0033	2.3960	1.41745e-03
				O	15.9904	70.0488	3.62905e-02
				^{235}U	235.0441	20.1085	7.08729e-04

Table 6.4. Material compositions used in the ES-3100 calculation models (cont.)

Material	Mix. No.	Theoretical density (g/cm³)	Volume fraction	Constituent	Atomic weight	Weight percent	Atomic density (atoms/b-cm)
UNH crystals (9000.0 g) $[UO_2(NO_3)]$	1	1.5644	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
UNH crystals (12000.0 g) $[UO_2(NO_3)]$	1	1.7531	1.0	H	1.0077	5.3154	5.56899e-02
				N	14.0033	3.7603	2.83489e-03
				O	15.9904	59.3663	3.91952e-02
				^{235}U	235.0441	31.5580	1.41746e-03
				^{238}U	238.0510	0.0000	0.00000e+00
UNH crystals (15000.0 g) $[UO_2(NO_3)]$	1	1.9418	1.0	H	1.0077	4.5605	5.29247e-02
				N	14.0033	4.2435	3.54365e-03
				O	15.9904	55.5825	4.06480e-02
				^{235}U	235.0441	35.6135	1.77184e-03
UNH crystals (18000.0 g) $[UO_2(NO_3)]$	1	2.1306	1.0	H	1.0077	3.9393	5.01589e-02
				N	14.0033	4.6411	4.25240e-03
				O	15.9904	52.4690	4.21006e-02
				^{235}U	235.0441	38.9506	2.12622e-03
UNH crystals (21000.0 g) $[UO_2(NO_3)]$	1	2.3193	1.0	H	1.0077	3.4192	4.73926e-02
				N	14.0033	4.9740	4.96109e-03
				O	15.9904	49.8623	4.35526e-02
				^{235}U	235.0441	41.7446	2.48057e-03
UNH crystals (24000.0 g) $[UO_2(NO_3)]$	1	2.5080	1.0	H	1.0077	2.9774	4.46274e-02
				N	14.0033	5.2568	5.66985e-03
				O	15.9904	47.6479	4.50055e-02
				^{235}U	235.0441	44.1179	2.83495e-03
Single-unit calculation models (NCT)							
Cat 277-4 canned spacer	2	1.6819	1.0	H	1.0077	4.6190	4.64221e-02
				^{10}B	10.013	0.7800	7.89197e-04
				^{11}B	11.0096	3.4530	3.17662e-03
				C	12.0001	1.5060	1.27114e-03
				O	15.9904	59.9960	3.80022e-02
				Na	22.9895	0.1300	5.72749e-05
				Mg	24.3048	0.3860	1.60857e-04
				Al	26.9818	21.1600	7.94320e-03
				Si	28.0853	1.3200	4.76042e-04
				S	32.0634	0.1500	4.73838e-05
				Ca	40.0803	6.1800	1.56174e-03
				Fe	55.8447	0.3200	5.80388e-05
Water-flooded CV	3	0.9982	1.0	H	1.0077	11.1909	6.67536e-02
				O	15.9904	88.8091	3.33856e-02

Table 6.4. Material compositions used in the ES-3100 calculation models (cont.)

Material	Mix. No.	Theoretical density (g/cm³)	Volume fraction	Constituent	Atomic weight	Weight percent	Atomic density (atoms/b-cm)
SS304 containment vessel body 16.60 lb but 15.74 lb used	8	7.9400	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 containment vessel lower flange used 3.36 lb	9	7.9400	0.97267	C	12.0001	0.0800	3.10060e-04
				Si	28.0853	1.0000	1.65599e-03
				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
SS304 containment vessel upper flange used 13.75 lb	10	7.9400	0.94348	C	12.0001	0.0800	3.00755e-04
				Si	28.0853	1.0000	1.60629e-03
				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
Cat 277-4 filling CV inner liner cavity	11	0.0712	0.75	Boron		100.0000	-
				^{10}B	10.013	18.4310	5.91899e-04
				^{11}B	11.0096	81.5690	2.38247e-03
		0.9165	1.0	Residual base			
				C	12.0001	2.7640	1.27109e-03
				O	15.9904	42.8340	1.48830e-02
				Na	22.9895	0.2390	5.72828e-05
				Mg	24.3048	0.7080	1.60843e-04
				Al	26.9818	38.8300	7.94295e-03
				Si	28.0853	2.4220	4.76027e-04
				S	32.0634	0.2750	4.73889e-05
				Ca	40.0803	11.3410	1.56169e-03
				Fe	55.8447	0.5870	5.80346e-05
		0.6942	1.0	Water			
				H	1.0077	11.1910	4.64239e-02
				O	15.9904	88.8090	2.31195e-02
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	—

Table 6.4. Material compositions used in the ES-3100 calculation models (cont.)

Material	Mix. No.	Theoretical density (g/cm³)	Volume fraction	Constituent	Atomic weight	Weight percent	Atomic density (atoms/b-cm)
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
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
silicone 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

Table 6.4. Material compositions used in the ES-3100 calculation models (cont.)

Material	Mix. No.	Theoretical density (g/cm^3)	Volume fraction	Constituent	Atomic weight	Weight percent	Atomic density (atoms/b-cm)
SS304 plug cover (pc) 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
SS304 internal flange	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
Reflective water	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)							
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	0.287	H	1.0077	11.1909	1.22702e-03
				O	15.9904	88.8091	6.13510e-04

Table 6.4. Material compositions used in the ES-3100 calculation models (cont.)

Material	Mix. No.	Theoretical density (g/cm³)	Volume fraction	Constituent	Atomic weight	Weight percent	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
SS304 internal flange	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
Reflective water	21	1.16235	1.0	H	1.0077	11.1909	7.75911e-06
				O	15.9904	88.8091	3.88058e-06

The elevated temperatures below the boiling point of water in the containment vessel are not sufficient for appreciable hydrogen loss. A Cat 277-4 canned spacer with a minimum density of 1.68 g/cm^3 and minimum dimensions of 3.95 in. diameter × 1.06 in. thickness has a minimum weight of 358 g (0.78 lb) for both NCT and HAC. Given the spacer thickness and dimensions used in the calculation model, the corresponding masses are ~323 g (0.72 lb) for both the square and round spacer models. This constituents 90% of the design mass.

Kaolite is a lightweight, low thermal conductivity, refractory material 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. 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. The as-manufactured condition is assumed for the Kaolite water content in the HAC array analysis.

All other material compositions for HAC are identical to the material compositions for NCT. For the HAC calculation model, the densities for the Kaolite of the body weldment liner inner cavity, the stainless steel of the internal flange, and the drum steel are adjusted to correspond with changes in dimensions. However, the atomic densities would remain unchanged in the HAC calculation model due to the conservation of mass.

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 304 stainless steel for the drum is taken from the Standard Composition Library of the Standardized Computer Analysis for Licensing Evaluation (SCALE) code system. (SCALE, Vol. 3, Sect. M8) 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.

The amount of hydrogenous packaging material used for packing the content in the containment vessel is an unknown variable. Polyethylene with a density of 0.92 g/cm^3 and 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 polyethylene bags used is unknown. Multiple bags may used to package the contents and to enclose the convenience cans, or bags may be omitted altogether. The actual amount of hydrogenous packing material used in the Model ES-3100 package is expected to be much less than 1 kg. Realistically, the number of polyethylene bags used to wrap a convenience can would be three bags at most. Given that each bag weighs ~33 g, this results in a maximum of ~297 g of polyethylene per ES-3100 package. An equivalent H/X ratio is calculated and displayed for informational purposes, designated as the "wrapped can H/X ratio" in the calculation results tables of Sects. 6.4 and 6.5. These H/X values are much less than the H/X assumed in the criticality calculations.

Given that a flooded containment vessel is assumed for both NCT and HAC calculations, the restriction on the hydrogen moderation is specified in terms of hydrogen density instead of the H/X ratio. The total amount of hydrogen contained in the package content, in the absorbed moisture or hydration molecules of the fissile content, and the water of a flooded containment vessel, shall not exceed an average density of 0.1117 g/cm^3 inside the volume of the containment vessel not occupied by the fissile material. This limit corresponds to the flooded condition assumed in the calculations where the fissile material is in the most reactive credible configuration consistent with the chemical and physical form of the contents. Volatile hydrogenous materials present or permitted in the package during NCT are polyethylene bags and absorbed water. Hypothetical Accident Conditions 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.

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. (SCALE, Vol. 1, Sect. C4) 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 (SCALE, Vol. 3, Sect. M8) and NITAWL-II (SCALE, Vol. 2, Sect. F2) are activated, providing resonance-corrected cross sections to the multigroup Monte Carlo functional module, KENO V.a (SCALE, Vol. 2, Sect. F11). 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 consists of a standard composition directory and table, an isotopic distribution directory and table, and a nuclide information table. The Materials Information Processor 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 library is a general-purpose criticality analysis library and the most complete library available in SCALE. 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. Cross section processing is performed automatically in the CSAS25 code sequence. By modeling the contents as precisely as possible, the information for correct cross section processing is introduced into the evaluation.

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 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_RvC** on the workstation. Input listings of the key cases indicated in Tables 6.1a–6.1c are provided in Appendix 6.9.7.

6.3.4 Demonstration of Maximum Reactivity

10 CFR 71.55(b) requires the evaluation of water leakage into the containment vessel, leakage of liquid contents out of the containment vessel, and other conditions which 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 with the exception of the containment vessel well. UNH solution resides inside both the containment vessel well and the containment vessel, including the sealed convenience cans. (Convenience cans are not included in the calculation models.) For this evaluation, a flooded containment vessel under full water reflection is also evaluated.

Credit for the high-integrity, watertight containment is not taken either in the single package analysis [10 CFR 71.55 (d, e)] or in the array analysis [10 CFR 71.59 (a)(1)] of undamaged packages. In the evaluation of undamaged packages under 10 CFR 71.59 (a)(1) and the evaluation of damaged packages under 10 CFR 71.59 (a)(2), the containment vessel is flooded with water, providing moderation to such an extent as to cause maximum reactivity of the content consistent with the chemical and physical form of the material present. Solid HEU, <u>not solution HEU</u>, is being shipped in the ES-3100. Consequently, in the evaluation of 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 HAC, based on results for tests specified in 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. (Meeting, Docket 71-93150) Given that credit for the high-integrity, watertight containment is not fully taken in this criticality evaluation (a flooded containment vessel under full water reflection), 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 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.

The term "water content fraction" means the fraction of the maximum specific gravity of water possible for any geometry region in the ES-3100 package. As described in Sect. 6.3.1.1, a geometry region is defined by dimensions and the material contained therein. Therefore, the water content is the fraction of the maximum specific gravity of water possible in a material in the Model 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 Cat 277-4, the maximum value is 0.6942 for both the single-unit and array geometries. The same values are used in the array calculation models because these 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 that 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 spectral 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/RV1, Y/DD-972/RV1). 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 (SAR) (Sect. 6.8.3). An additional bias is subtracted from the overall USL when assessing the results for package models of 1.5-in. diameter × 2-in. tall slug content. Contents are arranged in an ideal configuration consisting of stacked pentagonal rings of slugs in a tight-fitting configuration; i.e., no gaps between adjacent neighbors. The additional bias is required to account for gap uncertainty because positioning devices are not used in the convenience cans to control spacing and prevent an optimal arrangement from occurring (Sect. 6.4.1).

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 characterized as broken metal, uranium oxide, or UNH crystals. The bounding types of HEU content evaluated in this criticality analysis are: 3.24-in. diameter spheres and cylinders, 2.29-in. square bars, 1.5-in. diameter × 2-in. tall slugs, cubes ranging from 0.25 to 1 in. on a side, broken metal pieces of unspecified geometric shapes; uranium oxide, and UNH crystals.

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 32,940 g ^{235}U. Each can contains two 3.24 in. diameter-limited, 5490 g spheres of ^{235}U. The $k_{eff} + 2\sigma$ values increase from 0.836 to 0.868 with increasing MOIFR in the bare package, cases **nbsbsp_06_01_01** through **nbsbsp_06_01_15** (Appendix 6.9.6, Table 6.9.6-2). The $k_{eff} + 2\sigma$ values increase from 0.841 to 0.869 with increasing MOIFR in the water-reflected package, cases **nbsrsp_06_01_01** through **nbsrsp_06_01_15** (Appendix 6.9.6, Table 6.9.6-3). 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 the comparison of results for cases **nbsbsp_06_01_15** and **nbsrsp_06_01_15** indicates.

In the series of calculations using the ES-3100 package model with NCT geometry (cases **nbsrsp_06_01_01** through **nbsrsp_06_01_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} = 0.834) and high neutron leakage (NLF = 0.39). 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 0.834 to 0.865) and reduced NLF values (from 0.37 to 0.14). The increase in k_{eff} occurs due to reflection of neutrons that would otherwise escape the package back into the HEU content by water present in the regions of the package external to the content.

The ES-3100 package is not as efficient a reflector as full water reflection provided to the flooded containment vessel. For the containment vessel loaded with spherical content, the $k_{eff} + 2\sigma$ values increase monotonically from 0.793 to 0.884 as water content inside increases from the dry content to the flooded content condition [cases **cvrsp_06_01_06_01** through **cvrsp_06_01_06_15** (Appendix 6.9.6, Table 6.9.6-1, and Appendix 6.9.1, Fig. 6.9.1-1)]. The flooded containment vessel under full water reflection is a more reactive configuration than the containment vessel inside of flooded ES-3100 packaging, case **nbsrsp_06_01_15**. For this reason, calculation results for the flooded containment rather than a flooded package are reported in Tables 6.1a–6.1c for 10 CFR 71.55(b) and are taken into consideration in the determination of HEU fissile mass loading limits.

Case **hbsrsp_06_01_15** (Appendix 6.9.6, Table 6.9.6-6) 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 $k_{eff} + 2\sigma = 0.869$ for this HAC condition.

Consider the ES-3100 containment vessel loaded with three convenience cans for a total of 36,000 g ^{235}U. Each can contains a 3.24-in. diameter cylinder of HEU metal. At 100% enrichment, the $k_{eff} + 2\sigma$ values increase from 0.909 to 0.975 with increasing MOIFR in the bare package [cases **cvrcy_12_01_06_01** through **cvrcy_12_01_06_15** (Appendix 6.9.6, Table 6.9.6-8, and Appendix 6.9.1, Fig. 6.9.1-2)]. Examination of the results for cases **cvrcy_12_01_06_15** through **cvrcy_01_01_06_15** indicates that an adequately subcritical loading is achieved when the mass loading is limited to 18,000 g ^{235}U (case **cvrcy_09_01_06_15**). Case **cvrcy_12_03_06_15** reveals that the Cat 277-4 canned spacers are adequate for mass loading greater than 18,000 g ^{235}U but not exceeding 36,000 g ^{235}U.

Repeated for 3.24-in. diameter cylinders (Appendix 6.9.6, Tables 6.9.6-9, -10, and -17); 2.29-in. square bars (Appendix 6.9.6, Tables 6.9.6-19, -20, -21, and -24); and 1.5-in. diameter × 2-in. tall slugs (Appendix 6.9.6, Tables 6.9.6-26 through -30, and -35), this type of analysis demonstrates that single packages with restricted fissile material (^{235}U) loading remain subcritical over the entire range of water content or MOIFR. HEU bulk metal or alloy content not covered by the specified geometric shapes (HEU sphere, stacked spheres, cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited. However, billets, buttons, or large irregular pieces of solid HEU metal may be approved under limits for specified geometric shapes evaluated in this SAR, provided that a facility criticality safety evaluation/approval demonstrates these content loadings are bounded by the results of this SAR evaluation for specified geometric shapes.

Weighing ~1,090 g each, the 1.5-in. diameter × 2-in. tall slugs may be packed ten items per convenience can. Cases **nbsb5slg_02_01_01** through **nbsb5slg_02_01_15** (Appendix 6.9.6, Table 6.9.6-29) model a bare package with two pentagonal rings of slugs per content location, no Cat 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 0.898 to 0.946. Cases **nbsr5slg_02_01_01** through **nbsr5slg_02_01_15** (Appendix 6.9.6, Table 6.9.6-30) model a water-reflected package where the $k_{eff} + 2\sigma$ values range from 0.904 to 0.943. These results show that the most reactive configuration for bare and reflected packages is the flooded condition with the MOIFR=1.0.

As shown by the calculations for the spherical content model, water reflection external to a flooded ES-3100 package has an inconsequential effect on package reactivity. This is also true for content loadings of the ten 1.5-in. diameter × 2-in. tall slugs in pentagonal rings as the comparison of results for cases **nbsb5slg_02_01_15** and **nbsr5slg_02_01_15** indicates ($k_{eff} + 2\sigma \sim 0.946$).

Because positioning devices are not used in the convenience cans to control spacing and prevent an optimal arrangement of contents from occurring, a set of calculation models is evaluated where slug spacing is the variable for an optimal arrangement. The optimal configuration of slugs consists of stacked pentagonal rings. Case **cvr5slg0p0_02_01_06_15** (Appendix 6.9.6, Table 6.9.6-26, and Appendix 6.9.1, Fig. 6.9.1-4), case **cvr5slg0p5_02_01_06_15** (Appendix 6.9.6, Table 6.9.6-27), and case **cvr5slg1p0_02_01_06_15** (Appendix 6.9.6, Table 6.9.6-28) represent degrees of separation between adjacent neighbors in the pentagonal rings of 0.0 cm, 0.5 cm, and 1.0 cm, respectively. For this evaluation, the slugs are modeled as 100 wt % ^{235}U. Neither the convenience cans nor the Cat 277-4 canned spacers are included. The corresponding calculated $k_{eff} + 2\sigma$ values for 0.0-cm, 0.5-cm, and 1.0-cm spacing are 0.973 for case **cvr5slg0p0_02_01_06_15**, 0.979 for case **cvr5slg0p5_02_01_06_15**, and 0.982 for case **cvr5slg1p0_02_01_06_15**. Calculation results indicate the most reactive configuration occurs when the slugs are spaced 1.0 cm apart from direct contact with adjacent neighbors in the pentagonal rings. The 0.009 difference in the $k_{eff} + 2\sigma$ values is treated as an additional bias (i.e., subtracted from the overall USL) when applied to the results for package models based on no gaps between the contents. These results also indicate that Cat 277-4 canned spacers are required for the slug content.

As shown by the spherical 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 two pentagonal rings of slugs per content location with Cat 277-4 canned spacers between locations and HEU content at 100 wt % ^{235}U. For cases **cvr5slg0p0_02_03_06_15** and **nbsr5slg_02_03_15**, the $k_{eff} + 2\sigma$ values are 0.894 and 0.871, respectively.

For the flooded containment vessel under full water reflection and loaded with the slugs in a pentagonal arrangement and Cat 277-4 canned spacers between content locations, $k_{eff} + 2\sigma = 0.894$, case **cvr5slg0p0_02_06_15** [10 CFR 71.55(b).] This value is below the USL value of 0.916 adjusted for spacing uncertainty. For packages with the required 1.4-in. Cat 277-4 canned spacers, calculated $k_{eff} + 2\sigma$ values are 0.869 for the bare package, case **nbsb5slg_02_06_15**, and 0.871 for water-reflected package, case **nbsrbm_12_03_15** [10 CFR 71.55(d).] Case **hbsr5slg_02_03_15** (Appendix 6.9.6, Table 6.9.6-35) 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. 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 $k_{eff} + 2\sigma = 0.874$ for this HAC condition.

6.4.2 HEU Solid Metal of Unspecified Geometric Shapes or HEU Broken Metal

Like packages with HEU metal, the neutron multiplication factor for bare and reflected single packages with HEU broken metal 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 35,141 g ^{235}U. The $k_{eff} + 2\sigma$ values range from 0.816 to 0.896 with increasing MOIFR in the bare package [cases **nbsbbm_12_01_01** through **nbsbbm_12_01_15** (Appendix 6.9.6, Table 6.9.6-56)]. The $k_{eff} + 2\sigma$ values range from 0.823 to 0.895 with increasing MOIFR in the water-reflected package [cases **nbsrbm_12_01_01** through **nbsrbm_12_01_15** (Appendix 6.9.6, Table 6.9.6-57)]. The addition of water to the package reduces the NLF, thereby increasing k_{eff}. Water reflection of a flooded package is inconsequential to package reactivity as the comparison of results for cases **nbsbbm_12_01_15** and **nbsrbm_12_01_15** indicates.

For the containment vessel loaded with the broken metal content but without Cat 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ values increase from 0.751 to 0.951 as the water content in the containment vessel increases [cases **cvr3lha_12_01_09_01** through **cvr3lha_12_01_09_15** (Appendix 6.9.6, Table 6.9.6-48, and Appendix 6.9.3, Fig. 6.9.3.1-5)]. Cases **cvr3lha_12_01_09_15** through **cvr3lha_12_01_01_15** model the flooded containment vessel with 35 kg of broken HEU metal where the enrichment ranges from 100 to 20 wt % ^{235}U. Can spacers are required for criticality control for enrichments above 80 wt % ^{235}U.

For the flooded containment vessel under full water reflection and loaded with the broken metal content and Cat 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma = 0.893$, case **cvr3lha_12_03_09_15** [10 CFR 71.55(b)]. For packages with the required Cat 277-4 canned spacers, the calculated $k_{eff} + 2\sigma$ value is 0.881 for both the bare package, case **nbsbbm_12_03_15**, and for the water-reflected package, case **nbsrbm_12_03_15** [10 CFR 71.55(d)]. Case **hbsrbm_12_03_15** (Appendix 6.9.6,

Table 6.9.6-64) 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. 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 $k_{eff} + 2\sigma = 0.881$ for this HAC condition.

6.4.3 HEU Oxide

HEU oxide (and UNH crystal) content is not considered a "rigid" content solid or broken HEU metal. A different modeling approach is used to avoid uncertainty regarding the location of spacers in the containment vessel. For the calculation models of HEU oxide (and UNH crystals), the Cat 277-4 canned spacers are not actually modeled. Instead, the amount of water above the content is reduced proportionally by the free volume not occupied by can spacers.

Like packages with HEU metal or broken metal, the neutron multiplication factor for bare and reflected single packages with HEU oxide 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 24,000 g UO_2 (21,1124 g ^{235}U) and Cat 277-4 canned spacers between content locations. The $k_{eff} + 2\sigma$ values range from 0.708 to 0.791 with increasing MOIFR in the bare package [cases **nbsbox_01_11_03_01** through **nbsbox_01_11_03_15** (Appendix 6.9.6, Table 6.9.6-71)]. The $k_{eff} + 2\sigma$ values range from 0.716 to 0.790 with increasing MOIFR in the water-reflected package [cases **nbsrox_01_11_03_01** through **nbsrox_01_11_03_15** (Appendix 6.9.6, Table 6.9.6-72)]. The addition of water to the package reduces the NLF, thereby increasing k_{eff}. External water reflection of a flooded package is inconsequential to package reactivity as the comparison of results for cases **nbsbox_01_11_03_15** and **nbsrox_01_11_03_15** indicates. Results for cases **nbsrox_02_11_03_15** and **nbsrox_03_11_03_15** indicate that both the U_3O_8 content ($k_{eff} + 2\sigma = 0.605$) and UO_3 content ($k_{eff} + 2\sigma = 0.544$) are bounded by UO_2 content ($k_{eff} + 2\sigma = 0.790$).

For the containment vessel loaded with the HEU oxide but lacking Cat 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ values increase from 0.683 to 0.873 [cases **cvrox_01_11_01_01** through **cvrox_01_11_01_15** (Appendix 6.9.6, Table 6.9.6-70, and Appendix 6.9.1, Fig. 6.9.1-5)]. Can spacers are not required for criticality control. For the flooded containment vessel under full water reflection containment, the $k_{eff} + 2\sigma$ value is 0.873, case **cvrox_01_11_01_15** [10 CFR 71.55(b).] The $k_{eff} + 2\sigma$ value is 0.791 for both the bare package, case **nbsbox_01_11_01_15,** and for water-reflected package, case **nbsrox_01_11_01_15** [10 CFR 71.55(d).]

Case **hbsrox_01_11_01_15** (Appendix 6.9.6, Table 6.9.6-78) 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. 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 $k_{eff} + 2\sigma = 0.791$ for this HAC condition.

While HEU oxide content is non-hygroscopic or mildly hygroscopic with a bulk density over 6 times greater than water, HEU oxide (and UNH crystal) content is not considered a "rigid" content like solid or broken HEU metal. Thus a different modeling approach is used to avoid having to address uncertainties regarding the locations of can spacers in the containment vessel. For the calculation models of HEU oxide, the Cat 277-4 canned spacers are not actually modeled. Instead, the amount of water above the oxide content is reduced proportionally by the free volume not occupied by can spacers.

6.4.4 UNH Crystals

Unlike the other HEU contents, UNH crystals are soluble in water. The most reactive credible configuration for a solution occurs for a concentration at ~450 g^{235}U/l. Fixed by the inner dimensions of the containment vessel, the near optimum solution concentration occurs at a content mass loading of 9,000 g UNH crystals. This condition assumes the mixing of UNH crystals with water of the flooded containment vessel, producing a solution with a concentration on the order of 415 g^{235}U/l.

Similar to packages loaded with HEU metal, broken metal or oxide, the neutron multiplication factor for bare and reflected single packages with UNH crystals increases as a function of the MOIFR. Consider the ES-3100 package loaded with three convenience cans for a total of 24,000 g UNH crystals (11,303 g ^{235}U). The concentration is 1106 g^{235}U/l in the flooded containment vessel. The $k_{eff} + 2\sigma$ values range from 0.608 to 0.708 with increasing MOIFR in the bare package [cases **nbsbunhc_11_01_01** through **nbsbunhc_11_01_15** (Appendix 6.9.6, Table 6.9.6-83)]. However, the optimal concentration is not reached until the mass loading is reduced to 9,000 g UNH or 415 g^{235}U/l. For case **nbsbunhc_06_01_15**, the $k_{eff} + 2\sigma = 0.754$.

For cases **nbsrunhc_11_01_01** through **nbsrunhc_11_01_15** (Appendix 6.9.6, Table 6.9.6-84), the $k_{eff} + 2\sigma$ values range from 0.617 to 0.709 with increasing MOIFR in the water-reflected package. The addition of water to the package reduces the NLF, thereby increasing k_{eff}. Like the other HEU contents, cases **nbsbunhc_11_01_15** and **nbsrunhc_11_01_15** demonstrate that external water reflection of a flooded package is inconsequential to package reactivity.

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. Cases **obsrunhc_01_01_15** through **obsrunhc_11_01_15** (Appendix 6.9.6, Table 6.9.6-86) model the ES-3100 package where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. For a content loading of 24,000 g UNH, the uranium concentration drops from 1106 g^{235}U/l to 689 g^{235}U/l. For content loadings from 1,000 to 24,000 g of UNH crystals, the corresponding $k_{eff} + 2\sigma$ values range from 0.481 to 0.802, with the peak value of 0.813 occurring in the range of 15,000 to 18,0000 g UNH or from 514 to 429 g^{235}U/l.

For the flooded containment vessel loaded with the UNH crystals but without Cat 277-4 canned spacers between content locations, the $k_{eff} + 2\sigma$ values increase from 0.729 to 0.823 [cases **cvrunhc_11_01_01** through **cvrunhc_11_01_15** (Appendix 6.9.6, Table 6.9.6-82, and Appendix 6.9.1, Fig. 6.9.1-6)]. In the range of the optimal concentration (12,000–9,000 g UNH), the respective $k_{eff} + 2\sigma$ values are 0.855 for case **cvrunhc_07_01_15** and 0.857 for case **cvrunhc_06_01_15** [10 CFR 71.55(b).] Where dilution of UNH crystals is confined to the containment vessel, the reported $k_{eff} + 2\sigma$ values are 0.754 for the bare package (case **nbsbunhc_06_01_15**) and 0.751 for water-reflected package (case **nbsrunhc_07_01_15**) [10 CFR 71.55(d).] Where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well, the reported $k_{eff} + 2\sigma$ value is 0.813 for the water-reflected package (case **obsrunhc_09_01_15**).

Cases **hbsrunhc_06_01_15** (Appendix 6.9.6, Table 6.9.6-89) and **ibsrunhc_08_01_15** (Appendix 6.9.6, Table 6.9.6-91) represent the HAC model of the damaged ES-3100 package, where the outer dimensions of the package are reduced accordingly. For case **hbsrunhc_06_01_15**, the dilution of the UNH crystals is confined to the containment vessel. For case **ibsrunhc_08_01_15**, UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. The respective solution concentrations are 415 g^{235}U/l and 429 g^{235}U/l. 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 0.750 and 0.813 for this HAC condition.

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, 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 = 202, CSI = 0.4; N = 64, CSI = 0.8; N = 29, CSI = 1.7; and N = 10, CSI = 2.0. 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 32,940 g ^{235}U where each can contains two 3.24-in. diameter-limited, 5490-g spheres of ^{235}U. For package content without Cat 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.900 to 0.876 with increasing MOIFR in the package [cases **nbiasp_06_01_06_01** through **nbiasp_06_01_06_15** (Appendix 6.9.6, Table 6.9.6-4)]. For package content with Cat 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.851 to 0.822 with increasing MOIFR in the package [cases **nbiasp_06_03_06_01** through **nbiasp_06_03_06_15** (Appendix 6.9.6, Table 6.9.6-4)].

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 Cat 277-4 provides moderation, and neutrons are absorbed in the interspersed boron of this neutron poison. This results in a subcritical systems 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 ($k_{eff} + 2\sigma = 0.876$) approaches the reactivity of the single unit ($k_{eff} + 2\sigma = 0.869$).

Repeated for 3.24-in. diameter cylinders (Appendix 6.9.6, Table 6.9.6-11), 2.29-in. square bars (Appendix 6.9.6, Table 6.9.6-22), and 1.5-in. diameter × 2-in. tall slugs (Appendix 6.9.6, Table 6.9.6-31), this type of analysis demonstrates that arrays of packages with restricted fissile material loadings remain subcritical over the entire range of MOIFR. HEU bulk metal or alloy content not covered by the specified geometric shapes (HEU sphere, stacked spheres, cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited. However, billets, buttons, or large irregular pieces of solid HEU metal may be approved under limits for specified geometric shapes evaluated in this SAR, provided that a facility criticality safety evaluation/approval demonstrates these content loadings are bounded by the results of this SAR evaluation for specified geometric shapes.

As shown by the calculations for the spherical model, the neutron multiplication factors increase as a function of the ^{235}U mass and decreases as a function of MOIFR for the slugs. Consider the ~1,090-g, 1.5-in. diameter × 2-in. tall slugs that may be packed with ten items per convenience can. For a package content without the use of Cat 277-4 canned spacers, the $k_{eff} + 2\sigma$ values decrease from 0.991 to 0.954 with increasing MOIFR in the package [cases **nbia5slg_02_01_09_01** through **nbia5slg_02_01_09_15** (Appendix 6.9.6, Table 6.9.6-31)]. For packages with the required Cat 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.925 to 0.881 with increasing MOIFR in the package [cases **nbia5slg_02_03_09_01** through **nbia5slg_02_03_09_15** (Appendix 6.9.6, Table 6.9.6-31)].

The introduction of water above 0.01 MOIFR shows the effect of isolating the individual array units from each other. The neutron multiplication factor for the array approaches the k_{eff} value for the single, water-reflected unit at a full-content water fraction as demonstrated by comparing cases **nbia5slg_02_03_09_15** (keff + 2σ = 0.881) and **nbsr5slg_02_03_15** ($k_{eff} + 2\sigma = 0.871$).

The array case with a water fraction of MOIFR = 1.0e-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. Cases **nbia5slg_02_03_01_03** through **nbia5slg_02_03_09_03** (Appendix 6.9.6, Table 6.9.6-31) represent an infinite array of packages with the required Cat 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.530 to 0.925 as the enrichment is increased from 20.0 wt % to 100.0 wt % ^{235}U.

The adjusted USL for an infinite array of packages with slug content is 0.856. The adjustment accounts for both spacing uncertainity of the slugs (0.009) and excess moderation in the neutron poison (0.060). The $k_{eff} + 2\sigma$ value for case **nbia5slg_02_03_09_03** exceeds the USL of 0.856. However 80 wt % ^{235}U, case **nbia5slg_02_03_05_03** with $k_{eff} + 2\sigma = 0.848$ is below the USL. Therefore, a restriction is placed upon enrichment: values must be ≤80 wt % as prerequisite for shipment of the package with 32,767 g of uranium metal under a CSI = 0. Otherwise, the fissile mass loading must be reduced to 16,342 g ^{235}U for eliminating the restriction on enrichment.

Cases **nbfl5slg_02_03_01_03** through **nbfl5slg_02_03_09_03** (Appendix 6.96, Table 6.96-32) represents a 13 × 13 × 6 array of packages for which the corresponding rounded CSI = 0.4. The $k_{eff} + 2\sigma$ does not decrease sufficiently in the reduction of array size to permit increasing the limit on enrichment to >80 wt % for mass loadings of 32 kg uranium metal. These CSI determinations are contingent upon satisfactory results under the HAC evaluation (Sect. 6.6.1).

6.5.2 HEU Solid Metal of Unspecified Geometric Shapes or HEU Broken Metal

Like packages with HEU metal, the neutron multiplication factor for arrays of packages with HEU broken metal decreases as a function of MOIFR and increases as a function of the ^{235}U mass. For example, consider the ES-3100 package loaded with three convenience cans for a total of 35,141 g ^{235}U and no can spacers between content locations. The $k_{eff} + 2\sigma$ values range from 1.034 to 0.912 with increasing MOIFR [cases **nbiabm_12_01_09_01** through **nbiabm_12_01_09_15** (Appendix 6.9.6, Table 6.9.6-58)]. The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. Array reactivity ($k_{eff} + 2\sigma = 0.912$) approaches the reactivity of the water-saturated, water-reflected single package ($k_{eff} + 2\sigma = 0.895$). The $k_{eff} + 2\sigma$ values range from 0.710 to 1.037 as the ^{235}U mass increases from 925 to 35,141 g ^{235}U [cases **nbiabm_01_01_09_03** through **nbiabm_12_01_09_03** (Appendix 6.9.6, Table 6.9.6-58)]. (The fact that cases **nbiabm_01_01_09_03** and **nbiabm_02_01_09_03** are identical results from the use of a cube model for generating homogenized mass loading consistent with the broken metal study in Appendix 6.9.3, Sect. 6.9.3.1.)

In the series of calculations using the ES-3100 package model with NCT geometry (cases **nbiabm_01_*nn*_*mm*_03** through **nbiabm_12_*nn*_*mm*_03**), the enrichment of the content is varied from 20 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.

Ranges of enrichment are specified in Table 6.1b (10 CFR 71.59) for identifying fissile mass loading limits for HEU broken metal. Consider specifically enrichments >95 wt % ^{235}U. The containment vessel calculations (case **cvr3lha_12_01_09_15** versus case **cvr3lha_12_03_09_15**) indicate that Cat 277-4 canned spacers are required in this enrichment range, where the maximum evaluated fissile mass loading of 35,141 g ^{235}U is possible. However, the fissile mass loading must be limited to 2,774 g ^{235}U (case **nbiabm_04_03_09_03**) in order for the $k_{eff} + 2\sigma$ value (= 0.834) to be below the adjusted USL of 0.865. This fissile mass limit is conservative when applied to enrichments only slightly greater than 95 wt % ^{235}U. A reduction in the enrichment within the range of 80 to 95 wt % ^{235}U (cases **nbiabm_04_03_07_03** and **nbiabm_04_03_06_03**) does not result in a sufficient reduction in the $k_{eff} + 2\sigma$ from neutron absorption in ^{238}U to allow for increased mass loadings. Therefore, the uranium mass limit remains at ~2,775 g while the fissile mass loading limit decreases with the reudction in enrichment as illustrated in Table 6.1b. As stated previously, these fissile mass loading limit for a CSI = 0 are contingent upon the infinite array of damaged packages also being adequately subcritical for the HAC (Sect. 6.6.2).

This evaluation technique for determination of mass loading limits for enrichment intervals is repeated over the range of HEU enrichments identified in Table 6.1b. At HEU enrichment less than 60 wt % ^{235}U, the evaluated package mass loading limit of 35 kg uranium is achieved, so further delineation of fissile mass loading limits is not required.

6.5.3 HEU Oxide

Like packages with HEU metal or broken metal, the neutron multiplication factor for an array of packages with HEU oxide decreases as a function of MOIFR and increases as a function of the ^{235}U mass, [for example, cases **nbiaox_01_11_03_01** through **nbiaox_01_11_03_15** and **nbiaox_01_01_03_03** through

nbiaox_01_11_03_03 (Appendix 6.9.6, Table 6.9.6-73)]. The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. Array reactivity ($k_{eff} + 2\sigma = 0.801$) approaches the reactivity of the water-saturated, water-reflected unit single package ($k_{eff} + 2\sigma = 0.790$).

For the series of calculations using the ES-3100 package model with NCT geometry (Cases **nbiaox_01_*nn*_01_03**), $k_{eff} + 2\sigma$ values are below the adjusted USL of 0.865. The CSI = 0.0 for an infinite array of packages having a maximum of 21,125 g ^{235}U; suitability of this determination is contingent upon satisfactory results under the HAC evaluation (Sect. 6.6.3.)

6.5.4 UNH Crystals

Unlike HEU metal, broken metal or oxide content, UNH crystals are soluble in water (Sect. 6.4.4). Near optimum solution concentration occurs at content mass loadings of 9,000 g UNH crystals or 415 g ^{235}U/l.

Like 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 MOIFR. Cases **nbiaunhc_10_11_01_01** through **nbiaunhc_10_11_01_15** (Appendix 6.9.6, Table 6.9.6-85) reveal the effect of isolating the individual array units from each other with the introduction of water above ~0.01 MOIFR. Array reactivity ($k_{eff} + 2\sigma = 0.727$) approaches the reactivity of the water-saturated, water-reflected unit single package ($k_{eff} + 2\sigma = 0.708$).

The difference between cases **nbiaunhc_10_11_01_*nn*** and **nbiaunhc_10_11_03_*nn*** is the absence or presence of Cat 277-4 canned spacers in the packages. For the calculation models of UNH crystals, the Cat 277-4 canned spacers are not actually modeled. Instead, the amount of solution content distributed over the entire containment vessel is reduced proportionally by the free volume of the containment vessel not occupied by can spacers.

For the series of calculations using the ES-3100 package model with NCT geometry (Cases **nbiaunhc_10_*nn*_01_03**), $k_{eff} + 2\sigma$ values are below the adjusted USL of 0.865. For an infinite array of packages having a maximum of 24,000g UNH crystals, the CSI = 0.0 [10 CFR 71.59(a)(1),(b)]. The suitability of this determination depends upon satisfactory results under the HAC evaluation of Sect. 6.6.4 [10 CFR 71.59(a)(2), (b).]

The reported $k_{eff} + 2\sigma$ values for cases **obiaunhc_10_*nn*_01_03** (Appendix 6.9.6, Table 6.9.6-87) range from 0.557 to 1.026, where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. However, this condition is considered an accident condition, not credible for NCT. It requires intrusion of water into the containment vessel, dissolving of UNH crystals in the influent, and leakage of solution out of the containment vessels an infinite number of packages.

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 § CFR 71.73 (Hypothetical Accident Conditions). The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, and 5×5×2, 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 = 507, CSI = 0.1; N = 162, CSI = 0.3; N = 74, CSI = 0.7; and N = 25, CSI = 2.0. 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, or 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

Consider the ES-3100 package loaded with three convenience cans for a total of 32,940 g ^{235}U where each can contains two 3.24 in. diameter-limited, 5490 g spheres of ^{235}U. For package content without Cat 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.901 to 0.884 with increasing MOIFR in the package, cases **hbiasp_06_01_06_01** through **hbiasp_06_01_06_15** (Appendix 6.9.6, Table 6.9.6-7). For package content with Cat 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.856 to 0.827 with increasing MOIFR in the package, cases **hbiasp_06_03_06_01** through **hbiasp_06_03_06_15** (Appendix 6.9.6, Table 6.9.6-7). 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.

Repeated for 3.24-in. diameter cylinders (Appendix 6.9.6, Table 6.9.6-18), 2.29-in. square bars (Appendix 6.9.6, Table 6.9.6-25), and 1.5-in. diameter × 2-in. tall slugs (Appendix 6.9.6, Table 6.9.6-36), this type of analysis demonstrates that arrays of packages with restricted fissile material loadings remain subcritical over the entire range of MOIFR. HEU bulk metal or alloy content not covered by the specified geometric shapes (HEU sphere, stacked spheres, cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited. However, billets, buttons, or large irregular pieces of solid HEU metal may be approved under limits for specified geometric shapes evaluated in this SAR, provided that a facility criticality safety evaluation/approval demonstrates these content loadings are bounded by the results of this SAR evaluation for specified geometric shapes.

Consider the ~1,090 g, 1.5-in. diameter x 2-in. tall slugs that may be packed ten per convenience can. The $k_{eff} + 2\sigma$ value for case **hbia5slg_02_03_09_03** at 100 wt % ^{235}U exceeds the adjusted USL of 0.856. However, at 80 wt % case **hbia5slg_02_03_05_03** with $k_{eff} + 2\sigma = 0.855$ is below the adjusted USL. Therefore, the restriction upon enrichment under the NCT evaluation, which requires values be ≤80 wt % as prerequisite for shipment of the package under a CSI = 0, need not change. Likewise, the fissile mass loading limit must be reduced to 16,342 g ^{235}U for eliminating the restriction on enrichment.

Case **hbf25slg_02_03_09_03** (Appendix 6.9.6, Table 6.9.6-37) represent a 9×9×4 array of packages for which the corresponding rounded CSI = 0.4. The adjusted USL for a 9×9×4 array of packages with slug content is 0.866. The adjustment accounts for both spacing uncertainity of the slugs (0.009) and excess moderation in the neutron poison (0.050). Although case **hbf25slg_02_03_05_03** with $k_{eff} + 2\sigma = 0.860$ is below the adjusted USL of 0.866, the fissile mass loading limit is set by the NCT result which requires the enrichment not to exceed 80 wt % ^{235}U for 32 kg uranium mass loadings.

6.6.2 HEU Solid Metal of Unspecified Geometric Shapes or HEU Broken Metal

Consider the ES-3100 package loaded with three convenience cans for a total of 35,141 g ^{235}U, no can spacers between content locations. The $k_{eff} + 2\sigma$ values range from 1.055 to 0.932 with increasing MOIFR, cases **hbiabm_12_01_09_01** through **hbiabm_12_01_09_15** (Appendix 6.9.6, Table 6.9.6-65). The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. Array reactivity ($k_{eff} + 2\sigma = 0.932$) approaches the reactivity of the water-saturated, water-reflected single package ($k_{eff} + 2\sigma = 0.895$). The $k_{eff} + 2\sigma$ values range from 0.716 to 1.041 as the ^{235}U mass increases from 925 g to 35,141 g ^{235}U, cases **hbiabm_01_01_09_03** through **hbiabm_12_01_09_03** (Appendix 6.9.6, Table 6.9.6-65). (The fact that cases **hbiabm_01_01_09_03** and **hbiabm_02_01_09_03** are identical results through the use of cube model for generating homogenized mass loading consistent with broken metal study of Appendix 6.9.1.1.)

Cases **hbiabm_01_*nn*_*mm*_03** through **hbiabm_12_*nn*_*mm*_03** model the ES-3100 with the reduced diameter HAC package model where the enrichment of the content is varied from 20 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. 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.

Ranges of enrichment are specified in Table 6.1b (10 CFR 71.59) for identifying fissile mass loading limits for HEU broken metal. Consider specifically enrichments >95 wt % ^{235}U. The containment vessel calculations (case **cvr3lha_12_01_09_15** versus case **cvr3lha_12_03_09_15**) indicate that Cat 277-4 canned spacers are required in this enrichment range, where the maximum evaluated mass loading of 35,141 g ^{235}U is possible. However, the fissile mass loading must be limited to 2,774 g ^{235}U (case **hbiabm_04_03_09_03**) in order for the $k_{eff} + 2\sigma$ value (= 0.849) to be below the USL of 0.865. This fissile mass limit is conservative when applied to enrichments only slightly greater than 95 wt % ^{235}U. 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.

This evaluation technique for determination of mass loading limits for enrichment intervals is repeated over the range of HEU enrichments. At HEU enrichment less than 60 wt % ^{235}U, the package mass loading limit is achieved so no further delineation is required.

6.6.3 HEU Oxide

Like packages with HEU metal or broken metal, the neutron multiplication factor for an array of packages with HEU oxide decreases as a function of the MOIFR and increases as a function of the ^{235}U mass, for example, cases **hbiaox_01_11_03_01** through **hbiaox_01_11_03_15** and **hbiaox_01_01_03_03** through **hbiaox_01_11_03_03** (Appendix 6.9.6, Table 6.9.6-79). The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. Array reactivity ($k_{eff} + 2\sigma = 0.819$) approaches the reactivity of the water-saturated, water-reflected unit single package ($k_{eff} + 2\sigma = 0.791$).

For the series of calculations using the ES-3100 package model with NCT geometry (Cases **hbiaox_01_*nn*_01_03**), $k_{eff} + 2\sigma$ 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 a maximum of 21,125 g ^{235}U.

6.6.4 UNH Crystals

Unlike HEU metal, broken metal or oxide content, UNH crystals are soluble in water as mentioned in Sect. 6.4.4. Near optimum solution concentration occurs at content mass loadings of 9,000 g UNH crystals or 415 g^{235}U/l.

Like 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 the MOIFR. Cases **hbiaunhc_10_11_01_01** through **hbiaunhc_10_11_01_15** (Appendix 6.9.6, Table 6.9.6-90) reveal the effect of isolating the individual array units from each other with the introduction of water above ~0.01 MOIFR. Array reactivity ($k_{eff} + 2\sigma = 0.746$) approaches the reactivity of the water-saturated, water-reflected unit single package ($k_{eff} + 2\sigma = 0.707$).

The difference between cases **hbiaunhc_10_11_01_*nn*** and **hbiaunhc_10_11_03_*nn*** is the absence or presence of Cat 277-4 canned spacers in the packages. For the calculation models of UNH crystals, the Cat 277-4 canned spacers are not actually modeled. Instead, the amount of solution content distributed over the entire containment vessel is reduced proportionally by the free volume of the containment vessel not occupied by can spacers.

For the series of calculations using the ES-3100 package model with NCT geometry (cases **hbiaunhc_10_*nn*_01_03**), $k_{eff} + 2\sigma$ 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 = 0.0 for an infinite array of packages with a maximum of 24,000 g UNH crystals.

The reported $k_{eff} + 2\sigma$ values for cases **ibiaunhc_10_*nn*_01_03** (Appendix 6.9.6, Table 6.9.6-92) range from 0.561 to 1.041; where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. This accident condition requires intrusion of water into the containment vessel, dissolving of UNH crystals in the influent, and leakage of solution out of the containment vessel. 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.

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

6.7.1 Configuration (Not evaluated)

6.7.2 Results (Not evaluated)

6.8 BENCHMARK EXPERIMENTS

6.8.1 Applicability of Benchmark Experiments

The criticality validation is specific to uranium, plutonium or 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-972/R1. 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 uranium-233 systems, as described in the OECD Handbook. 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-972/R1 addresses determining an upper subcritical limit (USL) and for incorporating uncertainty and margin into this USL. Y/DD-972/R1 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, etc.) 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, indicating a bias value of 0.025. 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, guidance provided by NUREG/CR-5661 requires that the bias value of 0.025 be subtracted from 0.95 for determination of the USL, giving a value of 0.925.

6.9 APPENDICES

Appendix	Description
6.9.1	FISSILE CONTENT MODELS
6.9.2	HAC PACKAGE MODEL
6.9.3	PACKAGE MATERIAL COMPOSITIONS
6.9.4	SUPPORTING DOCUMENTS AND CORRESPONDENCE
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 IDENTIFIED IN TABLES 6.1a-c

APPENDIX 6.9.1

FISSILE CONTENT MODELS

APPENDIX 6.9.1

FISSILE CONTENT MODELS

Fig. 6.9.1-1 depicts the wire-mesh view of the 3.24-in. diameter HEU spherical 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 spherical content model contains two spheres per convenience can and 1-in. Cat 277-4 spacers between the convenience can locations. Spheres are at the maximum diameter which will fit through the opening of a convenience can. The spherical content is positioned one spherical radius (1.62-in) above the containment vessel bottom to ensure water moderation of the bottom content.

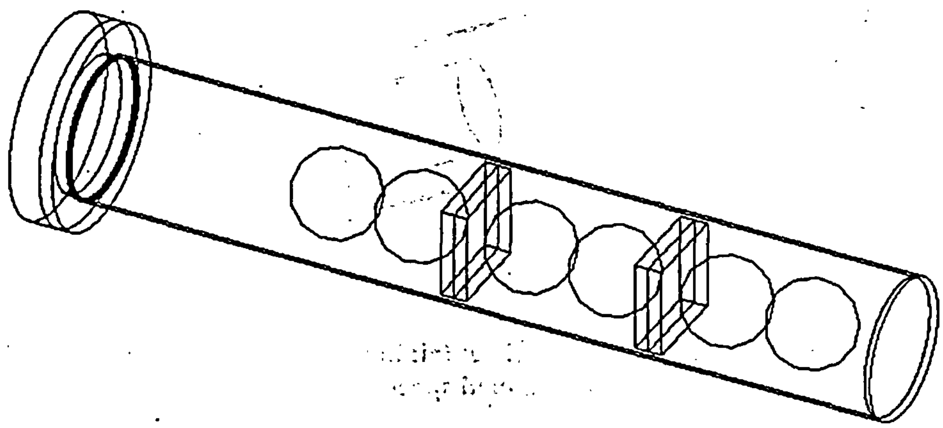


Fig. 6.9.1-1. Containment vessel containing 3.24-in. diameter spheres and 1-in. thick Cat 277-4 canned spacers.

Fig. 6.9.1-2 depicts the wire-mesh view of the 3.24-in. diameter 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-in. Cat 277-4 canned spacers between the can locations. The cylindrical content shown is at the maximum mass loading and the height of the cylinders may change depending upon the mass loading.

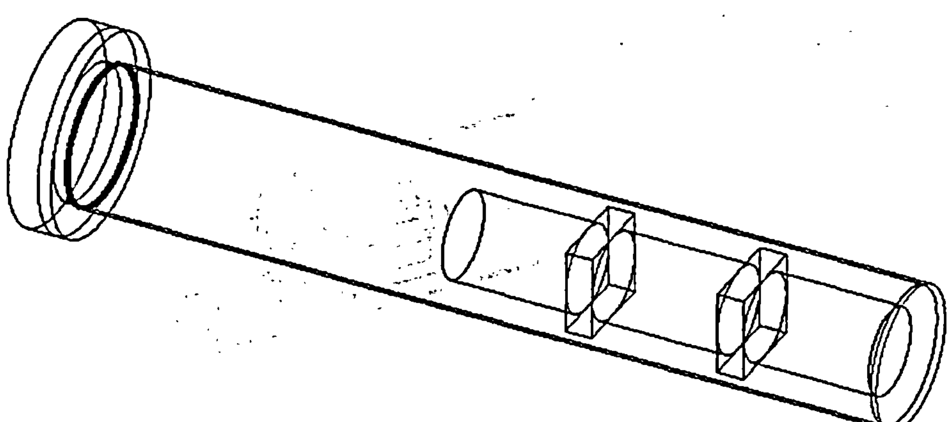


Fig. 6.9.1-2. Containment vessel containing 3.24-in. diameter cylinders and 1-in. thick Cat 277-4 canned spacers.

Fig. 6.9.1-3 depicts the wire-mesh view of the 2.29-in. HEU square bar content configuration inside the containment vessel. The interstitial water inside the containment vessel has been removed for illustration purposes. As can be seen from Fig. 6.9.1-3, the square bar content model contains one bar per convenience can and 1-in. Cat 277-4 canned spacers between the can locations. The 2.29-in. square bar is the largest size that will fit into the 3.24-in. inside diameter convenience can. Similar to the cylindrical model, the height of the square bar is dependent upon the HEU mass.

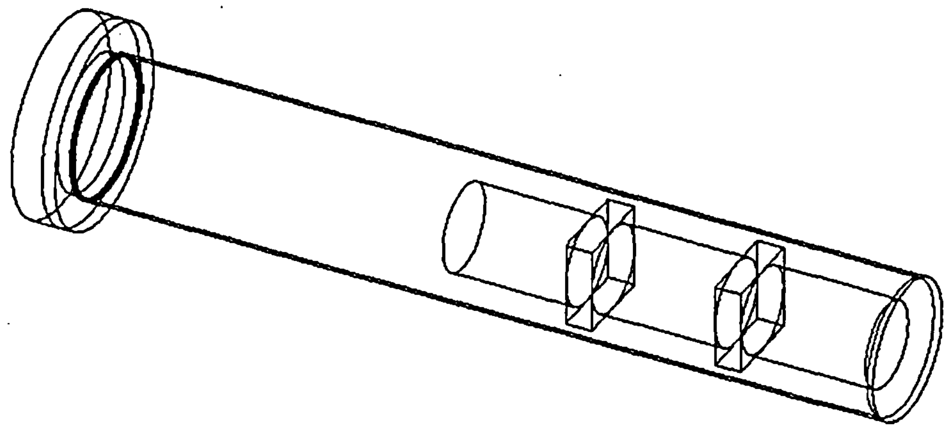


Fig. 6.9.1-3. Containment vessel containing 2.29-in. square bars and 1-in. thick Cat 277-4 canned spacers.

Fig. 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., no gaps between adjacent neighbors. The slug content model depicted in Fig. 6.9.1-4 contains two rings of the 1.5-in.-diam × 2.0-in.-tall slugs per convenience can and the Cat 277-4 canned spacers between the convenience cans locations. The interstitial water inside the containment vessel has been removed for illustration purposes.

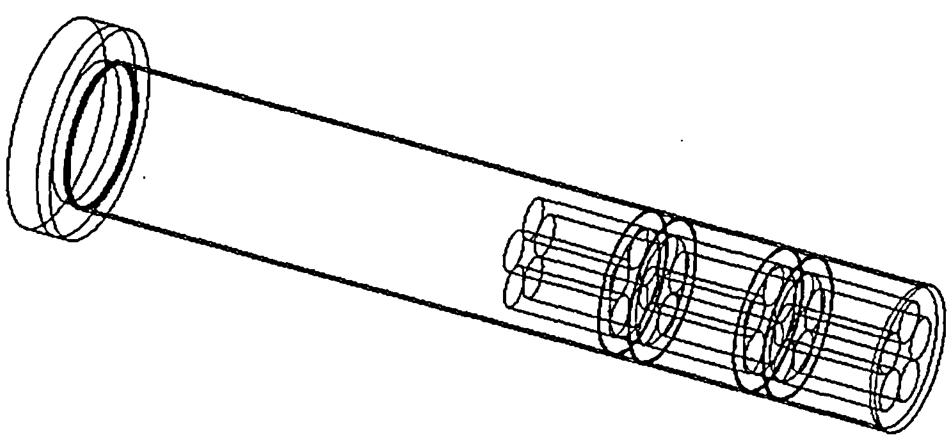


Fig. 6.9.1-4. Containment vessel containing the 1.5-in. dia. x 2.0-in. tall slugs, pentagonal ring configuration, 0.0 cm spacing between slugs, and 1-in. thick Cat 277-4 canned spacers.

Fig. 6.9.1-5 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.

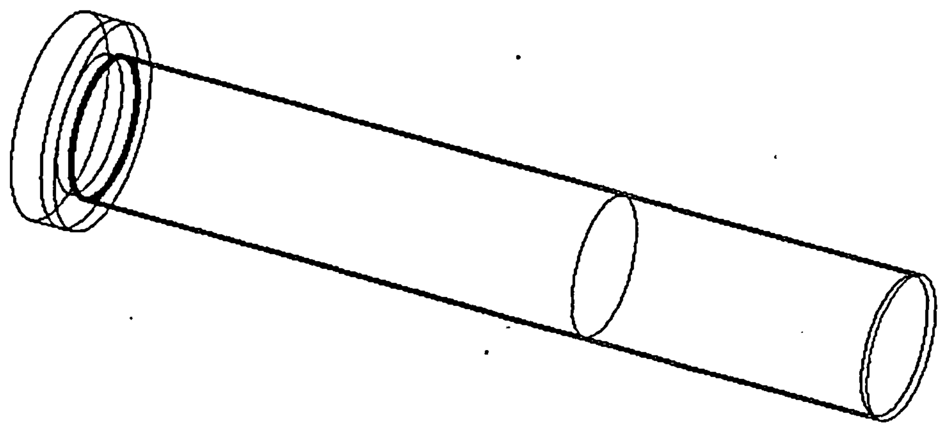


Fig. 6.9.1-5. Wire-mesh view of the containment vessel containing the HEU oxide mixture.

Fig. 6.9.1-6 depicts the wire-mesh view of the UNH crystals content inside the containment vessel. A solution of UNH crystals dissolved in water fills the entire volume of the containment vessel.

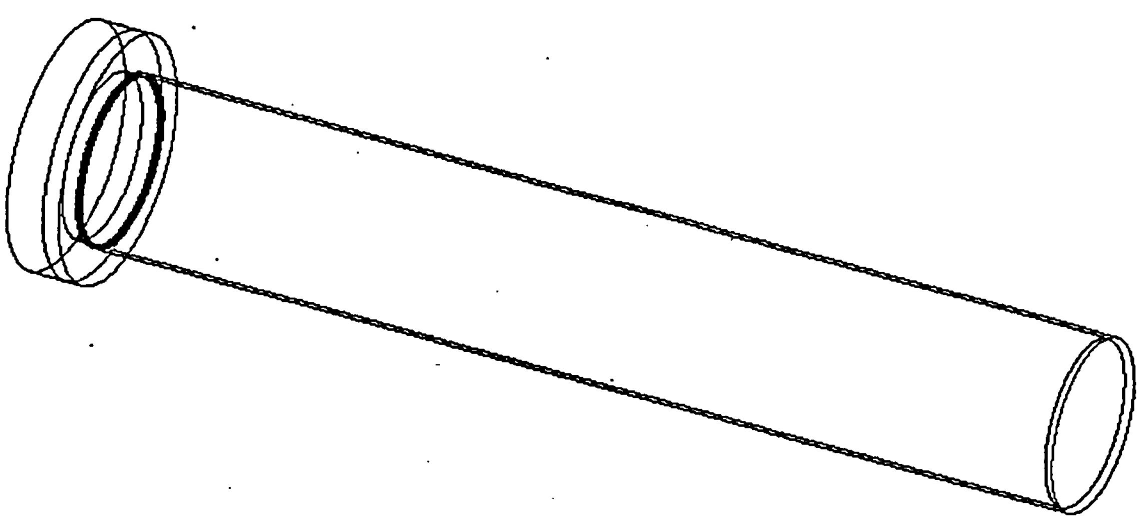


Fig. 6.9.1-6. Wire-mesh view of the containment vessel containing the UNH crystal mixture.

Wire-frame figures for the HEU broken metal models are presented in Appendix 6.9.3.1.

APPENDIX 6.9.2

HAC PACKAGE MODEL

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 HAC is used to predict the deformed outer-diameters of 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 5 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 calculated for each node point as indicated 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 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 of the NCT model are the 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.

Table 6.9.2.1-1. Deformation of 18.37 in. diameter ES3100 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.)	(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 NCT package model into an HAC package model

Dimension (cm)	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
OR_{Drum}	23.32990	21.77942	21.83809	20.87929
IR_{Drum}	23.17750	21.62702	21.68569	20.72689
$th_{Drum\ wall}$	0.15240	0.15240	0.15240	0.15240
OR_{Lid}	23.11400	21.56352	21.62219	20.66339
IR_{Lid}	22.96160	21.41112	21.46979	20.51099
$th_{Kaolite}$	12.10310	10.55262	10.61129	9.65249
Volume Fraction multipliers for conservation of mass in the components with modified volumes.				
	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
Kaolite of the containment vessel inner liner				
Mass (g)	117563.0	97080.4	97829.7	85839.8
Volume (cm^3)	134888.0	111387.0	112246.0	98489.5
Volume Fraction (VF) multiplier	–	1.21099	1.20171	1.36956
VF for water component of Kaolite	0.52294	0.63327[a]	0.62843[a]	0.71620[a]
VF for dry mix component of Kaolite	0.34864	0.42220[a]	0.41897[a]	0.47749[a]
Angle Iron				
Mass (g)	5621.76	4521.40	4561.66	3917.54
Volume (cm^3)	708.030	569.446	574.516	493.393
VF	1.0	1.24337	1.23239	1.43502
Drum Steel				
Mass (g)	25446.3	23397.6	23474.2	22231.2
Volume (cm^3)	3204.82	2946.80	2956.50	2799.90
VF	1.0	1.08756	1.08401	1.14462

[a] Volume Fraction (VF) for Kaolite components calculated by multiplying the VF used in the NCT model by volume fraction multiplier for the 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 are evaluated in order to eliminate any biases arising from spectral leakage effects in the reflector of 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 corresponding standard error (s_i) computed for 10 individual runs are shown in Table 6.9.2.2-1, -2, and -3. The same statistical method (Reference DAC-FS-900000-A014) used in the evaluation of Kaolite models (Appendix 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 6.9.2.2-1. 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	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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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

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 (cont.)

moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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
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

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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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

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 (cont.)

moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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
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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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
moifr	Random Number	"A" cases	k_{eff}	s	"B" cases	k_{eff}	s
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 (cont.)

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.

A 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 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 (5) 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 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 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 set 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 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.

Table 6.9.2.3-1. T-test values for establishing 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	S_{di}	t[a]
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**	**S_{di}**	**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**	**S_{di}**	**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_0 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.

For $|t| > 3.25$, the H_0 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 provides 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. diameter of the pre-test package. 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.

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 the HAC, the 17.26-in. reduced diameter for the "composite close-pack" package is slightly larger than the 17.20-in. diameter of the "MLR" calculation model used in the HAC calculations of Sect. 6.6. Therefore, packages evaluated with "MLR" calculation model of packages in a rectangular-pitch configuration is deemed adequate for the HAC criticality evaluation. Considering both the irregular shape of deformed drums and that array spacing is determined by overall (maximum) dimensions rather than mean or minimum dimension 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 18.37 in. diameter ES3100 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.)
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

APPENDIX 6.9.3

PACKAGE MATERIAL COMPOSITIONS

APPENDIX 6.9.3

PACKAGE MATERIAL COMPOSITIONS

Table 6.4 of Sect. 6.3.2 provides basic information and data 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, justification, or both for the material compositions used in the criticality calculations.

6.9.3.1 HEU

HEU considered for shipment in the ES-3100 is categorized into the following material forms: HEU solid or broken metal; HEU oxide; or uranyl nitrate hexahydrate (UNH) crystals. In the interest of adding conservatism, uranium is modeled ^{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 et al. 1978). 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 wt%-ages 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.

Table 6.9.3.1-1. Calculation of constituent weight-percentage values for uranyl nitrate hexahydrate crystals used in KENOV.a calculation models

Avogadro No. (N_o)	6.0221370E+23					
UNH $UO_2(NO_3)_2$+$6H_2O$	Atoms/Molecule	At.Wt.	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.=($\sum N_i A_i$)/No						2.7900

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 broken into pieces, and the enrichment. An analogy can be made for broken metal to the minimum critical mass of submerged metal lattices of regular-shaped fissile material. Using experimental data, the approximation of heterogeneous mixture of fissile material and moderator as a homogenous mixture is justified as follows.

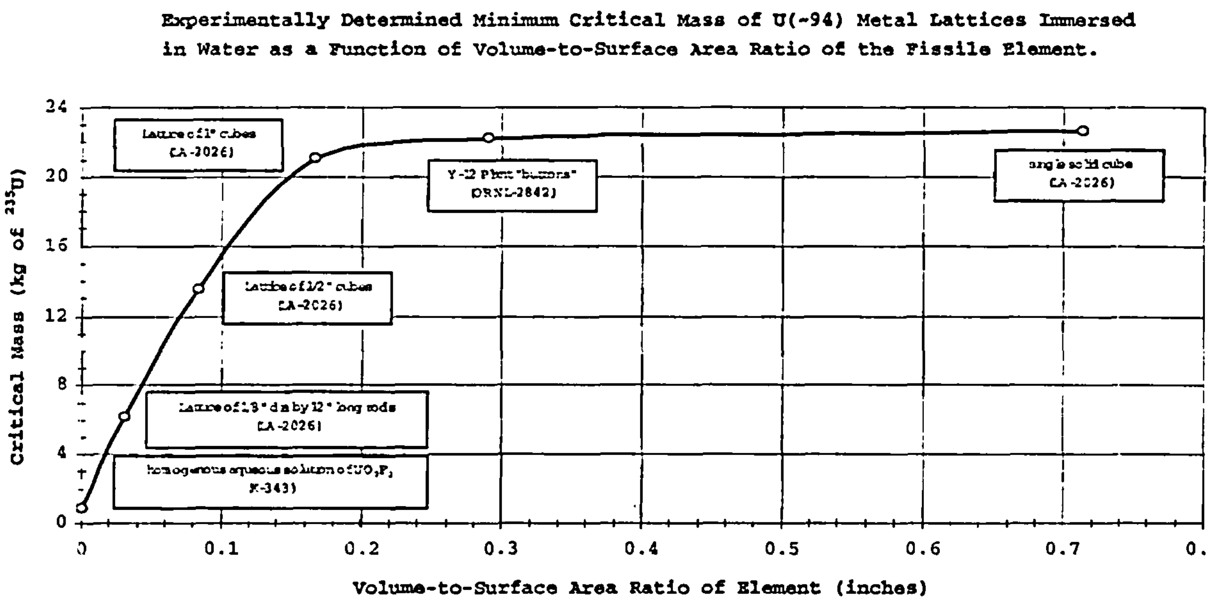


Fig. 6.3.9.1-1. Experimentally determined critical mass U(~94) metal lattices immersed in water as a function of volume-to-surface area ratio of fissile material. Source: TID-7028, Fig. 19, Y-12 data have been added.

Figure 6.3.9.1-1 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 (Paxton et al. 1964). 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.

Figure 6.3.9.1-2 depicts the experimentally determined minimum critical mass of U (~ 94) metal water and solution systems as a function density/concentration of ^{235}U (kg/l). The Figure 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 homogenous metal water mixtures. Conversely stated, the critical mass is greater for a heterogenous system than for a homogenous 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 homogenous mixture is justifiable and also conservative at the higher H/X ratios.

Approximating broken metal as a homogenous 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 Figure 6.9.1.3-3. 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

CCG-365, Figure 1 entitled "Survey of Experimental Data for Near-Spherical, Water Moderated Highly Enriched Uranium Systems with Thick Water Reflection."

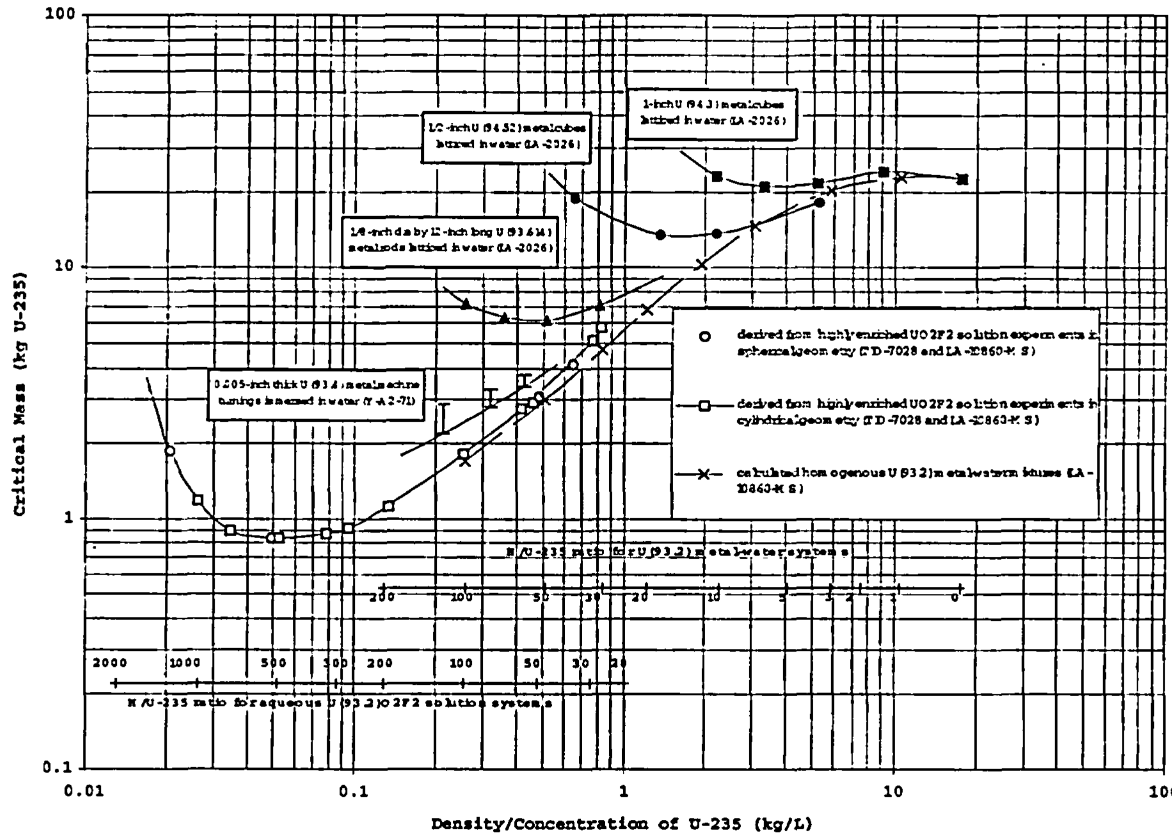


Fig. 6.3.9.1-2. Figure 1 of CCG-365.

lattice circumscribed by the inner wall of the containment vessel. Water fills the truncated cylindrical regions between 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.

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 units 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 Cat 277-4 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

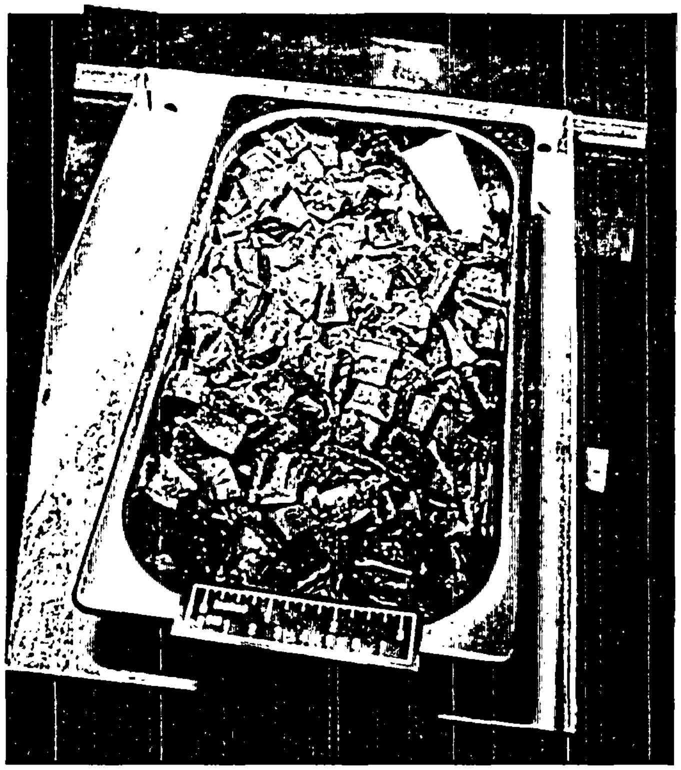


Fig. 6.9.3.1-3. Pan of HEU broken metal.

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 cubes 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 0.89 for increasing 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 attributed to the difference in the HEU for the arrays of whole cubes.

Calculation results for the "cha" models, where arrays of cubes are fully homogenized with the water for the flooded containment vessel, indicate the highest k_{eff} values. The neutron multiplication factor jumps from 0.89 to 0.96. This model is deemed to be overly conservative when applied to a 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. Given HEU metal is much denser than water, it will not float and become distributed throughout a flooded containment vessel, but will instead gravitate toward the bottom of the containment vessel.

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. can spacers, 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 × 3 × *n*	35,164	33,406	7,946	6.21	0.8479	0.0013	0.85
6 × 6 × *n*	35,973	34,175	7,904	6.04	0.8746	0.0010	0.88
12 × 12 × *n*	35,988	34,188	7,903	6.03	0.8773	0.0012	0.88
cubes homogenized within foot print of lattice ("lha" cases)							
3 × 3 × *n*	35,164	33,406	7,946	6.21	0.8764	0.0012	0.88
6 × 6 × *n*	35,973	34,175	7,904	6.04	0.8863	0.0013	0.89
12 × 12 × *n*	35,988	34,188	7,903	6.03	0.8891	0.0012	0.89
cubes homogenized within containment vessel ("cha" cases)							
3 × 3 × *n*	35,164	33,406	7,946	6.21	0.9489	0.0014	0.95
6 × 6 × *n*	35,973	34,175	7,904	6.04	0.9537	0.0013	0.96
12 × 12 × *n*	35,988	34,188	7,903	6.03	0.9529	0.0012	0.96

The calculation results for the homogeneous mixture model of HEU metal and water within a rectangular lattice bounds results for the explicit model. Also, the homogenization over the entire volume of the containment vessel is deemed overly conservative. For these reasons, the "lha" model is chosen for representation of HEU broken metal inside the flooded containment vessel under full water reflection. For conservatism the "cha" model is chosen to represent broken metal in single packages and array of packages under HCT and HAC. Details of the calculation models follow.

Explicit model of HEU metal cubes forming an array of unit cells. HEU metal cubes ranging from 1.0 in. to 0.25 in. are explicitly modeled, correspondingly arranged in a 3 × 3, 6 × 6, or 12 × 12 (horizontal plane) lattice, with N layers vertically. The height of the lattice or number of layers is determined by the HEU mass loading. HEU cubes are centered in the individual unit cells.

Figure 6.9.3.1-4 depicts an isometric cutaway view of the containment vessel and lid with three 12 × 12 × 18 arrays of HEU content separated by Cat 277-4 canned spacers. The water surrounding the HEU has been removed for the purpose of the illustration. Convenience cans are not modeled; therefore, the corner unit cells nearly touch the inside wall of the containment vessel. Spacing between cubes is limited by the inner diameter of the 5.06-in. (12.8524-cm) containment vessel. The footprint of the lattice is 3.57796 in. (9.08802 cm) square. Cat 277-4 canned spacers are modeled as square rather than cylindrical, where the area of the square spacer equals the radial area of the cylindrical spacer. This approximation preserves the neutron poison material present between HEU in actual can/containment vessel loadings (content in circular convenience cans separated by circular spacers).

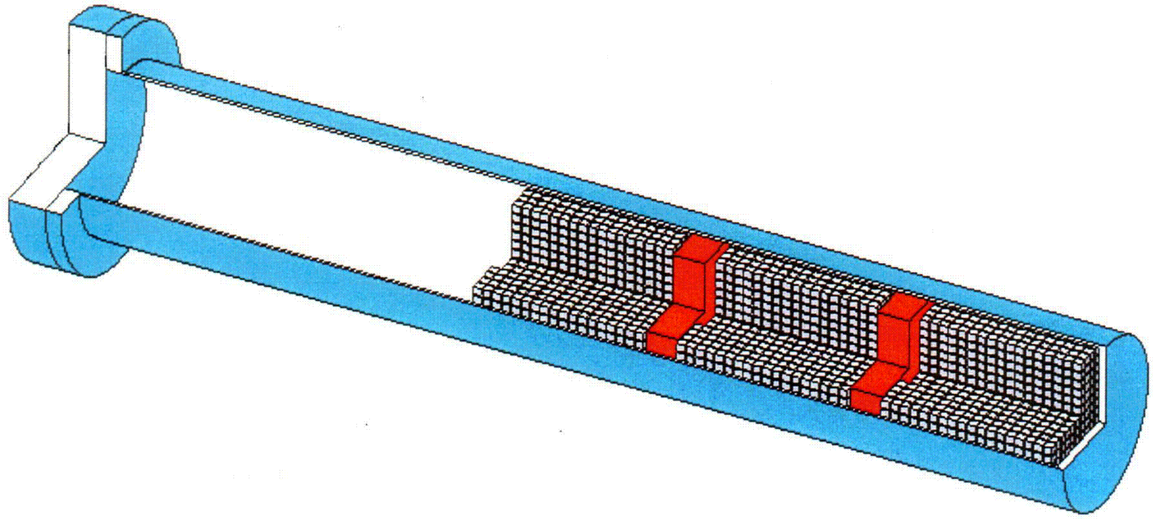


Figure 6.9.3.1-4. Isometric view of the "sqa" model with three 12x12x18 lattices of HEU contents.

The HEU mass is varied in a series of calculations; however, the enrichment and density are maintained constant. The uranium mass is reduced by removing one or more cubes from the array and the created vacancies are filled with water. Because convenience cans are not included in the calculation models, the location of the Cat 277-4 spacers between the arrays decreases as complete layers of cubes are removed. The volume of the containment vessel above the top layer of the top array of cubes is filled with full density water.

HEU metal homogeneously mixed with water within the rectangular lattice formed by the units cells. The HEU in the 3 × 3 × N, 6 × 6 × N, and 12 × 12 × N unit cells of the explicit model are homogeneously mixed with water in the rectangular lattice. Figure 6.9.3.1-5 depicts an isometric cutaway view of the containment vessel and lid with three rectangular lattices separated by Cat 277-4 canned spacers. The dimensions of each rectangular lattice are defined by the 12 × 12 × 18 array of unit cells of the explicit model. Each lattice location contains the same mass of HEU and water that the respective explicit cube models contain. The volume outside the rectangular lattices is filled with full density water.

HEU metal homogeneously mixed with water within the volume of the containment vessel. The HEU in the 3 × 3 × N, 6 × 6 × N, and 12 × 12 × N unit cells of the explicit model are homogeneously mixed with water in the volume of the containment vessel. Figure 6.9.3.1-6 depicts an isometric cutaway view of the containment vessel and lid with HEU content homogenized with water in the containment vessel. The three rectangular lattices are used to position the Cat 277-4 canned spacers for similarity with the "sqa" and "lha" models. The dimensions of each rectangular lattice are defined by the 12 × 12 × 18 array of unit cells of the explicit model. The mass of HEU and water of the explicit cube model is preserved.

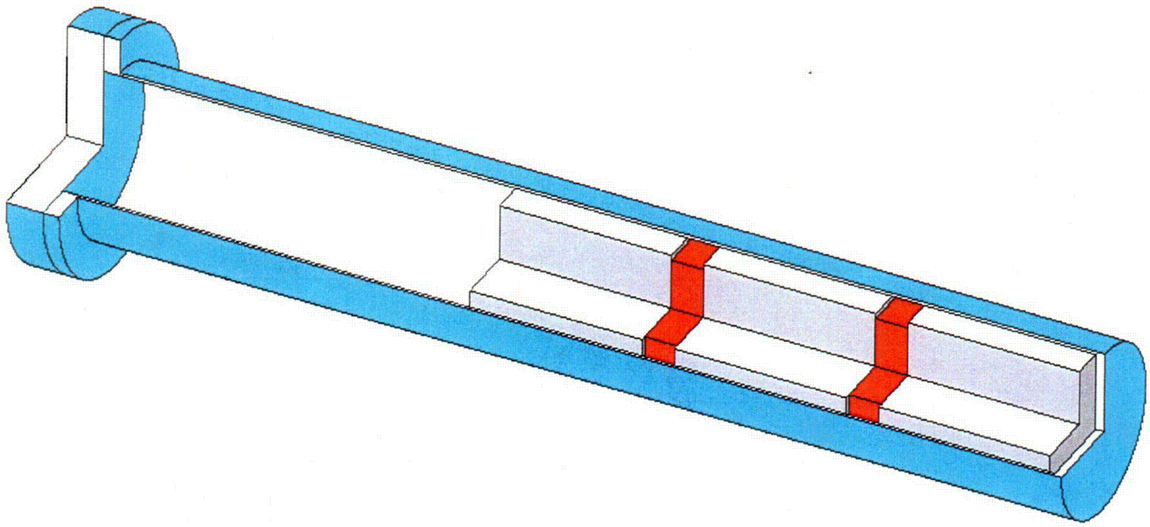


Figure 6.9.3.1-5. Isometric view of the homogeneous "lha" model with HEU homogeneously mixed with water within the rectangular lattice formed by the units cells.

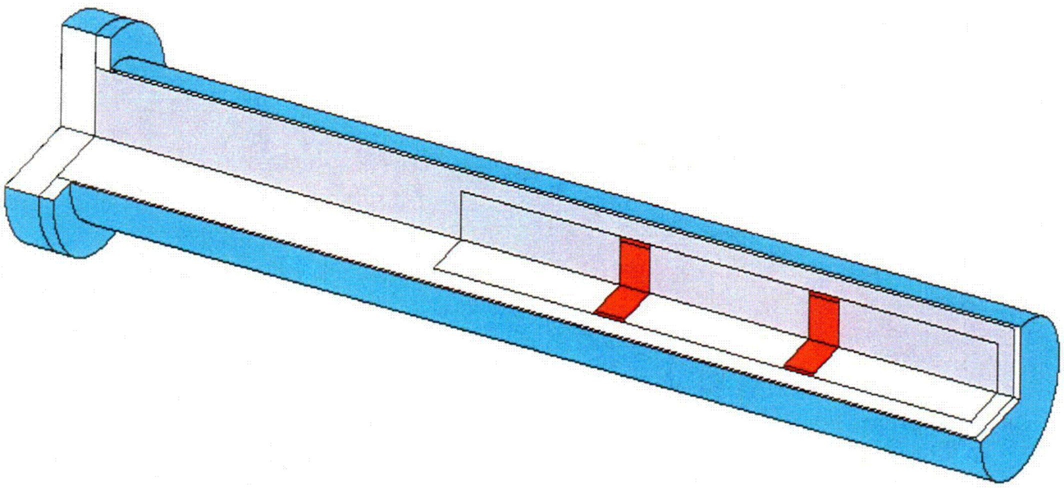


Figure 6.9.3.1-6. Isometric view of the homogeneous "cha" model with HEU homogeneously mixed with water within the containment vessel.

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 Catalog Nos. 277 and 277-4 (Cat 277-4)

Reactor Experiments, a subsidiary of Thermo Electron Corporation, manufactures a heat resistant shielding material designated Catalog No. 277 Dry Mix. The material is described as one combining 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

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in the boron constituent. Widely used in nuclear power plants applications, the heat resistant shielding material is capable of retaining a significant portion of its shielding properties up to 230°C (450°F). Vendor-supplied test data (Appendix 6.9.4) indicates that Cat. No. 277 retains approximately 90% of the hydrogen (water) content at an operating temperature of approximately 280°F and 70% at the recommended operating limit of 350°F. The latter temperature is well above HAC temperatures expected inside the Body Weldment liner inner-cavity.

The boron content has been increased from 1.56 wt % to 4.23 wt % for application to the ES-3100. This new material is designated neutron poison Catalog No. 277-4 (Cat 277-4). 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. The boron carbide grit partial sizes used are also small after passing through mesh sizes of 200 and 40 (63 to 355 μm). Cat 277-4 contains a large amount of hydrated alumina, also known as aluminum trihydrate [$Al(OH)_3$]. It is a non-abrasive powder with a specific gravity of 2.42. Given that both materials are of like density and similar partial size, separation and in-homogeneity of Cat 277-4 material is not expected during the controlled vibration casting process.

Information appearing under the heading "Cat 277-4" at the bottom of Table 6.9.3.3-1 provides details of the composition data provided by the vendor. The atomic weights (At. Wt.) listed in Table 6.9.3.3-1 are obtained from the 14th Edition of *Nuclides and Isotopes*. The atomic weights are consistent with values used by the vendor to derive the number densities shown (green box) using the constituent wt %'s (green box). This is evident by the close agreement with the calculated number densities shown in the column to the right (red box); the difference is attributed to round-off in the values reported by the vendor. The calculated number densities for hydrogen and oxygen are adjusted to "extract" the water component from the material specification, and the constituent wt %'s are recalculated accordingly (orange box). The density of the non-aqueous component of Cat 277-4 is 0.9877 g/cm^3 and the density of water in the Cat2 77-4 is 0.6942 g/cm^3.

Some of these values for the atomic weights, notably oxygen, are slightly different than ones provided in the Standard Composition Library for SCALE4.4a. Thus for consistency, the value of 15.9949 is used for the atomic weight of oxygen which resulted in slight differences in the constituent wt %'s for hydrogen and oxygen in water.

Table 6.9.3.3-2 provides a material specification where both the water and boron components have been extracted from the material specification for the neutron poison. Cat 277-4 is specified in KENO V.a as three arbitrary materials: **arbmnp277** having a density of 0.9165 g/cm^3, **arbmnph2o** having a density of 0.6942 g/cm^3 and **arbmboron** having a density of 7.1195e-02 g/cm^3. This material description allows for clear specification of reduced boron and water contents required in the evaluation of NCT and HAC. These values are used in the criticality calculations based on the vender's material specification. As mentioned previously, full water content is used in the NCT calculations while 90 % of the water content is used in the HAC.

Material testing results available after criticality calculations were completed reveal that the moisture content in Cat 277-4 is approximately 30% and not the 42% value as given in the vendor's material specification. Thermogravimetric Analysis (TGA) tests preformed on nine samples at temperature up to 800°C (1472°F) are the basis for the data presented in Table 6.9.3.3-3. For the six wet samples storied in a plastic bag for five weeks after being poured, the test residue percentages ranged from 59.22 to 65.56 wt %indicating moisture contents ranging from 40.78 to 34.44 wt % in the pre-tested sample. For the three samples eight weeks old stored in plastic bags for two weeks and left to air dry for six weeks, the test residue percentages ranged from 67.8 to 68.57 wt % indicating 32.2 to 31.43 wt % moisture content in the pre-test samples.

Table 6.9.3.3-1. Calculation of constituent weight-percentage values for Cat 277-4 used in KENOV.a calculation models

Avogadro No. (N_o)	6.022137e+23								
H_2O in NP277-4									
Atom	wt%		At. Wt.	calc. N_i	N_iA_i			calc. w_i	
Hydrogen	11.1913		1.0078	4.6422e+22	4.6784e+22			11.1913	
Oxygen	88.8087		15.9949	2.3211e+22	3.7126e+23			88.8087	
Water	100.0000		18.0105	6.9633e+22	4.1804e+23				
den.=($\sum N_iA_i$)/No					0.6942				
NP277-4									
Atom	Given wt%	Given N_i	At. Wt.	calc. N_i	N_iA_i	adjusted N_i	adj. N_iA_i	calc. w_i	Wt% / At.Wt.
Hydrogen	4.619	4.64e+22	1.0078	4.6422e+22	4.6784e+22	0.0000e+00	0.0000e+00	0.0000	0.0000
Boron	4.233	3.96e+21	10.8126	3.9652e+21	4.2875e+22	3.9652e+21	4.2875e+22	7.2080	6.6663e-03
Carbon	1.506	1.27e+21	12.0000	1.2711e+21	1.5254e+22	1.2711e+21	1.5254e+22	2.5644	2.1370e-03
Oxygen	59.996	3.79e+22	15.9949	3.7992e+22	6.0768e+23	1.4781e+22	2.3642e+23	39.7463	2.4849e-02
Sodium	0.130	5.87e+19	22.9895	5.7275e+19	1.3167e+21	5.7275e+19	1.3167e+21	0.2214	9.6289e-05
Magnesium	0.386	2.32e+21	24.3051	1.6086e+20	3.9097e+21	1.6086e+20	3.9097e+21	0.6573	2.7043e-04
Aluminum	21.160	7.93e+21	26.9818	7.9432e+21	2.1432e+23	7.9432e+21	2.1432e+23	36.0313	1.3354e-02
Silicon	1.320	4.76e+20	28.0853	4.7604e+20	1.3370e+22	4.7604e+20	1.3370e+22	2.2477	8.0031e-04
Sulfur	0.150	4.80e+19	32.0636	4.7384e+19	1.5193e+21	4.7384e+19	1.5193e+21	0.2554	7.9661e-05
Calcium	6.180	1.56e+21	40.0803	1.5617e+21	6.2595e+22	1.5617e+21	6.2595e+22	10.5233	2.6256e-03
Iron	0.320	5.72e+19	55.8447	5.8039e+19	3.2412e+21	5.8039e+19	3.2412e+21	0.5449	9.7574e-05
summations	100.000	1.02e+23		9.9955e+22	1.0129e+24	3.0322e+22	5.9482e+23	100.0000	
At. Wt. material									19.6169
assumed density	1.6819								
den.=($\sum N_iA_i$)/No					1.6819		0.9877		0.9877

Table 6.9.3.3-2. Calculation of constituent weight-percentage values for Cat 277-4 used in KENOV.a calculation models

Avogadro No. (N_o)	6.022137e+23

H_2O in NP277-4

Atom	wt%	At. Wt.	calc. N_i	N_iA_i	calc. w_i
Hydrogen	11.1913	1.0078	4.6422e+22	4.6784e+22	11.1913
Oxygen	88.8087	15.9949	2.3211e+22	3.7126e+23	88.8087
Water	100.0000	18.0105	6.9633e+22	4.1804e+23	
den.=($\sum N_iA_i$)/No				0.6942	

Boron in NP277-4

Atom	wt%	At. Wt.	calc. N_i	N_iA_i
Boron-10	18.4309	10.0129		
Boron-11	81.5691	11.0093		
Boron	100.0000	10.8110	3.9658e+21	4.2875e+22
den.=($\sum N_iA_i$)/No				7.1195e-02

NP277-4

Atom	Given wt%	Given N_i	At. Wt.	calc. N_i	N_iA_i	adjusted N_i	adj. N_iA_i	calc. w_i	Wt% / At.Wt.
Hydrogen	4.619	4.64e+22	1.0078	4.6422e+22	4.6784e+22	0.0000e+00	0.0000e+00	0.0000	0.0000
Boron	4.233	3.96e+21	10.8110	3.9658e+21	4.2875e+22	0.0000e+00	0.0000e+00	0.0000	0.0000
Carbon	1.506	1.27e+21	12.0000	1.2711e+21	1.5254e+22	1.2711e+21	1.5254e+22	2.7636	2.3030e-03
Oxygen	59.996	3.79e+22	15.9949	3.7992e+22	6.0768e+23	1.4781e+22	2.3642e+23	42.8337	2.6780e-02
Sodium	0.130	5.87e+19	22.9895	5.7275e+19	1.3167e+21	5.7275e+19	1.3167e+21	0.2386	1.0377e-04
Magnesium	0.386	2.32e+21	24.3051	1.6086e+20	3.9097e+21	1.6086e+20	3.9097e+21	0.7083	2.9144e-04
Aluminum	21.160	7.93e+21	26.9818	7.9432e+21	2.1432e+23	7.9432e+21	2.1432e+23	38.8302	1.4391e-02
Silicon	1.320	4.76e+20	28.0853	4.7604e+20	1.3370e+22	4.7604e+20	1.3370e+22	2.4223	8.6248e-04
Sulfur	0.150	4.80e+19	32.0636	4.7384e+19	1.5193e+21	4.7384e+19	1.5193e+21	0.2753	8.5849e-05
Calcium	6.180	1.56e+21	40.0803	1.5617e+21	6.2595e+22	1.5617e+21	6.2595e+22	11.3408	2.8295e-03
Iron	0.320	5.72e+19	55.8447	5.8039e+19	3.2412e+21	5.8039e+19	3.2412e+21	0.5872	1.0515e-04
summations	100.000	1.02e+23		9.9956e+22	1.0129e+24	2.6357e+22	5.5195e+23	100.0000	
At. Wt. material									20.9415
assumed density	1.6819								
den.=($\sum N_iA_i$)/No					1.6819		0.9165		0.9165

Table 6.9.3.3-3. Data for TGA analysis of Cat 277-4 samples

Material Density 1.68 g/cm³ (105 lb/ft³)									
Wet Sample Data					Dry Sample Data				
	150°C (302°F)		800°C (1472°F)			150°C (302°F)		800°C (1472°F)	
Present	Max	Min	Max	Min	Present	Max	Min	Max	Min
Wt%	93.40%	84.20%	65.56%	59.22%	Wt%	98.53%	97.87%	68.57%	67.80%
Weight Loss	Min	Max	Min	Max	Weight Loss	Min	Max	Min	Max
Wt%	6.60%	15.80%	34.44%	40.78%	Wt%	1.47%	2.13%	31.43%	32.20%
Water Present	Max	Min	Min	Min	Water Present	Max	Min	Min	Min
Wt%	80.84%	61.26%	0.00%	0.00%	Wt%	95.32%	93.39%	0.00%	0.00%
Water Loss	Min	Max	Max	Max	Water Loss	Min	Max	Max	Max
Wt%	19.16%	38.74%	100.00%	100.00%	Wt%	4.68%	6.61%	100.00%	100.00%
Water Density Present	Max	Min	Min	Min	Water Density Present	Max	Min	Min	Min
lb/ft³	29.23	26.23	0	0	lb/ft³	31.46	31.57	0	0
g/cm³	0.468	0.420	0	0	g/cm³	0.504	0.506	0	0
Water Density Loss	Min	Max	Max	Max	Water Density Loss	Min	Max	Max	Max
lb/ft³	6.93	16.59	36.16	42.82	lb/ft³	1.54	2.24	33.00	33.81
g/cm³	0.111	0.266	0.579	0.686	g/cm³	0.025	0.036	0.529	0.542

The wettest sample generated a 59.22 wt % weight residue at 800°C (1472°F) for a water content of approximately 0.685 g/cm³ (0.4078*105 lb/ft³ = 42.78 lb/ft³.) This represents approximately 98.7% of the value in the material specification; consequently, the material specification provided by the vendor is believed to correspond to the water content present in the pre-cured mix.

For the dry samples held at 302°F, the water present ranged form 95.32 to 93.39 wt % while the water loss ranged form 4.68 to 6.61 wt %. Corresponding densities ranged from 0.504 to 0.506 g/cm³ for residual water present and 0.025 to 0.036 g/cm³ for water lost. For the same samples subsequently held at 800 °C (1472°F), the sample having 68.57 wt % weight residue is considered the driest sample in terms of initial water content. Using a material nominal density of approximately 105 lb/ft³, the total water density loss is 0.529 g/cm³. Using a minimum density of 100 lb/ft³, the total water density loss is 0.504 g/cm³. This water density of 0.504 g/cm³ is taken to represent the "room temperature" moisture of cured material, which is approximately 73% of the value both given in the vendor's material specification and used in the criticality calculations for the SAR.

As shown in Table 6.9.3.3-4, a material specification for cured Cat 277-4 is derived from the vendor's pre-cured specification. The hydrogen content is set to 3.372 wt % (73% of the vendor specification), and the wt %'s for the remaining elements are normalized. Assuming a minimum material density of 1.6 g/cm³, the component densities for Cat 277-4 are 0.4821 g/cm³ for water, 6.8614e-02 g/cm³ for boron, and 1.0493 g/cm³ for the remaining material.

Table 6.9.3.3-4. Calculation of adjusted constituent weight-percentage values for Cat 277-4 used in KENOV.a calculation models

Avogadro No. (N_o)	6.022137e+23				
H_2O in NP277-4					
Atom	**wt%**	**At. Wt.**	**calc. N_i**	**N_iA_i**	**calc. w_i**
Hydrogen	11.1913	1.0078	3.2238e+22	3.2489e+22	11.1913
Oxygen	88.8087	15.9949	1.6119e+22	2.5782e+23	88.8087
Water	100.0000	18.0105	4.8357e+22	2.9031e+23	
den.=($\sum N_iA_i$)/No				0.4821	

Boron in NP277-4				
Atom	**wt%**	**At. Wt.**	**calc. N_i**	**N_iA_i**
Boron-10	18.4309	10.0129		
Boron-11	81.5691	11.0093		
Boron	100.0000	10.8110	3.8220e+21	4.1320e+22
den.=($\sum N_iA_i$)/No				6.8614e-02

NP277-4										
Atom	**Given wt%**	**adj to 73%H**	**Given N_i**	**At. Wt.**	**calc. N_i**	**N_iA_i**	**adjusted N_i**	**adj. N_iA_i**	**calc. w_i**	**Wt% /**
Hydrogen	4.619	3.372	4.64e+22	1.0078	3.2238e+22	3.2489e+22	0.0000e+00	0.0000e+00	0.0000	0.0000
Boron	4.233	4.288	3.96e+21	10.8110	3.8220e+21	4.1320e+22	0.0000e+00	0.0000e+00	0.0000	0.0000
Carbon	1.506	1.526	1.27e+21	12.0000	1.2251e+21	1.4701e+22	1.2251e+21	1.4701e+22	2.3264	1.9387e-03
Oxygen	59.996	60.780	3.79e+22	15.9949	3.6615e+22	5.8565e+23	2.0496e+22	3.2782e+23	51.8782	3.2434e-02
Sodium	0.130	0.132	5.87e+19	22.9895	5.5198e+19	1.2690e+21	5.5198e+19	1.2690e+21	0.2008	8.7351e-05
Magnesium	0.386	0.391	2.32e+21	24.3051	1.5503e+20	3.7679e+21	1.5503e+20	3.7679e+21	0.5963	2.4533e-04
Aluminum	21.160	21.437	7.93e+21	26.9818	7.6552e+21	2.0655e+23	7.6552e+21	2.0655e+23	32.6868	1.2114e-02
Silicon	1.320	1.337	4.76e+20	28.0853	4.5878e+20	1.2885e+22	4.5878e+20	1.2885e+22	2.0391	7.2602e-04
Sulfur	0.150	0.152	4.80e+19	32.0636	4.5666e+19	1.4642e+21	4.5666e+19	1.4642e+21	0.2317	7.2266e-05
Calcium	6.180	6.261	1.56e+21	40.0803	1.5051e+21	6.0325e+22	1.5051e+21	6.0325e+22	9.5465	2.3818e-03
Iron	0.320	0.324	5.72e+19	55.8447	5.5935e+19	3.1236e+21	5.5935e+19	3.1236e+21	0.4943	8.8516e-05
summations	100.000		1.02e+23		8.3830e+22	9.6354e+23	3.1652e+22	6.3191e+23	100.0000	
At. Wt. material										19.9646
assumed density	1.6									
den.=($\sum N_iA_i$)/No						1.6000		1.0493		1.0493

Figure 6.9.3.3-1 depicts the sample water content versus temperature for the three dry samples of the TGA tests. The maximum NCT temperature is assumed to be 120°C (248°F) while the maximum HAC temperature based on testing is estimated at 150°C (302°F). These curves reveal that very little water loss occurs in this temperature range. Given the sample residues are 98.27 and 97.8 wt % of the initial sample, the corresponding NCT and HAC residual water densities are 0.475 and 0.467 g/cm^3, respectively. These values represent 98.5% of full water content in the cured material specification for the NCT and 96.8% of the water content for the HAC. These values are not significantly different from full water density.

New criticality calculations with the revised material specification for Cat 277-4 are run using a select set of cases to produce data for establishing a bias, termed the "CSI dependent reduction factor." This bias adjustment is applied to the USL for screening criticality results in the criticality calculations run with the vendor's (pre-cured) material specification. It compensates for the over estimation of neutron absorption in the criticality calculations used to establish fissile mass loading limits.

Tables 6.9.6-93 through 6.9.6-97 provide comparison of case results between calculations run with the vendor's material specification and calculations run with the revised material specification. Comparison of results for cases **nbiabm_12_01_09_*nn*** based on the vendor's specification to results for cases **nbiabm160_12_01_09_*nn*** run using the revised specification reveal that differences ($\Delta k_{eff} + 2\sigma$) are greatest in the driest array where neutronic interaction between units is greatest. Differences are smallest in flooded arrays where packages are nearly isolated from each other. Comparison of results for cases **nbiabm_*nn*_01_09_03** to cases **nbiabm160_*nn*_01_09_03** reveal that differences diminish as the content fissile mass is decreased. Differences appear to be relatively constant as a function of enrichment (i.e., cases **nbiabm_07_01_*nn*_03** and cases **nbiabm160_07_01_*nn*_03**). Also, it is apparent from the differences given in the tables that the difference decreases as the array size decreases. Conservative bias adjustment factors for the USL are as follows: 0.06 for infinite arrays cases, 0.06 for a 13×13×6 size array; 0.05 for a 9×9×4 size array; and 0.04 for 7×7×3 and 5×5×2 size arrays, and 0.02 for single package. The bias adjustment factor for the single package is derived from results for the flooded array (degenerate single package case).

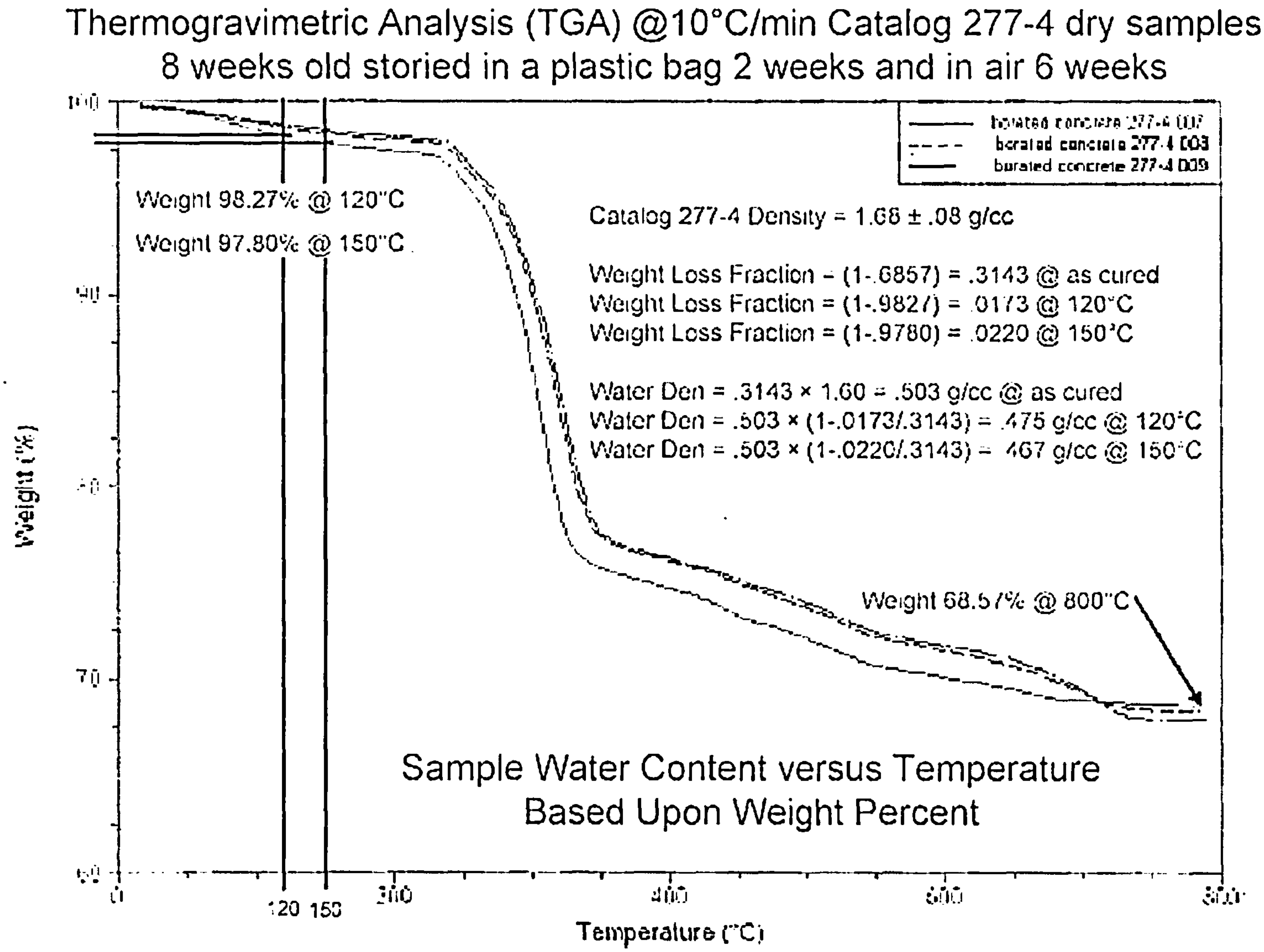


Figure 6.9.3.3-1. Sample water content versus temperature for the three dry samples of the TGA tests.

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. The density of the fired material is about 25 lb/ft³. 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,

$$S.G._{max} = \frac{14.5\ \text{qt}}{20\ \text{lb dry}} \times \frac{25\ \text{lb}}{\text{ft}^3} \times \frac{0.946\ \ell}{1\ \text{qt}} \times \frac{998.2\ \text{g}}{\ell} \times \frac{35.32\ \text{ft}^3}{10^6\ \text{cm}^3} = \frac{0.6045\ \text{g}}{\text{cm}^3} .$$

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		

Weight measurements were taken during the casting of Kaolite 1600 for production of a series of drum body weldment (M2E801343A011) and top plug (M2E801343A014) parts for the ES-2100 (Rowland 2001). Tables 6.9.3.4-2 and 6.9.3.4-3 provide detailed information. 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 Kaolite and 0.58 lb 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 lbs (2,440.32 g) of water. Given that the average volume is 5.72 ft³, then the average density of Kaolite is 22.63 lb/ft³.

The volume of the Kaolite region in the KENO models is 1.63417 × 5 cm³. For NCT, the density of Kaolite is 0.34438 g/cm³, and the density of water is 0.01493 g/cm³. 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 (Part Serial Number 97) such that the corresponding density of water is 0.00527 g/cm³. 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/cm³. The full range of NCT and HAC conditions would be covered by a variation of water in the Kaolite from 0 g/cm³ to 0.51655 g/cm³ in a calculation model.

The Kaolite components of ES-3100 shipping package were not yet 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 instead 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 Smith and Byington 2003). Test samples were produced. These were classified into three groups: high

Table 6.9.3.4-1. Fabrication data, before and after baking drum body weldment (Drawing M2E801343A011)

								before baking			after baking		
Part Serial Number	clean & empty (lb)	filled with water (lb)	before baking (lb)	after baking (lb)	density after baking (lb/ft^3)	water conditions (lb)	volume (ft^3)	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	23.98	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 6.9.3.4-2. Fabrication data, before and after baking top plug (Drawing M2E801343A014)

Part Serial Number	clean & empty (lb)	filled with water (lb)	before baking (lb)	after baking (lb)	density after baking (lb/ft³)	water conditions (lb)	volume (ft³)	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	-0.10
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	21.80	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	10.52	59.70	53.00	28.10	23.74	48.10	3.28	42.48	16.99	25.48	17.58	16.99	0.58
std.dev.					6.3565						100%	96.67%	3.33%
computed on means					22.27	49.18	0.79	42.48	16.99	25.48	17.58	16.99	0.58

[a] No explanation is given for the negative amount of water in Part 18. 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.

density, medium density, and low density. The predominate number of samples fall into the medium density category (22.04 lb/ft^3), representing the expected, improved Kaolite production process. (Smith and Byington, Appendix 2.10.4, Table 5) A material specification for use in criticality calculations was derived from the medium density test sample data (TS Kaolite). However, the TS data is based upon 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 SAR.

A set of criticality calculations were performed for each of the packaging material specifications (i.e., the TS and the AM Kaolite), using three different package water contents to represent the range of NCT and HAC. Y-12 statisticians were asked to determine whether or not the observed difference 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 calculaitons is for dry Kaolite (i.e., low water content, IS= 1e-04 spg 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 spg 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 finite array. Each package was modeled having 36 kg of 100% enriched uranium in the form of 3.24-in. diameter 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:

(c) $d_i = (k_{effBi} - k_{effAi})/n$ and,
(d) $s_{di} = \sqrt{[\,[\,n\Sigma d_i^{\,2} - (\,\Sigma d_i\,)^2\,]\,/\,n(n-1)\,]}$ (conservatively defined for the t-test appropriate for small sample sizes),

where, A_i 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 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 set 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: 0.70, 10.0 and 0.95 for dry Kaolite, for NCT Kaolite and for flooded Kaolite, respectively. A value 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_0 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 H_0 hypothesis is rejected. Therefore, it can be concluded that the mean estimate of the difference of the AM Kaolite is significantly different than 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.

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

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. [Standard Composition Library]

6.9.3.6 Calculation of equivalent water mass for polyethylene

In the calculation models for evaluation of NCT, water is substituted for polyethylene 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:

Hydrogen in 1 kg of polyethylene [$(CH_2)_2$, molecular weight = 28.0312; density = 0.92]:

$$\text{1 kg polyethylene} = \frac{1000\ \text{g}}{0.92\ \text{g/cm}^3} = 1087.0197\ \text{cm}^3$$

$$\text{H number density} = \frac{(0.92)(4)(6.02252\times10^{23})}{(28.0312)(10^{24})} = 7.906502\times10^{-2}\text{at/bn-cm}$$

$$\text{H in 1 kg} = (1087.0197\text{cm}^3)(7.906502\times10^{-2}) = 85.945234\ \text{at-cm}^2\text{/bn}$$

Grams of water [H_2O, molecular weight = 18.0110; density = 0.9982] with hydrogen content equivalent to 1 kg of polyethylene:

$$\text{equivalent g of } H_2O = \frac{(85.945234)(18.0110)(10^{24})}{(2)(6.02252\times10^{23})} = 1285.1427\ \text{g}$$

APPENDIX 6.9.4

SUPPORTING DOCUMENTS AND CORRESPONDENCE

APPENDIX 6.9.4

SUPPORTING DOCUMENTS AND CORRESPONDENCE

-----Original Message-----
From: Oliver, Michael D. [mailto:michael.oliver@thermo.com]
Sent: Friday, August 13, 2004 11:28 AM
To: Byington, G {Jerry} A (GAB)
Subject: RE: Weight percents of the chemistry for the 244, and 277

Thermo

CATALOG NO. 277 SHIELDING

Heat Resistant • Borated • Hydrogenated

Catalog No. 277 is available as a castable dry mix or precast blocks.

TECHNICAL DATA

Properties.

Hydrogen: 3.4×10^{22} atoms/cc

Boron: 1.43×10^{21} atoms/cc

Weight Percent Boron: 1.56%

Macroscopic Thermal Neutron Cross Section. $\Sigma = 1.1\ cm^{-1}$

Density: 1.60 g/cc (105 lbs/cu ft)

Recommended Temperature Limit: 350°F (177°C)

Machinability: Fair. Can be sawcut and drilled.

Thermal Conductivity. $k \doteq 0.3$ BTU-ft/(hr)(ft)²(°F)
$= 1.24 \times 10^{-3}$ cal-cm/(sec)(cm)²(°C)

Specific Heat = 0.22 cal/g°C

Coefficient of Thermal Expansion $= 8 \times 10^{-6}$ inches per inch per °F
$= 1.4 \times 10^{-5}$ cm per cm per °C

Compressive Strength = Approximately 1000 psi

Tensile Strength = Approximately 100 psi

Radiation Resistance, gammas: 1×10^{11} Rads

Radiation Resistance, neutrons: $5 \times 10^{19}\ n/cm^2$

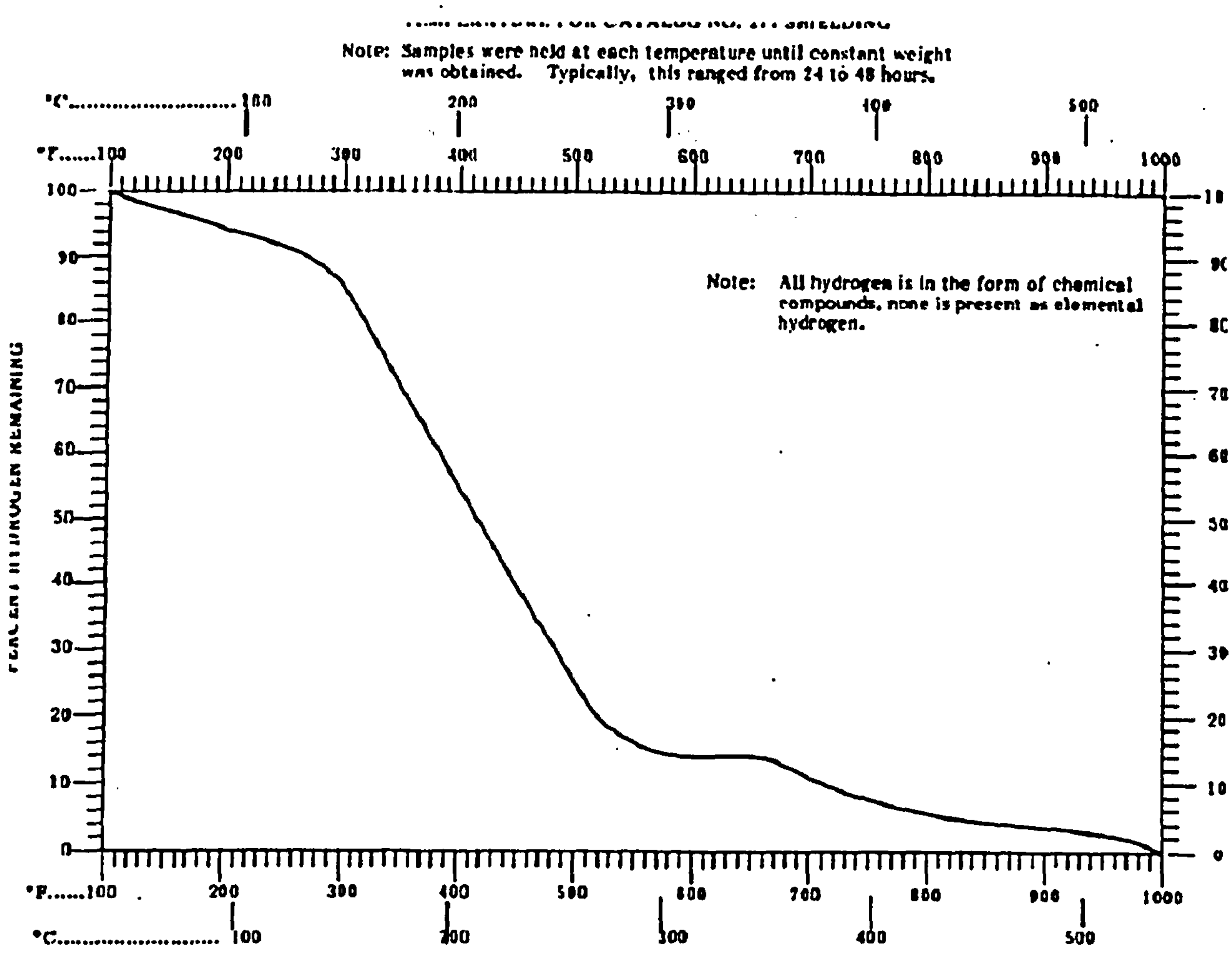
TYPICAL ELEMENTAL ANALYSIS

Element	Weight Percent
Oxygen	58.65%
Aluminum	23.01
Calcium	8.83
Hydrogen	3.37
Silicon	2.13
Boron	1.56
Sodium	0.50
Magnesium	0.50
Iron	0.27
Sulfur	0.10

Recommended shelf life for Catalog No. 277, under dry-storage conditions is 6 month

-----Original Message-----
From: Oliver, Michael D. [mailto:michael.oliver@thermo.com]
Sent: Monday, August 16, 2004 3:38 PM
To: gab@y12.doe.gov
Subject: Email

Attached copy of requested information. We can certainly make 4% boron loaded type 277 , currently waiting quote back on raw material ...but should not affect price to much



-----Original Message-----
From: Oliver, Michael D. [mailto:michael.oliver@thermo.com]
Sent: Thursday, August 26, 2004 7:50 AM
To: gab@y12.doe.gov
Subject: Type 277 - 4

Sorry about the delay, was required to be in meetings all day yesterday.

Element	Percentage	(atoms / cm 3)
Hydrogen	4.619 %	4.64E + 22
Boron	4.233 %	3.96E +21
Carbon	1.506 %	1.27E +21
Oxygen	59.996 %	3.79E +22
sodium	0.13 %	5.87E +19
aluminum	21.16%	7.93E + 21
silicone	1.32 %	4.76 E +20
sulfur	0.15 %	4.80 E + 19
calcium	6.18%	1.56E + 21
iron	0.32 %	5.72 E + 19

Thus rounding off all percentages = 100 % calculated assuming 300deg. 95.5% water retention ..

-----Original Message-----
From: Ted Cremer [mailto:ted@adelphitech.com]
Sent: Monday, August 30, 2004 2:30 PM
To: decluejf@y12.doe.gov
Subject: boron carbide elemental composition used in cat#277-4 elemental composition calculation

Dear John,

Below is the ThermoReax Boron carbide elemental composition that I have, and which I used in calculating the elemental composition of cat#277-4 mixture.

Note the boron carbide used by ThermoReax is not pure boron carbide but has a small amount of a frit like compound as seen by the silicon, oxygen, sodium, and iron.

Also there are unaccounted trace amounts of element (0.17%) since the composition does not add up to 100.00%.

71.00%	boron
25.25%	carbon
2.07%	oxygen
0.35%	silicon
1.15%	iron
0.01%	sodium
99.83%	TOTAL

I hope this helps. Please contact me if you need additional information. Specific questions regarding mixing or fabrication however can be best answered by Mike Oliver at ThermoReax, email: michael.oliver@thermo.com.

Sincerely,

Ted

Dr. Ted Cremer
Shielding Engineer
ThermoReax
e-mail: ted@adelphitech.com
pager (650) 760 — 0924
phone (650) 598 -9800 x16

APPENDIX 6.9.5

MISCELLANEOUS INFORMATION AND DATA

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.

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 for mixture (meter) changes to the subscript for compound (c). 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
^{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	=	$\rho_m N_o / A_m$.	(1a)
N_i	=	$w_i \rho_m N_o / A_i$.	(1b)
ρ_m	=	$1/\Sigma w_i/\rho_i$.	(2)
A_m	=	$1/\Sigma w_i/A_i$.	(3a)
	=	$\Sigma n_i A_i$	(3b)
w_i	=	m_i/m_m .	(4a)
	=	$n_i A_i/\Sigma n_i A_i$.	(4b)
n_i	=	N_i/N_m .	(5a)
	=	$(w_i/A_i)/\Sigma(w_i/A_i)$.	(5b)

where,

N_o	=	0.602252×10^{24} (atoms/mole) Avogadro's number,
N	=	atom density (atoms/cm^3), $N_m = \Sigma N_i$,
ρ	=	density (g/cm^3) ,
A	=	atomic mass (g-mole) ,
w	=	weight fraction, $\Sigma w_i = 1$,
n	=	atom fraction, $\Sigma n_i = 1$,
subscript "m"	=	of the mixture ,
subscript "i"	=	ith component of the mixture ,
(atoms/cm^3)(1/10^{24})	=	atoms/barn-cm.

APPENDIX 6.9.6

ABRIDGED SUMMARY TABLES OF CRITICALITY CALCULATION RESULTS

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, and 6.6 of this document. These tables are an abridged version of the tables provided in Y/LF-718 and are identified with the suffix "A" accordingly. The index for the complete list of tables in Y/LF-718 is as follows:

SPHERICAL CONTENT

CYLINDRICAL CONTENT

SQUARE BAR CONTENT

5 SLUGS CONTENT

Table 6.9.6-32 Results for the nbfl5slg (NCT, 12x12x6 array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model.

Table 6.9.6-33 Results for the nbf25slg (NCT, 9x9x4 array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model.

Table 6.9.6-34 Results for the nbf35slg (NCT, 7x7x3 array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-35 Results for the hbsr5slg (HAC, refl., single unit, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model.

Table 6.9.6-36 Results for the hbia5slg (HAC, infinite array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model.

Table 6.9.6-37 Results for the hbf25slg (HAC, 9x9x4 array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model.

6 SLUGS CONTENT

Table 6.9.6-38 Results for the cvr6slg (hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs in CV) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-39 Results for the nbsb6slg (NCT, bare, single unit, hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-40 Results for the nbsr6slg (NCT, refl., single unit, hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-41 Results for the nbia6slg (NCT, infinite array, hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-42 Results for the nbfl6slg (NCT, 12x12x6 array, hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-43 Results for the nbf26slg (NCT, 9x9x4 array, hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-44 Results for the nbf36slg (NCT, 7x7x3 array, hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-45 Results for the hbsr6slg (HAC, refl., single unit, hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-46 Results for the hbia6slg (HAC, infinite array, hexagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model. [abridged summary table not presented in this appendix]

BROKEN METAL CONTENT

Table 6.9.6-47 Results for the cvr3sqa calculation model.

Table 6.9.6-48 Results for the cvr3lha calculation model.

HEU OXIDE CONTENT

Table 6.9.6-70 Results for the cvrox (HEU Oxide content in CV) calculation model.

Table 6.9.6-71 Results for the nbsbox (NCT, bare, single unit, HEU Oxide content) calculation model.

Table 6.9.6-72 Results for the nbsrox (NCT, refl., single unit, HEU Oxide content) calculation model.

Table 6.9.6-73 Results for the nbiaox (NCT, infinite array, HEU Oxide content) calculation model.

Table 6.9.6-74 Results for the nbflox (NCT, 12x12x6 array, HEU Oxide content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-75 Results for the obsbox (NCT, bare, single unit, dispersed HEU Oxide content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-76 Results for the obsrox (NCT, refl., single unit, dispersed HEU Oxide content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-77 Results for the obiaox (NCT, infinite array, dispersed HEU Oxide content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-78 Results for the hbsrox (HAC, refl., single unit, HEU Oxide content) calculation model.

Table 6.9.6-79 Results for the hbiaox (HAC, infinite array, HEU Oxide content) calculation model.

Table 6.9.6-80 Results for the ibsrox (HAC, refl., single unit, dispersed HEU Oxide content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-81 Results for the ibiaox (HAC, infinite array, dispersed HEU Oxide content) calculation model. [abridged summary table not presented in this appendix]

UNH CRYSTALS CONTENT

Table 6.9.6-82 Results for the cvrunhc (UNH Crystals content in CV) calculation model.

Table 6.9.6-83 Results for the nbsbunhc (NCT, bare, single unit, UNH Crystals content) calculation model.

Table 6.9.6-84 Results for the nbsrunhc (NCT, refl., single unit, UNH Crystals content) calculation model.

Table 6.9.6-85 Results for the nbiaunhc (NCT, infinite array, UNH Crystals content) calculation model.

Table 6.9.6-86 Results for the obsrunhc (NCT, refl., single unit, UNH Crystals content) calculation model.

Table 6.9.6-87 Results for the obiaunhc (NCT, infinite array, UNH Crystals content) calculation model.

Table 6.9.6-88 Deleted from Y/LF-718

Table 6.9.6-89 Results for the hbsrunhc (HAC, refl., single unit, UNH Crystals content) calculation model. [abridged summary table not presented in this appendix]

Table 6.9.6-90 Results for the hbiaunhc (HAC, infinite array, UNH Crystals content) calculation model.

Table 6.9.6-1-A. Abridged results for the cvrsp (3.24-in. dia. spherical content in CV) calculation model

case name	no. spheres	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	mocfr	k_{eff}	σ	$k_{eff}+2σ$
cvrsp_06_01_06_01	6	0.0	100	32938.2	32938.2	0.0	0.00	0.30	1.0E-20	0.79111	0.00100	0.79310
cvrsp_06_01_06_06	6	0.0	100	32938.2	32938.2	844.9	0.67	0.30	1.0E-01	0.79417	0.00100	0.79617
cvrsp_06_01_06_07	6	0.0	100	32938.2	32938.2	1689.8	1.34	0.30	2.0E-01	0.79824	0.00098	0.80020
cvrsp_06_01_06_08	6	0.0	100	32938.2	32938.2	2534.7	2.01	0.30	3.0E-01	0.80500	0.00107	0.80714
cvrsp_06_01_06_09	6	0.0	100	32938.2	32938.2	3379.7	2.68	0.30	4.0E-01	0.81624	0.00123	0.81871
cvrsp_06_01_06_10	6	0.0	100	32938.2	32938.2	4224.6	3.35	0.30	5.0E-01	0.82420	0.00117	0.82655
cvrsp_06_01_06_11	6	0.0	100	32938.2	32938.2	5069.5	4.02	0.30	6.0E-01	0.83789	0.00111	0.84011
cvrsp_06_01_06_12	6	0.0	100	32938.2	32938.2	5914.4	4.69	0.30	7.0E-01	0.84758	0.00119	0.84995
cvrsp_06_01_06_13	6	0.0	100	32938.2	32938.2	6759.3	5.36	0.30	8.0E-01	0.86127	0.00105	0.86337
cvrsp_06_01_06_14	6	0.0	100	32938.2	32938.2	7604.2	6.03	0.30	9.0E-01	0.87305	0.00109	0.87523
cvrsp_06_01_06_15	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E+00	0.88160	0.00123	0.88407

Table 6.9.6-2-A. Abridged results for the nbsbsp (NCT, bare, single unit, 3.24-in. dia. spherical content) calculation model

case name	no. spheres	np277-4 thickness (in)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	nlf	k_{eff}	σ	$k_{eff}+2σ$
Spherical content, single unit, bare												
nbsbsp_06_01_01	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0E-20	0.394	0.83389	0.00108	0.83605
nbsbsp_06_01_02	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0E-05	0.394	0.83336	0.00120	0.83577
nbsbsp_06_01_03	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0E-04	0.394	0.83386	0.00113	0.83611
nbsbsp_06_01_04	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0E-03	0.395	0.83622	0.00123	0.83868
nbsbsp_06_01_05	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0E-02	0.392	0.83415	0.00110	0.83634
nbsbsp_06_01_06	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0E-01	0.370	0.83745	0.00128	0.84001
nbsbsp_06_01_08	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	3.0E-01	0.314	0.84570	0.00105	0.84779
nbsbsp_06_01_15	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0E+00	0.143	0.86528	0.00133	0.86794
nbsbsp_06_01_15	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0E+00	0.143	0.86528	0.00133	0.86794
nbsbsp_05_01_15	5	0.0	27448.5	27448.5	8740.4	8.31	0.36	1.0E+00	0.145	0.85835	0.00108	0.86051
nbsbsp_04_01_15	4	0.0	21958.8	21958.8	9031.7	10.74	0.45	1.0E+00	0.147	0.84398	0.00111	0.84619
nbsbsp_03_01_15	3	0.0	16469.1	16469.1	9323.1	14.78	0.60	1.0E+00	0.151	0.82197	0.00119	0.82435
nbsbsp_02_01_15	2	0.0	10979.4	10979.4	9614.4	22.86	0.91	1.0E+00	0.156	0.77901	0.00104	0.78109
nbsbsp_01_01_15	1	0.0	5489.7	5489.7	9905.7	47.10	1.81	1.0E+00	0.168	0.68009	0.00094	0.68197
nbsbsp_06_03_01	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0E-20	0.398	0.78570	0.00102	0.78774
nbsbsp_06_03_02	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0E-05	0.397	0.78742	0.00107	0.78956
nbsbsp_06_03_03	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0E-04	0.396	0.78560	0.00110	0.78779
nbsbsp_06_03_04	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0E-03	0.397	0.78566	0.00115	0.78796
nbsbsp_06_03_05	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0E-02	0.394	0.78827	0.00113	0.79052
nbsbsp_06_03_06	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0E-01	0.372	0.79218	0.00101	0.79421
nbsbsp_06_03_08	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	3.0E-01	0.316	0.79771	0.00104	0.79978
nbsbsp_06_03_15	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0E+00	0.145	0.81120	0.00110	0.81340

Table 6.9.6-3-A. Abridged results for the nbsrsp (NCT, refl., single unit, 3.24-in. dia. spherical content) calculation model

case name	no. spheres	np277-4 thickness (in)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	nlf	k_{eff}	σ	$k_{eff}+2σ$
Spherical content, single unit, reflected												
nbsrsp_06_01_01	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0e-20	1.8e-03	0.83867	0.00115	0.84097
nbsrsp_06_01_02	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0e-05	1.8e-03	0.83861	0.00108	0.84077
nbsrsp_06_01_03	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0e-04	1.7e-03	0.83709	0.00114	0.83936
nbsrsp_06_01_04	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0e-03	1.7e-03	0.83580	0.00115	0.83811
nbsrsp_06_01_05	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0e-02	1.7e-03	0.84065	0.00106	0.84276
nbsrsp_06_01_06	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0e-01	1.6e-03	0.83913	0.00113	0.84139
nbsrsp_06_01_08	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	3.0e-01	1.3e-03	0.84860	0.00109	0.85077
nbsrsp_06_01_15	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0e+00	6.1e-04	0.86714	0.00099	0.86911
nbsrsp_06_01_15	6	0.0	32938.2	32938.2	8449.1	6.70	0.30	1.0e+00	6.1e-04	0.86714	0.00099	0.86911
nbsrsp_05_01_15	5	0.0	27448.5	27448.5	8740.4	8.31	0.36	1.0e+00	5.9e-04	0.85775	0.00121	0.86016
nbsrsp_04_01_15	4	0.0	21958.8	21958.8	9031.7	10.74	0.45	1.0e+00	6.5e-04	0.84535	0.00111	0.84758
nbsrsp_03_01_15	3	0.0	16469.1	16469.1	9323.1	14.78	0.60	1.0e+00	6.4e-04	0.82235	0.00107	0.82449
nbsrsp_02_01_15	2	0.0	10979.4	10979.4	9614.4	22.86	0.91	1.0e+00	6.3e-04	0.77928	0.00121	0.78170
nbsrsp_01_01_15	1	0.0	5489.7	5489.7	9905.7	47.10	1.81	1.0e+00	8.3e-04	0.67961	0.00113	0.68188
nbsrsp_06_03_01	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0e-20	1.8e-03	0.78976	0.00097	0.79169
nbsrsp_06_03_02	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0e-05	1.7e-03	0.79103	0.00108	0.79319
nbsrsp_06_03_03	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0e-04	1.7e-03	0.78822	0.00111	0.79045
nbsrsp_06_03_04	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0e-03	1.8e-03	0.79044	0.00122	0.79289
nbsrsp_06_03_05	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0e-02	1.8e-03	0.78870	0.00114	0.79098
nbsrsp_06_03_06	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	1.0e-01	1.7e-03	0.79094	0.00127	0.79348
nbsrsp_06_03_08	6	1.0	32938.2	32938.2	8063.3	6.39	0.30	3.0e-01	1.3e-03	0.79791	0.00108	0.80007

Table 6.9.6-4-A. Abridged results for the nbiasp (NCT, infinite array, 3.24-in. dia. spherical content) calculation model

case name	no. spheres	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
nbiasp_06_01_06_01	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-20	0.89743	0.00118	0.89979
nbiasp_06_01_06_02	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-05	0.90074	0.00120	0.90314
nbiasp_06_01_06_03	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-04	0.89780	0.00117	0.90013
nbiasp_06_01_06_04	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-03	0.90007	0.00102	0.90212
nbiasp_06_01_06_05	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-02	0.89499	0.00119	0.89737
nbiasp_06_01_06_06	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-01	0.87945	0.00124	0.88194
nbiasp_06_01_06_08	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	3.0E-01	0.86911	0.00112	0.87136
nbiasp_06_01_06_15	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E+00	0.87376	0.00108	0.87592
nbiasp_06_01_06_03	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-04	0.89780	0.00117	0.90013
nbiasp_05_01_06_03	5	0.0	100	27448.5	27448.5	8740.4	8.31	0.36	1.0E-04	0.88401	0.00099	0.88599
nbiasp_04_01_06_03	4	0.0	100	21958.8	21958.8	9031.7	10.74	0.45	1.0E-04	0.86437	0.00113	0.86662
nbiasp_03_01_06_03	3	0.0	100	16469.1	16469.1	9323.1	14.78	0.60	1.0E-04	0.83541	0.00108	0.83756
nbiasp_02_01_06_03	2	0.0	100	10979.4	10979.4	9614.4	22.86	0.91	1.0E-04	0.78577	0.00122	0.78821
nbiasp_01_01_06_03	1	0.0	100	5489.7	5489.7	9905.7	47.10	1.81	1.0E-04	0.68267	0.00123	0.68514
nbiasp_06_03_06_01	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-20	0.84884	0.00102	0.85088
nbiasp_06_03_06_02	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-05	0.85147	0.00141	0.85429
nbiasp_06_03_06_03	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-04	0.84891	0.00109	0.85110
nbiasp_06_03_06_04	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-03	0.84699	0.00123	0.84945
nbiasp_06_03_06_05	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-02	0.84583	0.00117	0.84816
nbiasp_06_03_06_06	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-01	0.82731	0.00108	0.82947
nbiasp_06_03_06_08	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	3.0E-01	0.81796	0.00110	0.82015
nbiasp_06_03_06_15	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E+00	0.81960	0.00123	0.82206

Table 6.9.6-6-A. Abridged results for the hbsrsp (HAC, refl., single unit, 3.24-in. dia. spherical content) calculation model

case name	no. spheres	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
hbsrsp_06_01_15	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E+00	0.86614	0.00129	0.86872
hbsrsp_05_01_15	5	0.0	100	27448.5	27448.5	8740.4	8.31	0.36	1.0E+00	0.85845	0.00121	0.86087
hbsrsp_04_01_15	4	0.0	100	21958.8	21958.8	9031.7	10.74	0.45	1.0E+00	0.84508	0.00099	0.84706
hbsrsp_06_03_15	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E+00	0.81452	0.00105	0.81662

Table 6.9.6-7-A. Abridged results for the hbiasp (HAC, infinite array, 3.24-in. dia. spherical content) calculation model

case name	no. spheres	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
hbiasp_06_01_06_01	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-20	0.90598	0.00116	0.90830
hbiasp_06_01_06_02	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-05	0.90484	0.00125	0.90734
hbiasp_06_01_06_03	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-04	0.90411	0.00128	0.90667
hbiasp_06_01_06_04	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-03	0.90400	0.00123	0.90646
hbiasp_06_01_06_05	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-02	0.90219	0.00118	0.90455
hbiasp_06_01_06_06	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E-01	0.88890	0.00115	0.89119
hbiasp_06_01_06_08	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	3.0E-01	0.87532	0.00108	0.87748
hbiasp_06_01_06_15	6	0.0	100	32938.2	32938.2	8449.1	6.70	0.30	1.0E+00	0.88108	0.00123	0.88353
hbiasp_05_01_06_03	5	0.0	100	27448.5	27448.5	8740.4	8.31	0.36	1.0E-04	0.88907	0.00133	0.89173
hbiasp_04_01_06_03	4	0.0	100	21958.8	21958.8	9031.7	10.74	0.45	1.0E-04	0.86978	0.00104	0.87186
hbiasp_03_01_06_03	3	0.0	100	16469.1	16469.1	9323.1	14.78	0.60	1.0E-04	0.83949	0.00122	0.84192
hbiasp_06_03_06_01	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-20	0.85373	0.00114	0.85601
hbiasp_06_03_06_02	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-05	0.85471	0.00132	0.85736
hbiasp_06_03_06_03	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-04	0.85570	0.00132	0.85834
hbiasp_06_03_06_04	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-03	0.85621	0.00113	0.85847
hbiasp_06_03_06_05	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-02	0.85302	0.00117	0.85537
hbiasp_06_03_06_06	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E-01	0.83977	0.00108	0.84193
hbiasp_06_03_06_08	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	3.0E-01	0.82703	0.00138	0.82978
hbiasp_06_03_06_15	6	1.0	100	32938.2	32938.2	8063.3	6.39	0.30	1.0E+00	0.82522	0.00110	0.82742

Table 6.9.6-8-A. Abridged results for cvrcy (3.24-in. dia. cylindrical content in CV) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	mocfr	k_{eff}	σ	$k_{eff}+2σ$
cvrcy_12_01_06_01	0.0	100	36000.0	36000.0	0.0	0.00	0.28	1.0E-20	0.90618	0.00118	0.90854
cvrcy_12_01_06_06	0.0	100	36000.0	36000.0	828.7	0.60	0.28	1.0E-01	0.90869	0.00107	0.91084
cvrcy_12_01_06_07	0.0	100	36000.0	36000.0	1657.3	1.20	0.28	2.0E-01	0.91147	0.00102	0.91350
cvrcy_12_01_06_08	0.0	100	36000.0	36000.0	2486.0	1.80	0.28	3.0E-01	0.91561	0.00108	0.91776
cvrcy_12_01_06_09	0.0	100	36000.0	36000.0	3314.7	2.40	0.28	4.0E-01	0.92366	0.00110	0.92587
cvrcy_12_01_06_10	0.0	100	36000.0	36000.0	4143.3	3.00	0.28	5.0E-01	0.92921	0.00112	0.93145
cvrcy_12_01_06_11	0.0	100	36000.0	36000.0	4972.0	3.60	0.28	6.0E-01	0.93779	0.00105	0.93989
cvrcy_12_01_06_12	0.0	100	36000.0	36000.0	5800.7	4.21	0.28	7.0E-01	0.94617	0.00123	0.94863
cvrcy_12_01_06_13	0.0	100	36000.0	36000.0	6629.3	4.81	0.28	8.0E-01	0.95559	0.00142	0.95843
cvrcy_12_01_06_14	0.0	100	36000.0	36000.0	7458.0	5.41	0.28	9.0E-01	0.96421	0.00123	0.96667
cvrcy_12_01_06_15	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.97272	0.00133	0.97537
cvrcy_12_01_06_15	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.97272	0.00133	0.97537
cvrcy_12_01_05_15	0.0	97.7	36000.0	35172.0	8287.2	6.15	0.28	1.0E+00	0.96387	0.00127	0.96642
cvrcy_12_01_04_15	0.0	95	36000.0	34200.0	8287.9	6.33	0.29	1.0E+00	0.95343	0.00103	0.95548
cvrcy_12_01_03_15	0.0	90	36000.0	32400.0	8289.1	6.68	0.31	1.0E+00	0.93356	0.00133	0.93623
cvrcy_12_01_02_15	0.0	40	36000.0	14400.0	8301.1	15.05	0.69	1.0E+00	0.70289	0.00100	0.70489
cvrcy_12_01_01_15	0.0	20	36000.0	7200.0	8306.0	30.11	1.38	1.0E+00	0.57351	0.00100	0.57552
cvrcy_12_03_06_15	1.0	100	36000.0	36000.0	7900.9	5.73	0.28	1.0E+00	0.90335	0.00103	0.90542
cvrcy_12_03_05_15	1.0	97.7	36000.0	35172.0	7901.4	5.86	0.28	1.0E+00	0.89471	0.00113	0.89697
cvrcy_12_03_04_15	1.0	95	36000.0	34200.0	7902.1	6.03	0.29	1.0E+00	0.88468	0.00118	0.88703
cvrcy_12_03_03_15	1.0	90	36000.0	32400.0	7903.3	6.37	0.31	1.0E+00	0.86598	0.00104	0.86807
cvrcy_12_03_02_15	1.0	40	36000.0	14400.0	7915.3	14.35	0.69	1.0E+00	0.64117	0.00090	0.64297
cvrcy_12_03_01_15	1.0	20	36000.0	7200.0	7920.2	28.71	1.38	1.0E+00	0.51635	0.00083	0.51802
cvrcy_12_01_06_15	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.97272	0.00133	0.97537
cvrcy_11_01_06_15	0.0	100	30000.0	30000.0	8605.0	7.49	0.33	1.0E+00	0.95936	0.00128	0.96192
cvrcy_10_01_06_15	0.0	100	24000.0	24000.0	8923.4	9.70	0.42	1.0E+00	0.93454	0.00118	0.93690
cvrcy_09_01_06_15	0.0	100	18000.0	18000.0	9241.8	13.40	0.55	1.0E+00	0.89945	0.00125	0.90194
cvrcy_08_01_06_15	0.0	100	15000.0	15000.0	9401.0	16.36	0.66	1.0E+00	0.87179	0.00103	0.87386
cvrcy_07_01_06_15	0.0	100	12000.0	12000.0	9560.2	20.79	0.83	1.0E+00	0.83218	0.00110	0.83438
cvrcy_06_01_06_15	0.0	100	9000.0	9000.0	9719.4	28.19	1.11	1.0E+00	0.78107	0.00116	0.78340

Table 6.9.6-8-A. Abridged results for cvrcy (3.24-in. dia. cylindrical content in CV) calculation model (cont.)

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	mocfr	k_{eff}	σ	$k_{eff}+2σ$
cvrcy_05_01_06_15	0.0	100	6000.0	6000.0	9878.6	42.97	1.66	1.0E+00	0.69591	0.00096	0.69783
cvrcy_04_01_06_15	0.0	100	3000.0	3000.0	10037.8	87.33	3.32	1.0E+00	0.55287	0.00105	0.55497
cvrcy_03_01_06_15	0.0	100	1998.0	1998.0	10091.0	131.82	4.99	1.0E+00	0.47470	0.00092	0.47654
cvrcy_02_01_06_15	0.0	100	1500.0	1500.0	10117.4	176.05	6.64	1.0E+00	0.42529	0.00083	0.42696
cvrcy_01_01_06_15	0.0	100	999.0	999.0	10144.0	265.03	9.97	1.0E+00	0.36109	0.00075	0.36260

Table 6.9.6-10-A. Abridged results for the nbsrcy (NCT, refl., single unit, 3.24-in. dia. cylindrical content) calculational model

case name	np277-4 thickness (in)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
nbsrcy_12_01_01	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-20	0.92061	0.00131	0.92323
nbsrcy_12_01_02	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-05	0.91798	0.00115	0.92028
nbsrcy_12_01_03	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-04	0.91873	0.00108	0.92088
nbsrcy_12_01_04	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-03	0.91992	0.00126	0.92245
nbsrcy_12_01_05	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-02	0.92079	0.00129	0.92337
nbsrcy_12_01_06	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-01	0.92510	0.00121	0.92753
nbsrcy_12_01_08	0.0	36000.0	36000.0	8286.7	6.01	0.28	3.0E-01	0.93225	0.00111	0.93448
nbsrcy_12_01_15	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.95141	0.00113	0.95367
nbsrcy_12_01_15	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.95141	0.00113	0.95367
nbsrcy_11_01_15	0.0	30000.0	30000.0	8605.0	7.49	0.33	1.0E+00	0.94008	0.00104	0.94216
nbsrcy_10_01_15	0.0	24000.0	24000.0	8923.4	9.70	0.42	1.0E+00	0.91767	0.00109	0.91985
nbsrcy_09_01_15	0.0	18000.0	18000.0	9241.8	13.40	0.55	1.0E+00	0.88306	0.00136	0.88579
nbsrcy_08_01_15	0.0	15000.0	15000.0	9401.0	16.36	0.66	1.0E+00	0.85544	0.00103	0.85750
nbsrcy_07_01_15	0.0	12000.0	12000.0	9560.2	20.79	0.83	1.0E+00	0.81919	0.00112	0.82144
nbsrcy_06_01_15	0.0	9000.0	9000.0	9719.4	28.19	1.11	1.0E+00	0.76344	0.00113	0.76570
nbsrcy_05_01_15	0.0	6000.0	6000.0	9878.6	42.97	1.66	1.0E+00	0.67773	0.00113	0.67999
nbsrcy_04_01_15	0.0	3000.0	3000.0	10037.8	87.33	3.32	1.0E+00	0.53189	0.00096	0.53381
nbsrcy_03_01_15	0.0	1998.0	1998.0	10091.0	131.82	4.99	1.0E+00	0.45075	0.00084	0.45243
nbsrcy_02_01_15	0.0	1500.0	1500.0	10117.4	176.05	6.64	1.0E+00	0.40038	0.00092	0.40222
nbsrcy_01_01_15	0.0	999.0	999.0	10144.0	265.03	9.97	1.0E+00	0.33444	0.00079	0.33602
nbsrcy_12_03_15	1.0	36000.0	36000.0	7900.9	5.73	0.28	1.0E+00	0.88971	0.00124	0.89219
nbsrcy_11_03_15	1.0	30000.0	30000.0	8219.3	7.15	0.33	1.0E+00	0.86577	0.00128	0.86833
nbsrcy_10_03_15	1.0	24000.0	24000.0	8537.6	9.29	0.42	1.0E+00	0.83197	0.00112	0.83421
nbsrcy_09_03_15	1.0	18000.0	18000.0	8856.0	12.84	0.55	1.0E+00	0.78713	0.00104	0.78921
nbsrcy_08_03_15	1.0	15000.0	15000.0	9015.2	15.69	0.66	1.0E+00	0.75450	0.00102	0.75654
nbsrcy_07_03_15	1.0	12000.0	12000.0	9174.4	19.96	0.83	1.0E+00	0.71126	0.00097	0.71320
nbsrcy_06_03_15	1.0	9000.0	9000.0	9333.6	27.07	1.11	1.0E+00	0.65045	0.00118	0.65281
nbsrcy_05_03_15	1.0	6000.0	6000.0	9492.8	41.30	1.66	1.0E+00	0.56333	0.00102	0.56537
nbsrcy_04_03_15	1.0	3000.0	3000.0	9652.0	83.98	3.32	1.0E+00	0.42579	0.00082	0.42743
nbsrcy_03_03_15	1.0	1998.0	1998.0	9705.2	126.78	4.99	1.0E+00	0.35419	0.00081	0.35582
nbsrcy_02_03_15	1.0	1500.0	1500.0	9731.6	169.34	6.64	1.0E+00	0.30842	0.00069	0.30980
nbsrcy_01_03_15	1.0	999.0	999.0	9758.2	254.95	9.97	1.0E+00	0.25341	0.00074	0.25488

Table 6.9.6-11-A. Abridged results for the nbiacy (NCT, infinite array, 3.24-in. dia. cylindrical content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	k_{eff}+2σ
nbiacy_12_01_06_03	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E-04	0.99274	0.00101	0.99476
nbiacy_11_01_06_03	0.0	100	30000.0	30000.0	8605.0	7.49	0.33	1.0E-04	0.97308	0.00114	0.97537
nbiacy_10_01_06_03	0.0	100	24000.0	24000.0	8923.4	9.70	0.42	1.0E-04	0.94559	0.00124	0.94808
nbiacy_09_01_06_03	0.0	100	18000.0	18000.0	9241.8	13.40	0.55	1.0E-04	0.90384	0.00112	0.90609
nbiacy_08_01_06_03	0.0	100	15000.0	15000.0	9401.0	16.36	0.66	1.0E-04	0.87500	0.00105	0.87710
nbiacy_07_01_06_03	0.0	100	12000.0	12000.0	9560.2	20.79	0.83	1.0E-04	0.83324	0.00126	0.83577
nbiacy_06_01_06_03	0.0	100	9000.0	9000.0	9719.4	28.19	1.11	1.0E-04	0.77578	0.00128	0.77835
nbiacy_05_01_06_03	0.0	100	6000.0	6000.0	9878.6	42.97	1.66	1.0E-04	0.68386	0.00100	0.68587
nbiacy_04_01_06_03	0.0	100	3000.0	3000.0	10037.8	87.33	3.32	1.0E-04	0.52756	0.00100	0.52955
nbiacy_03_01_06_03	0.0	100	1998.0	1998.0	10091.0	131.82	4.99	1.0E-04	0.44314	0.00090	0.44495
nbiacy_02_01_06_03	0.0	100	1500.0	1500.0	10117.4	176.05	6.64	1.0E-04	0.38794	0.00082	0.38958
nbiacy_01_01_06_03	0.0	100	999.0	999.0	10144.0	265.03	9.97	1.0E-04	0.32160	0.00066	0.32291
nbiacy_12_03_06_03	1.0	100	36000.0	36000.0	7900.9	5.73	0.28	1.0E-04	0.93384	0.00100	0.93584
nbiacy_11_03_06_03	1.0	100	30000.0	30000.0	8219.3	7.15	0.33	1.0E-04	0.90763	0.00120	0.91003
nbiacy_10_03_06_03	1.0	100	24000.0	24000.0	8537.6	9.29	0.42	1.0E-04	0.87005	0.00120	0.87246
nbiacy_09_03_06_03	1.0	100	18000.0	18000.0	8856.0	12.84	0.55	1.0E-04	0.81559	0.00126	0.81811
nbiacy_08_03_06_03	1.0	100	15000.0	15000.0	9015.2	15.69	0.66	1.0E-04	0.78005	0.00111	0.78227
nbiacy_07_03_06_03	1.0	100	12000.0	12000.0	9174.4	19.96	0.83	1.0E-04	0.73342	0.00104	0.73551
nbiacy_06_03_06_03	1.0	100	9000.0	9000.0	9333.6	27.07	1.11	1.0E-04	0.66882	0.00106	0.67094
nbiacy_05_03_06_03	1.0	100	6000.0	6000.0	9492.8	41.30	1.66	1.0E-04	0.57862	0.00097	0.58057
nbiacy_04_03_06_03	1.0	100	3000.0	3000.0	9652.0	83.98	3.32	1.0E-04	0.43205	0.00082	0.43369
nbiacy_03_03_06_03	1.0	100	1998.0	1998.0	9705.2	126.78	4.99	1.0E-04	0.35677	0.00079	0.35835
nbiacy_02_03_06_03	1.0	100	1500.0	1500.0	9731.6	169.34	6.64	1.0E-04	0.31083	0.00085	0.31253
nbiacy_01_03_06_03	1.0	100	999.0	999.0	9758.2	254.95	9.97	1.0E-04	0.25382	0.00076	0.25534

Table 6.9.6-17-A. Abridged results for the hbsrcy (HAC, refl., single unit, 3.24-in. dia. cylindrical content) calculation model

case name	np277-4 thickness (in)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
hbsrcy_12_01_15	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.95146	0.00143	0.95432
hbsrcy_11_01_15	0.0	30000.0	30000.0	8605.0	7.49	0.33	1.0E+00	0.93910	0.00121	0.94153
hbsrcy_10_01_15	0.0	24000.0	24000.0	8923.4	9.70	0.42	1.0E+00	0.91883	0.00117	0.92118
hbsrcy_09_01_15	0.0	18000.0	18000.0	9241.8	13.40	0.55	1.0E+00	0.88271	0.00139	0.88548
hbsrcy_08_01_15	0.0	15000.0	15000.0	9401.0	16.36	0.66	1.0E+00	0.85844	0.00113	0.86070
hbsrcy_07_01_15	0.0	12000.0	12000.0	9560.2	20.79	0.83	1.0E+00	0.81875	0.00103	0.82082
hbsrcy_06_01_15	0.0	9000.0	9000.0	9719.4	28.19	1.11	1.0E+00	0.76621	0.00101	0.76823
hbsrcy_05_01_15	0.0	6000.0	6000.0	9878.6	42.97	1.66	1.0E+00	0.68192	0.00105	0.68402
hbsrcy_04_01_15	0.0	3000.0	3000.0	10037.8	87.33	3.32	1.0E+00	0.53591	0.00091	0.53772
hbsrcy_03_01_15	0.0	1998.0	1998.0	10091.0	131.82	4.99	1.0E+00	0.45517	0.00082	0.45680
hbsrcy_02_01_15	0.0	1500.0	1500.0	10117.4	176.05	6.64	1.0E+00	0.40419	0.00091	0.40601
hbsrcy_01_01_15	0.0	999.0	999.0	10144.0	265.03	9.97	1.0E+00	0.33990	0.00076	0.34142
hbsrcy_12_03_15	1.0	36000.0	36000.0	7900.9	5.73	0.28	1.0E+00	0.88659	0.00107	0.88873
hbsrcy_11_03_15	1.0	30000.0	30000.0	8219.3	7.15	0.33	1.0E+00	0.86608	0.00108	0.86824
hbsrcy_10_03_15	1.0	24000.0	24000.0	8537.6	9.29	0.42	1.0E+00	0.83520	0.00104	0.83729
hbsrcy_09_03_15	1.0	18000.0	18000.0	8856.0	12.84	0.55	1.0E+00	0.78641	0.00102	0.78845
hbsrcy_08_03_15	1.0	15000.0	15000.0	9015.2	15.69	0.66	1.0E+00	0.75510	0.00115	0.75740
hbsrcy_07_03_15	1.0	12000.0	12000.0	9174.4	19.96	0.83	1.0E+00	0.71190	0.00099	0.71388
hbsrcy_06_03_15	1.0	9000.0	9000.0	9333.6	27.07	1.11	1.0E+00	0.65281	0.00101	0.65483
hbsrcy_05_03_15	1.0	6000.0	6000.0	9492.8	41.30	1.66	1.0E+00	0.56709	0.00108	0.56924
hbsrcy_04_03_15	1.0	3000.0	3000.0	9652.0	83.98	3.32	1.0E+00	0.42685	0.00077	0.42840
hbsrcy_03_03_15	1.0	1998.0	1998.0	9705.2	126.78	4.99	1.0E+00	0.35593	0.00091	0.35774
hbsrcy_02_03_15	1.0	1500.0	1500.0	9731.6	169.34	6.64	1.0E+00	0.31089	0.00078	0.31245
hbsrcy_01_03_15	1.0	999.0	999.0	9758.2	254.95	9.97	1.0E+00	0.25413	0.00067	0.25548

Table 6.9.6-18-A. Abridged results for the hbiacy (HAC, infinite array, 3.24-in. dia. cylindrical content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	k_{eff}+2σ
hbiacy_12_01_06_03	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E-04	1.00250	0.00115	1.00480
hbiacy_11_01_06_03	0.0	100	30000.0	30000.0	8605.0	7.49	0.33	1.0E-04	0.98029	0.00117	0.98263
hbiacy_10_01_06_03	0.0	100	24000.0	24000.0	8923.4	9.70	0.42	1.0E-04	0.95252	0.00105	0.95462
hbiacy_09_01_06_03	0.0	100	18000.0	18000.0	9241.8	13.40	0.55	1.0E-04	0.90990	0.00133	0.91257
hbiacy_08_01_06_03	0.0	100	15000.0	15000.0	9401.0	16.36	0.66	1.0E-04	0.87838	0.00121	0.88080
hbiacy_07_01_06_03	0.0	100	12000.0	12000.0	9560.2	20.79	0.83	1.0E-04	0.83805	0.00114	0.84032
hbiacy_12_03_06_03	1.0	100	36000.0	36000.0	7900.9	5.73	0.28	1.0E-04	0.94177	0.00130	0.94437
hbiacy_11_03_06_03	1.0	100	30000.0	30000.0	8219.3	7.15	0.33	1.0E-04	0.91391	0.00106	0.91602
hbiacy_10_03_06_03	1.0	100	24000.0	24000.0	8537.6	9.29	0.42	1.0E-04	0.87618	0.00118	0.87854
hbiacy_09_03_06_03	1.0	100	18000.0	18000.0	8856.0	12.84	0.55	1.0E-04	0.82125	0.00095	0.82315
hbiacy_08_03_06_03	1.0	100	15000.0	15000.0	9015.2	15.69	0.66	1.0E-04	0.78349	0.00112	0.78573

Table 6.9.6-19-A. Abridged results for the cvrsq (2.29-in. square bar content in CV) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	mocfr	k_{eff}	σ	$k_{eff}+2σ$
cvrsq_12_01_06_01	0.0	100	36000.0	36000.0	0.0	0.00	0.28	1.0E-20	0.78954	0.00104	0.79161
cvrsq_12_01_06_06	0.0	100	36000.0	36000.0	828.7	0.60	0.28	1.0E-01	0.78851	0.00106	0.79062
cvrsq_12_01_06_07	0.0	100	36000.0	36000.0	1657.3	1.20	0.28	2.0E-01	0.79252	0.00109	0.79471
cvrsq_12_01_06_08	0.0	100	36000.0	36000.0	2486.0	1.80	0.28	3.0E-01	0.79887	0.00112	0.80112
cvrsq_12_01_06_09	0.0	100	36000.0	36000.0	3314.7	2.40	0.28	4.0E-01	0.80888	0.00105	0.81098
cvrsq_12_01_06_10	0.0	100	36000.0	36000.0	4143.3	3.00	0.28	5.0E-01	0.81942	0.00106	0.82154
cvrsq_12_01_06_11	0.0	100	36000.0	36000.0	4972.0	3.60	0.28	6.0E-01	0.83074	0.00134	0.83342
cvrsq_12_01_06_12	0.0	100	36000.0	36000.0	5800.7	4.21	0.28	7.0E-01	0.84211	0.00113	0.84436
cvrsq_12_01_06_13	0.0	100	36000.0	36000.0	6629.3	4.81	0.28	8.0E-01	0.85451	0.00117	0.85686
cvrsq_12_01_06_14	0.0	100	36000.0	36000.0	7458.0	5.41	0.28	9.0E-01	0.86588	0.00107	0.86802
cvrsq_12_01_06_15	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.87878	0.00124	0.88127
cvrsq_12_01_06_15	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.87878	0.00124	0.88127
cvrsq_12_01_05_15	0.0	97.7	36000.0	35172.0	8287.2	6.15	0.28	1.0E+00	0.86960	0.00115	0.87189
cvrsq_12_01_04_15	0.0	95	36000.0	34200.0	8287.9	6.33	0.29	1.0E+00	0.85668	0.00132	0.85931
cvrsq_12_01_03_15	0.0	90	36000.0	32400.0	8289.1	6.68	0.31	1.0E+00	0.84209	0.00111	0.84430
cvrsq_12_01_02_15	0.0	40	36000.0	14400.0	8301.1	15.05	0.69	1.0E+00	0.64480	0.00102	0.64683
cvrsq_12_01_01_15	0.0	20	36000.0	7200.0	8306.0	30.11	1.38	1.0E+00	0.53825	0.00089	0.54002

Table 6.9.6-21-A. Abridged results for the nbsrsq (NCT, refl., single unit, 2.29-in. square bar content) calculation model

case name	np277-4 thickness (in)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
nbsrsq_12_01_01	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-20	0.83718	0.00109	0.83935
nbsrsq_12_01_02	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-05	0.83299	0.00132	0.83563
nbsrsq_12_01_03	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-04	0.83404	0.00112	0.83628
nbsrsq_12_01_04	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-03	0.83324	0.00111	0.83547
nbsrsq_12_01_05	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-02	0.83589	0.00108	0.83806
nbsrsq_12_01_06	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E-01	0.83874	0.00133	0.84139
nbsrsq_12_01_08	0.0	36000.0	36000.0	8286.7	6.01	0.28	3.0E-01	0.84511	0.00114	0.84740
nbsrsq_12_01_15	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.86078	0.00108	0.86293
nbsrsq_12_01_15	0.0	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.86078	0.00108	0.86293
nbsrsq_11_01_15	0.0	30000.0	30000.0	8605.0	7.49	0.33	1.0E+00	0.85539	0.00134	0.85806
nbsrsq_10_01_15	0.0	24000.0	24000.0	8923.4	9.70	0.42	1.0E+00	0.84281	0.00104	0.84489
nbsrsq_09_01_15	0.0	18000.0	18000.0	9241.8	13.40	0.55	1.0E+00	0.82414	0.00108	0.82630
nbsrsq_08_01_15	0.0	15000.0	15000.0	9401.0	16.36	0.66	1.0E+00	0.80847	0.00100	0.81048
nbsrsq_07_01_15	0.0	12000.0	12000.0	9560.2	20.79	0.83	1.0E+00	0.78515	0.00105	0.78724
nbsrsq_06_01_15	0.0	9000.0	9000.0	9719.4	28.19	1.11	1.0E+00	0.74816	0.00105	0.75026
nbsrsq_05_01_15	0.0	6000.0	6000.0	9878.6	42.97	1.66	1.0E+00	0.68531	0.00106	0.68744
nbsrsq_04_01_15	0.0	3000.0	3000.0	37.8	87.33	3.32	1.0E+00	0.55298	0.00088	0.55475
nbsrsq_03_01_15	0.0	1998.0	1998.0	91.0	131.82	4.99	1.0E+00	0.47790	0.00092	0.47973
nbsrsq_02_01_15	0.0	1500.0	1500.0	117.4	176.05	6.64	1.0E+00	0.42439	0.00080	0.42598
nbsrsq_01_01_15	0.0	999.0	999.0	144.0	265.03	9.97	1.0E+00	0.35717	0.00075	0.35866

Table 6.9.6-22-A. Abridged results for the nbiasq (NCT, infinite array, 2.29-in. square bar content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
nbiasq_12_01_06_03	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E-04	0.90390	0.00117	0.90624
nbiasq_11_01_06_03	0.0	100	30000.0	30000.0	8605.0	7.49	0.33	1.0E-04	0.88820	0.00109	0.89038
nbiasq_10_01_06_03	0.0	100	24000.0	24000.0	8923.4	9.70	0.42	1.0E-04	0.87124	0.00126	0.87376
nbiasq_09_01_06_03	0.0	100	18000.0	18000.0	9241.8	13.40	0.55	1.0E-04	0.84613	0.00110	0.84832
nbiasq_08_01_06_03	0.0	100	15000.0	15000.0	9401.0	16.36	0.66	1.0E-04	0.82748	0.00128	0.83004
nbiasq_07_01_06_03	0.0	100	12000.0	12000.0	9560.2	20.79	0.83	1.0E-04	0.80019	0.00108	0.80235
nbiasq_06_01_06_03	0.0	100	9000.0	9000.0	9719.4	28.19	1.11	1.0E-04	0.75995	0.00114	0.76222
nbiasq_05_01_06_03	0.0	100	6000.0	6000.0	9878.6	42.97	1.66	1.0E-04	0.69022	0.00108	0.69237
nbiasq_04_01_06_03	0.0	100	3000.0	3000.0	10037.8	87.33	3.32	1.0E-04	0.55434	0.00103	0.55640
nbiasq_03_01_06_03	0.0	100	1998.0	1998.0	10091.0	131.82	4.99	1.0E-04	0.47315	0.00083	0.47481
nbiasq_02_01_06_03	0.0	100	1500.0	1500.0	10117.4	176.05	6.64	1.0E-04	0.41982	0.00084	0.42150
nbiasq_01_01_06_03	0.0	100	999.0	999.0	10144.0	265.03	9.97	1.0E-04	0.34607	0.00080	0.34766

Table 6.9.6-24-A. Abridged results for the hbsrsq (HAC, refl., single unit, 2.29-in. square bar content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	k_{eff}+2σs
hbsrsq_12_01_15	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E+00	0.86403	0.00111	0.86625
hbsrsq_11_01_15	0.0	100	30000.0	30000.0	8605.0	7.49	0.33	1.0E+00	0.85466	0.00113	0.85691
hbsrsq_10_01_15	0.0	100	24000.0	24000.0	8923.4	9.70	0.42	1.0E+00	0.84480	0.00110	0.84700

Table 6.9.6-25-A. Abridged results for the hbiasq (HAC, infinite array, 2.29-in. square bar content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	k_{eff}+2σ
hbiasq_12_01_06_03	0.0	100	36000.0	36000.0	8286.7	6.01	0.28	1.0E-04	0.90900	0.00131	0.91163
hbiasq_12_01_05_03	0.0	97.7	36000.0	35172.0	8287.2	6.15	0.28	1.0E-04	0.90136	0.00108	0.90351
hbiasq_12_01_04_03	0.0	95	36000.0	34200.0	8287.9	6.33	0.29	1.0E-04	0.89098	0.00114	0.89327
hbiasq_12_01_03_03	0.0	90	36000.0	32400.0	8289.1	6.68	0.31	1.0E-04	0.87325	0.00101	0.87528
hbiasq_12_01_02_03	0.0	40	36000.0	14400.0	8301.1	15.05	0.69	1.0E-04	0.66015	0.00099	0.66214
hbiasq_12_01_01_03	0.0	20	36000.0	7200.0	8306.0	30.11	1.38	1.0E-04	0.54176	0.00101	0.54378
hbiasq_09_01_06_03	0.0	100	18000.0	18000.0	9241.8	13.40	0.55	1.00E-04	0.85137	0.00103	0.85343

Table 6.9.6-26-A. Abridged results for the cvr5slg0p0 (pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content, 0.0 cm spacing, in CV) calculation model

case name	content separation (cm)	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	mocfr	k_{eff}	σ	$k_{eff}+2σ$
5 slug content, 0.0 cm spacing, containment vessel												
cvr5slg0p0_02_01_06_01	0.0	0.0	100	32684.3	32684.3	0.0	0.00	0.30	1.0E-20	0.86219	0.00130	0.86479
cvr5slg0p0_02_01_06_06	0.0	0.0	100	32684.3	32684.3	846.3	0.68	0.30	1.0E-01	0.86531	0.00121	0.86774
cvr5slg0p0_02_01_06_07	0.0	0.0	100	32684.3	32684.3	1692.5	1.35	0.30	2.0E-01	0.87260	0.00112	0.87485
cvr5slg0p0_02_01_06_08	0.0	0.0	100	32684.3	32684.3	2538.8	2.03	0.30	3.0E-01	0.88362	0.00112	0.88587
cvr5slg0p0_02_01_06_09	0.0	0.0	100	32684.3	32684.3	3385.0	2.70	0.30	4.0E-01	0.89451	0.00125	0.89701
cvr5slg0p0_02_01_06_10	0.0	0.0	100	32684.3	32684.3	4231.3	3.38	0.30	5.0E-01	0.90733	0.00115	0.90964
cvr5slg0p0_02_01_06_11	0.0	0.0	100	32684.3	32684.3	5077.6	4.05	0.30	6.0E-01	0.91907	0.00140	0.92187
cvr5slg0p0_02_01_06_12	0.0	0.0	100	32684.3	32684.3	5923.8	4.73	0.30	7.0E-01	0.93142	0.00108	0.93357
cvr5slg0p0_02_01_06_13	0.0	0.0	100	32684.3	32684.3	6770.1	5.41	0.30	8.0E-01	0.94374	0.00117	0.94607
cvr5slg0p0_02_01_06_14	0.0	0.0	100	32684.3	32684.3	7616.3	6.08	0.30	9.0E-01	0.95584	0.00110	0.95803
cvr5slg0p0_02_01_06_15	0.0	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E+00	0.97037	0.00130	0.97296
cvr5slg0p0_02_03_06_15	0.0	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E+00	0.89140	0.00124	0.89389
cvr5slg0p0_02_03_05_15	0.0	1.0	97.7	32693.8	31941.8	8076.8	6.60	0.31	1.0E+00	0.88491	0.00121	0.88734
cvr5slg0p0_02_03_04_15	0.0	1.0	95	32704.9	31069.7	8076.8	6.79	0.32	1.0E+00	0.87633	0.00113	0.87858
cvr5slg0p0_02_03_03_15	0.0	1.0	90	32725.6	29453.0	8076.8	7.16	0.34	1.0E+00	0.85795	0.00109	0.86013
cvr5slg0p0_02_03_02_15	0.0	1.0	40	32933.9	13173.5	8076.8	16.00	0.76	1.0E+00	0.65888	0.00097	0.66081
cvr5slg0p0_02_03_01_15	0.0	1.0	20	33017.9	6603.6	8076.8	31.92	1.51	1.0E+00	0.54445	0.00082	0.54609

Table 6.9.6-27-A. Abridged results for the cvr5slg0p5 (pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content, 0.5 cm spacing in CV) calculation model

case name	content separation (cm)	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	mocfr	k_{eff}	σ	k_{eff}+2σ
5 slug content, 0.5 cm spacing, containment vessel:												
cvr5slg0p5_02_01_06_01	0.5	0.0	100	32684.3	32684.3	0.0	0.00	0.30	1.0E-20	0.84295	0.00104	0.84504
cvr5slg0p5_02_01_06_06	0.5	0.0	100	32684.3	32684.3	846.3	0.68	0.30	1.0E-01	0.84869	0.00107	0.85083
cvr5slg0p5_02_01_06_07	0.5	0.0	100	32684.3	32684.3	1692.5	1.35	0.30	2.0E-01	0.85906	0.00123	0.86153
cvr5slg0p5_02_01_06_08	0.5	0.0	100	32684.3	32684.3	2538.8	2.03	0.30	3.0E-01	0.86884	0.00110	0.87105
cvr5slg0p5_02_01_06_09	0.5	0.0	100	32684.3	32684.3	3385.0	2.70	0.30	4.0E-01	0.88170	0.00112	0.88394
cvr5slg0p5_02_01_06_10	0.5	0.0	100	32684.3	32684.3	4231.3	3.38	0.30	5.0E-01	0.89681	0.00139	0.89959
cvr5slg0p5_02_01_06_11	0.5	0.0	100	32684.3	32684.3	5077.6	4.05	0.30	6.0E-01	0.91414	0.00124	0.91661
cvr5slg0p5_02_01_06_12	0.5	0.0	100	32684.3	32684.3	5923.8	4.73	0.30	7.0E-01	0.92813	0.00117	0.93046
cvr5slg0p5_02_01_06_13	0.5	0.0	100	32684.3	32684.3	6770.1	5.41	0.30	8.0E-01	0.94368	0.00117	0.94602
cvr5slg0p5_02_01_06_14	0.5	0.0	100	32684.3	32684.3	7616.3	6.08	0.30	9.0E-01	0.95880	0.00123	0.96126
cvr5slg0p5_02_01_06_15	0.5	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E+00	0.97649	0.00132	0.97913

Table 6.9.6-28-A. Abridged results for the cvr5slg1p0 (pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content, 1.0 cm spacing in CV) calculation model

case name	content separation (cm)	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	mocfr	k_{eff}	σ	k_{eff}+2σ
5 slug content, 1.0 cm spacing, containment vessel												
cvr5slg1p0_02_01_06_01	1.0	0.0	100	32684.3	32684.3	0.0	0.00	0.30	1.0E-20	0.83039	0.00127	0.83293
cvr5slg1p0_02_01_06_06	1.0	0.0	100	32684.3	32684.3	846.3	0.68	0.30	1.0E-01	0.83803	0.00099	0.84001
cvr5slg1p0_02_01_06_07	1.0	0.0	100	32684.3	32684.3	1692.5	1.35	0.30	2.0E-01	0.84786	0.00114	0.85015
cvr5slg1p0_02_01_06_08	1.0	0.0	100	32684.3	32684.3	2538.8	2.03	0.30	3.0E-01	0.86347	0.00120	0.86588
cvr5slg1p0_02_01_06_09	1.0	0.0	100	32684.3	32684.3	3385.0	2.70	0.30	4.0E-01	0.87593	0.00125	0.87844
cvr5slg1p0_02_01_06_10	1.0	0.0	100	32684.3	32684.3	4231.3	3.38	0.30	5.0E-01	0.89246	0.00110	0.89465
cvr5slg1p0_02_01_06_11	1.0	0.0	100	32684.3	32684.3	5077.6	4.05	0.30	6.0E-01	0.91058	0.00131	0.91320
cvr5slg1p0_02_01_06_12	1.0	0.0	100	32684.3	32684.3	5923.8	4.73	0.30	7.0E-01	0.92796	0.00126	0.93047
cvr5slg1p0_02_01_06_13	1.0	0.0	100	32684.3	32684.3	6770.1	5.41	0.30	8.0E-01	0.94598	0.00128	0.94854
cvr5slg1p0_02_01_06_14	1.0	0.0	100	32684.3	32684.3	7616.3	6.08	0.30	9.0E-01	0.96077	0.00120	0.96317
cvr5slg1p0_02_01_06_15	1.0	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E+00	0.97875	0.00138	0.98152

Table 6.9.6-29-A. Abridged results for the nbsb5slg (NCT, bare, single unit, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	k_{eff}+2σ
5 Slug content, single unit, bare											
nbsb5slg_02_01_01	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-20	0.89875	0.00110	0.90094
nbsb5slg_02_01_02	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-05	0.89585	0.00127	0.89839
nbsb5slg_02_01_03	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-04	0.89933	0.00127	0.90187
nbsb5slg_02_01_04	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-03	0.89677	0.00123	0.89924
nbsb5slg_02_01_05	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-02	0.89752	0.00137	0.90026
nbsb5slg_02_01_06	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-01	0.90271	0.00133	0.90538
nbsb5slg_02_01_08	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	3.0E-01	0.91498	0.00127	0.91752
nbsb5slg_02_01_15	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E+00	0.94360	0.00106	0.94572

Table 6.9.6-30-A. Abridged results for the nbsr5slg (NCT, refl., single unit, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
5 Slug content, single unit, reflected											
nbsr5slg_02_01_01	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-20	0.90253	0.00113	0.90479
nbsr5slg_02_01_02	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-05	0.90121	0.00131	0.90383
nbsr5slg_02_01_03	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-04	0.90238	0.00124	0.90487
nbsr5slg_02_01_04	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-03	0.90334	0.00125	0.90585
nbsr5slg_02_01_05	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-02	0.90222	0.00134	0.90491
nbsr5slg_02_01_06	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-01	0.90594	0.00108	0.90809
nbsr5slg_02_01_08	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	3.0E-01	0.91716	0.00119	0.91954
nbsr5slg_02_01_15	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E+00	0.94090	0.00129	0.94348
nbsr5slg_02_03_01	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-20	0.83367	0.00116	0.83600
nbsr5slg_02_03_02	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-05	0.83402	0.00110	0.83622
nbsr5slg_02_03_03	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-04	0.83519	0.00118	0.83755
nbsr5slg_02_03_04	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-03	0.83384	0.00103	0.83590
nbsr5slg_02_03_05	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-02	0.83427	0.00139	0.83705
nbsr5slg_02_03_06	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-01	0.83640	0.00124	0.83888
nbsr5slg_02_03_08	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	3.0E-01	0.84732	0.00137	0.85005
nbsr5slg_02_03_15	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E+00	0.86889	0.00105	0.87099

Table 6.9.6-31-A. Abridged results for the nbia5slg (NCT, infinite array, 1.5-in. dia. x 2.0-in. tall slugs content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
nbia5slg_02_01_09_01	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-20	0.98826	0.00115	0.99056
nbia5slg_02_01_09_02	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-05	0.98712	0.00109	0.98931
nbia5slg_02_01_09_03	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-04	0.98528	0.00114	0.98757
nbia5slg_02_01_09_04	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-03	0.98607	0.00126	0.98859
nbia5slg_02_01_09_05	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-02	0.98398	0.00119	0.98636
nbia5slg_02_01_09_06	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E-01	0.95953	0.00112	0.96178
nbia5slg_02_01_09_08	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	3.0E-01	0.94730	0.00119	0.94967
nbia5slg_02_01_09_15	0.0	100	32684.3	32684.3	8462.6	6.76	0.30	1.0E+00	0.95227	0.00109	0.95446
nbia5slg_02_03_09_01	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-20	0.91964	0.00137	0.92237
nbia5slg_02_03_09_02	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-05	0.91946	0.00121	0.92188
nbia5slg_02_03_09_03	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-04	0.92210	0.00125	0.92459
nbia5slg_02_03_09_04	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-03	0.91868	0.00114	0.92095
nbia5slg_02_03_09_05	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-02	0.91375	0.00124	0.91622
nbia5slg_02_03_09_06	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-01	0.89260	0.00118	0.89496
nbia5slg_02_03_09_08	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	3.0E-01	0.87649	0.00108	0.87865
nbia5slg_02_03_09_15	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E+00	0.87906	0.00115	0.88136
nbia5slg_02_03_09_03	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-04	0.92210	0.00125	0.92459
nbia5slg_02_03_08_03	1.0	97.7	32693.8	31941.8	8076.8	6.60	0.31	1.0E-04	0.90987	0.00117	0.91222
nbia5slg_02_03_07_03	1.0	95	32704.9	31069.7	8076.8	6.79	0.32	1.0E-04	0.89944	0.00108	0.90160
nbia5slg_02_03_06_03	1.0	90	32725.6	29453.0	8076.8	7.16	0.34	1.0E-04	0.88415	0.00129	0.88673
nbia5slg_02_03_05_03	1.0	80	32767.0	26213.6	8076.8	8.04	0.38	1.0E-04	0.84537	0.00117	0.84770
nbia5slg_02_03_04_03	1.0	70	32808.6	22966.0	8076.8	9.18	0.43	1.0E-04	0.80278	0.00117	0.80512
nbia5slg_02_03_03_03	1.0	60	32850.2	19710.1	8076.8	10.70	0.51	1.0E-04	0.76170	0.00105	0.76381
nbia5slg_02_03_02_03	1.0	40	32933.9	13173.5	8076.8	16.00	0.76	1.0E-04	0.65904	0.00097	0.66097
nbia5slg_02_03_01_03	1.0	20	33017.9	6603.6	8076.8	31.92	1.51	1.0E-04	0.52832	0.00107	0.53047
nbia5slg_01_01_09_01	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E-20	0.87639	0.00113	0.87865
nbia5slg_01_01_09_02	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E-05	0.87833	0.00113	0.88058
nbia5slg_01_01_09_03	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E-04	0.87659	0.00133	0.87925
nbia5slg_01_01_09_04	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E-03	0.87633	0.00121	0.87876
nbia5slg_01_01_09_05	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E-02	0.87563	0.00106	0.87774

Table 6.9.6-31-A. Abridged results for the nbia5slg (NCT, infinite array, 1.5-in. dia. x 2.0-in. tall slugs content) calculation model (cont.)

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	molfr	k_{eff}	σ	$k_{eff}+2σ$
nbia5slg_01_01_09_06	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E-01	0.86132	0.00141	0.86414
nbia5slg_01_01_09_08	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	3.0E-01	0.85044	0.00128	0.85300
nbia5slg_01_01_09_15	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E+00	0.86094	0.00111	0.86315
nbia5slg_01_03_09_03	1.0	100	16342.1	16342.1	8944.0	14.28	0.61	1.0E-04	0.78367	0.00110	0.78587
nbia5slg_01_03_08_03	1.0	97.7	16346.9	15970.9	8944.0	14.62	0.62	1.0E-04	0.77611	0.00101	0.77813
nbia5slg_01_03_07_03	1.0	95	16352.5	15534.8	8944.0	15.03	0.64	1.0E-04	0.76454	0.00104	0.76662
nbia5slg_01_03_06_03	1.0	90	16362.8	14726.5	8944.0	15.85	0.68	1.0E-04	0.74992	0.00116	0.75224
nbia5slg_01_03_05_03	1.0	80.0	16383.5	13106.8	8944.0	17.81	0.76	1.0E-04	0.71627	0.00095	0.71817
nbia5slg_01_03_04_03	1.0	70.0	16404.3	11483.0	8944.0	20.33	0.87	1.0E-04	0.67740	0.00108	0.67957
nbia5slg_01_03_03_03	1.0	60.0	16425.1	9855.1	8944.0	23.69	1.01	1.0E-04	0.64050	0.00099	0.64247
nbia5slg_01_03_02_03	1.0	40.0	16466.9	6586.8	8944.0	35.44	1.51	1.0E-04	0.55075	0.00095	0.55265
nbia5slg_01_03_01_03	1.0	20.0	16509.0	3301.8	8944.0	70.70	3.02	1.0E-04	0.43622	0.00076	0.43774
nbia5slg_01_01_09_03	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E-04	0.87659	0.00133	0.87925
nbia5slg_01_01_08_03	0.0	97.7	16346.9	15970.9	9329.8	15.25	0.62	1.0E-04	0.86918	0.00109	0.87137
nbia5slg_01_01_07_03	0.0	95	16352.5	15534.8	9329.8	15.68	0.64	1.0E-04	0.85792	0.00130	0.86053
nbia5slg_01_01_06_03	0.0	90	16362.8	14726.5	9329.8	16.54	0.68	1.0E-04	0.84137	0.00101	0.84339
nbia5slg_01_01_05_03	0.0	80	16383.5	13106.8	9329.8	18.58	0.76	1.0E-04	0.80367	0.00110	0.80587
nbia5slg_01_01_04_03	0.0	70	16404.3	11483.0	9329.8	21.21	0.87	1.0E-04	0.76557	0.00104	0.76766
nbia5slg_01_01_03_03	0.0	60	16425.1	9855.1	9329.8	24.71	1.01	1.0E-04	0.72246	0.00109	0.72464
nbia5slg_01_01_02_03	0.0	40	16466.9	6586.8	9329.8	36.97	1.51	1.0E-04	0.62808	0.00096	0.62999
nbia5slg_01_01_01_03	0.0	20	16509.0	3301.8	9329.8	73.75	3.02	1.0E-04	0.50518	0.00097	0.50713

Table 6.9.6-32-A. Abridged results for the nbf15slg (NCT, 13x13x6 array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
nbf15slg_02_03_09_03	1.0	100	32684.3	32684.3	8076.8	6.45	1.0E-04	0.89447	0.00110	0.89667
nbf15slg_02_03_08_03	1.0	97.7	32693.8	31941.8	8076.8	6.60	1.0E-04	0.88447	0.00119	0.88686
nbf15slg_02_03_07_03	1.0	95	32704.9	31069.7	8076.8	6.79	1.0E-04	0.87514	0.00119	0.87751
nbf15slg_02_03_06_03	1.0	90	32725.6	29453.0	8076.8	7.16	1.0E-04	0.85977	0.00127	0.86231
nbf15slg_02_03_05_03	1.0	80	32767.0	26213.6	8076.8	8.04	1.0E-04	0.82074	0.00105	0.82284
nbf15slg_02_03_04_03	1.0	70	32808.6	22966.0	8076.8	9.18	1.0E-04	0.78042	0.00111	0.78263
nbf15slg_02_03_03_03	1.0	60	32850.2	19710.1	8076.8	10.70	1.0E-04	0.73650	0.00129	0.73907
nbf15slg_02_03_02_03	1.0	40	32933.9	13173.5	8076.8	16.00	1.0E-04	0.63896	0.00102	0.64100
nbf15slg_02_03_01_03	1.0	20	33017.9	6603.6	8076.8	31.92	1.0E-04	0.50762	0.00083	0.50928

Table 6.9.6-33-A. Abridged results for the nbf25slg (NCT, 9x9x4 array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculational model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
nbf25slg_02_03_09_03	1.0	100	32684.3	32684.3	8076.8	6.45	1.0E-04	0.88881	0.00137	0.89156
nbf25slg_02_03_08_03	1.0	97.7	32693.8	31941.8	8076.8	6.60	1.0E-04	0.88074	0.00125	0.88325
nbf25slg_02_03_07_03	1.0	95	32704.9	31069.7	8076.8	6.79	1.0E-04	0.86945	0.00116	0.87177
nbf25slg_02_03_06_03	1.0	90	32725.6	29453.0	8076.8	7.16	1.0E-04	0.85456	0.00119	0.85695
nbf25slg_02_03_05_03	1.0	80	32767.0	26213.6	8076.8	8.04	1.0E-04	0.81500	0.00127	0.81754
nbf25slg_02_03_04_03	1.0	70	32808.6	22966.0	8076.8	9.18	1.0E-04	0.77478	0.00128	0.77734
nbf25slg_02_03_03_03	1.0	60	32850.2	19710.1	8076.8	10.70	1.0E-04	0.72981	0.00113	0.73206
nbf25slg_02_03_02_03	1.0	40	32933.9	13173.5	8076.8	16.00	1.0E-04	0.63235	0.00113	0.63461
nbf25slg_02_03_01_03	1.0	20	33017.9	6603.6	8076.8	31.92	1.0E-04	0.50484	0.00087	0.50657

Table 6.9.6-35-A. Abridged results for the hbsr5slg (HAC, refl., single unit, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	k_{eff}+2σ
hbsr5slg_02_03_01	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-20	0.83554	0.00113	0.83780
hbsr5slg_02_03_15	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E+00	0.87209	0.00117	0.87442

Table 6.9.6-36-A. Results for the hbia5slg (HAC, infinite array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	k_{eff}+2σ
1.5-in. dia x 2.0-in. tall slugs content, infinite array											
hbia5slg_02_03_09_03	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-04	0.92878	0.00109	0.93096
hbia5slg_02_03_08_03	1.0	97.7	32693.8	31941.8	8076.8	6.60	0.31	1.0E-04	0.91839	0.00117	0.92072
hbia5slg_02_03_07_03	1.0	95	32704.9	31069.7	8076.8	6.79	0.32	1.0E-04	0.90930	0.00123	0.91176
hbia5slg_02_03_06_03	1.0	90	32725.6	29453.0	8076.8	7.16	0.34	1.0E-04	0.89242	0.00140	0.89522
hbia5slg_02_03_05_03	1.0	80	32767.0	26213.6	8076.8	8.04	0.38	1.0E-04	0.85238	0.00111	0.85459
hbia5slg_02_03_04_03	1.0	70	32808.6	22966.0	8076.8	9.18	0.43	1.0E-04	0.81230	0.00114	0.81458
hbia5slg_02_03_03_03	1.0	60	32850.2	19710.1	8076.8	10.70	0.51	1.0E-04	0.76887	0.00107	0.77101
hbia5slg_02_03_02_03	1.0	40	32933.9	13173.5	8076.8	16.00	0.76	1.0E-04	0.66753	0.00097	0.66948
hbia5slg_02_03_01_03	1.0	20	33017.9	6603.6	8076.8	31.92	1.51	1.0E-04	0.53594	0.00089	0.53772
hbia5slg_01_01_09_03	0.0	100	16342.1	16342.1	9329.8	14.90	0.61	1.0E-04	0.88551	0.00119	0.88789
hbia5slg_01_01_08_03	0.0	97.7	16346.9	15970.9	9329.8	15.25	0.62	1.0E-04	0.87508	0.00101	0.87710
hbia5slg_01_01_07_03	0.0	95	16352.5	15534.8	9329.8	15.68	0.64	1.0E-04	0.86565	0.00115	0.86795
hbia5slg_01_01_06_03	0.0	90	16362.8	14726.5	9329.8	16.54	0.68	1.0E-04	0.84698	0.00117	0.84933
hbia5slg_01_01_05_03	0.0	80	16383.5	13106.8	9329.8	18.58	0.76	1.0E-04	0.81274	0.00111	0.81495
hbia5slg_01_01_04_03	0.0	70	16404.3	11483.0	9329.8	21.21	0.87	1.0E-04	0.77073	0.00104	0.77282
hbia5slg_01_01_03_03	0.0	60	16425.1	9855.1	9329.8	24.71	1.01	1.0E-04	0.73161	0.00106	0.73373
hbia5slg_01_01_02_03	0.0	40	16466.9	6586.8	9329.8	36.97	1.51	1.0E-04	0.63541	0.00106	0.63753
hbia5slg_01_01_01_03	0.0	20	16509.0	3301.8	9329.8	73.75	3.02	1.0E-04	0.51220	0.00080	0.51381

Table 6.9.6-37-A. Results for the hbf25slg (HAC, 9x9x4 array, pentagonal rings of 1.5-in. dia. x 2.0-in. tall slugs content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
1.5-in. dia x 2.0-in. tall slugs content, 9x9x4 array											
hbf25slg_02_03_09_03	1.0	100	32684.3	32684.3	8076.8	6.45	0.30	1.0E-04	0.89364	0.00113	0.89590
hbf25slg_02_03_08_03	1.0	97.7	32693.8	31941.8	8076.8	6.60	0.31	1.0E-04	0.88549	0.00116	0.88782
hbf25slg_02_03_07_03	1.0	95	32704.9	31069.7	8076.8	6.79	0.32	1.0E-04	0.87500	0.00114	0.87729
hbf25slg_02_03_06_03	1.0	90	32725.6	29453.0	8076.8	7.16	0.34	1.0E-04	0.85804	0.00107	0.86019

Table 6.9.6-47-A. Abridged results for the cvr3sqa calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal, explicit cube content in containment vessel, reflected											
cvr3sqa_12_03_09_15	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E+00	0.86123	0.00122	0.86366
cvr3sqa_12_03_08_15	1.0	97.7	35151.7	34343.2	7946.4	6.04	0.29	1.0E+00	0.85324	0.00121	0.85567
cvr3sqa_12_03_07_15	1.0	95	35163.7	33405.5	7946.4	6.21	0.30	1.0E+00	0.84786	0.00127	0.85040
cvr3sqa_12_03_06_15	1.0	90	35185.9	31667.3	7946.4	6.55	0.31	1.0E+00	0.83069	0.00123	0.83316
cvr3sqa_12_03_05_15	1.0	80	35230.5	28184.4	7946.4	7.36	0.35	1.0E+00	0.80146	0.00106	0.80357
cvr3sqa_12_03_04_15	1.0	70	35275.1	24692.6	7946.4	8.40	0.40	1.0E+00	0.77108	0.00110	0.77329
cvr3sqa_12_03_03_15	1.0	60	35319.9	21192.0	7946.4	9.79	0.47	1.0E+00	0.73855	0.00104	0.74063
cvr3sqa_12_03_02_15	1.0	40	35409.8	14163.9	7946.4	14.64	0.70	1.0E+00	0.66147	0.00111	0.66370
cvr3sqa_12_03_01_15	1.0	20	35500.2	7100.0	7946.4	29.21	1.40	1.0E+00	0.56218	0.00099	0.56417

Table 6.9.6-48-A. Abridged results for the cvr3lha calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal content homogenized over convenience can volume, containment vessel, reflected											
cvr3lha_12_01_09_01	0.0	100	35141.5	35141.5	0.0	0.00	0.28	1.0E-20	0.74867	0.00102	0.75071
cvr3lha_12_01_09_06	0.0	100	35141.5	35141.5	833.2	0.62	0.28	1.0E-01	0.76358	0.00115	0.76588
cvr3lha_12_01_09_07	0.0	100	35141.5	35141.5	1666.4	1.24	0.28	2.0E-01	0.77847	0.00118	0.78083
cvr3lha_12_01_09_08	0.0	100	35141.5	35141.5	2499.7	1.86	0.28	3.0E-01	0.79737	0.00107	0.79950
cvr3lha_12_01_09_09	0.0	100	35141.5	35141.5	3332.9	2.48	0.28	4.0E-01	0.81560	0.00126	0.81813
cvr3lha_12_01_09_10	0.0	100	35141.5	35141.5	4166.1	3.09	0.28	5.0E-01	0.83861	0.00114	0.84089
cvr3lha_12_01_09_11	0.0	100	35141.5	35141.5	4999.3	3.71	0.28	6.0E-01	0.86042	0.00104	0.86250
cvr3lha_12_01_09_12	0.0	100	35141.5	35141.5	5832.5	4.33	0.28	7.0E-01	0.88177	0.00110	0.88396
cvr3lha_12_01_09_13	0.0	100	35141.5	35141.5	6665.8	4.95	0.28	8.0E-01	0.90379	0.00128	0.90634
cvr3lha_12_01_09_14	0.0	100	35141.5	35141.5	7499.0	5.57	0.28	9.0E-01	0.92819	0.00140	0.93099
cvr3lha_12_01_09_15	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E+00	0.94836	0.00122	0.95081
cvr3lha_12_01_09_15	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E+00	0.94836	0.00122	0.95081
cvr3lha_12_01_08_15	0.0	97.7	35151.7	34343.2	8332.2	6.33	0.29	1.0E+00	0.94013	0.00106	0.94226
cvr3lha_12_01_07_15	0.0	95	35163.7	33405.5	8332.2	6.51	0.30	1.0E+00	0.93088	0.00121	0.93330
cvr3lha_12_01_06_15	0.0	90	35185.9	31667.3	8332.2	6.87	0.31	1.0E+00	0.91839	0.00150	0.92138
cvr3lha_12_01_05_15	0.0	80	35230.5	28184.4	8332.2	7.72	0.35	1.0E+00	0.88809	0.00115	0.89039
cvr3lha_12_01_04_15	0.0	70	35275.1	24692.6	8332.2	8.81	0.40	1.0E+00	0.86146	0.00108	0.86363
cvr3lha_12_01_03_15	0.0	60	35319.9	21192.0	8332.2	10.26	0.47	1.0E+00	0.82815	0.00113	0.83042
cvr3lha_12_01_02_15	0.0	40	35409.8	14163.9	8332.2	15.35	0.70	1.0E+00	0.75451	0.00118	0.75688
cvr3lha_12_01_01_15	0.0	20	35500.2	7100.0	8332.2	30.63	1.40	1.0E+00	0.65972	0.00115	0.66201
cvr3lha_12_03_09_15	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E+00	0.89069	0.00114	0.89296
cvr3lha_12_03_08_15	1.0	97.7	35151.7	34343.2	7946.4	6.04	0.29	1.0E+00	0.88473	0.00112	0.88697
cvr3lha_12_03_07_15	1.0	95	35163.7	33405.5	7946.4	6.21	0.30	1.0E+00	0.87641	0.00119	0.87880
cvr3lha_12_03_06_15	1.0	90	35185.9	31667.3	7946.4	6.55	0.31	1.0E+00	0.86162	0.00123	0.86407
cvr3lha_12_03_05_15	1.0	80	35230.5	28184.4	7946.4	7.36	0.35	1.0E+00	0.83529	0.00126	0.83782
cvr3lha_12_03_04_15	1.0	70	35275.1	24692.6	7946.4	8.40	0.40	1.0E+00	0.80640	0.00118	0.80875
cvr3lha_12_03_03_15	1.0	60	35319.9	21192.0	7946.4	9.79	0.47	1.0E+00	0.77298	0.00100	0.77497
cvr3lha_12_03_02_15	1.0	40	35409.8	14163.9	7946.4	14.64	0.70	1.0E+00	0.70140	0.00099	0.70338
cvr3lha_12_03_01_15	1.0	20	35500.2	7100.0	7946.4	29.21	1.40	1.0E+00	0.60484	0.00103	0.60689

Table 6.9.6-48-A. Abridged results for the cvr3lha calculation model (cont.)

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal content homogenized over convenience can volume, containment vessel, reflected											
cvr3lha_12_03_09_15	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E+00	0.89069	0.00114	0.89296
cvr3lha_11_03_09_15	1.0	100	29592.8	29592.8	8240.9	7.27	0.34	1.0E+00	0.87551	0.00131	0.87813
cvr3lha_10_03_09_15	1.0	100	23119.4	23119.4	8584.4	9.69	0.43	1.0E+00	0.84417	0.00122	0.84660
cvr3lha_09_03_09_15	1.0	100	17570.7	17570.7	8878.8	13.19	0.57	1.0E+00	0.79752	0.00121	0.79994
cvr3lha_08_03_09_15	1.0	100	14796.4	14796.4	9026.0	15.92	0.67	1.0E+00	0.76926	0.00109	0.77144
cvr3lha_07_03_09_15	1.0	100	11097.3	11097.3	9222.3	21.69	0.90	1.0E+00	0.72426	0.00128	0.72682
cvr3lha_06_03_09_15	1.0	100	8323.0	8323.0	9369.5	29.38	1.20	1.0E+00	0.68561	0.00126	0.68813
cvr3lha_05_03_09_15	1.0	100	5548.7	5548.7	9516.7	44.77	1.80	1.0E+00	0.59386	0.00105	0.59595
cvr3lha_04_03_09_15	1.0	100	2774.3	2774.3	9664.0	90.92	3.59	1.0E+00	0.51037	0.00108	0.51253
cvr3lha_03_03_09_15	1.0	100	1849.6	1849.6	9713.0	137.07	5.39	1.0E+00	0.47187	0.00108	0.47403
cvr3lha_02_03_09_15	1.0	100	924.8	924.8	9762.1	275.53	10.70	1.0E+00	0.41652	0.00122	0.41896
cvr3lha_01_03_09_15	1.0	100	924.8	924.8	9762.1	275.53	10.70	1.0E+00	0.41652	0.00122	0.41896

Table 6.9.6-49-A. Abridged results for the cvr3cha calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	molfr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal content homogenized over containment vessel volume, containment vessel, reflected											
cvr3cha_12_03_09_15	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E+00	0.96588	0.00141	0.96869
cvr3cha_11_03_09_15	1.0	100	29592.8	29592.8	8240.9	7.27	0.34	1.0E+00	0.95945	0.00153	0.96251
cvr3cha_10_03_09_15	1.0	100	23119.4	23119.4	8584.4	9.69	0.43	1.0E+00	0.94813	0.00132	0.95076
cvr3cha_09_03_09_15	1.0	100	17570.7	17570.7	8878.8	13.19	0.57	1.0E+00	0.93941	0.00134	0.94209
cvr3cha_08_03_09_15	1.0	100	14796.4	14796.4	9026.0	15.92	0.67	1.0E+00	0.93570	0.00140	0.93850
cvr3cha_07_03_09_15	1.0	100	11097.3	11097.3	9222.3	21.69	0.90	1.0E+00	0.92460	0.00139	0.92737
cvr3cha_06_03_09_15	1.0	100	8323.0	8323.0	9369.5	29.38	1.20	1.0E+00	0.91736	0.00146	0.92027
cvr3cha_05_03_09_15	1.0	100	5548.7	5548.7	9516.7	44.77	1.80	1.0E+00	0.90506	0.00146	0.90798
cvr3cha_04_03_09_15	1.0	100	2774.3	2774.3	9664.0	90.92	3.59	1.0E+00	0.86307	0.00140	0.86587
cvr3cha_03_03_09_15	1.0	100	1849.6	1849.6	9713.0	137.07	5.39	1.0E+00	0.83140	0.00128	0.83397
cvr3cha_02_03_09_15	1.0	100	924.8	924.8	9762.1	275.53	10.70	1.0E+00	0.73804	0.00126	0.74056
cvr3cha_01_03_09_15	1.0	100	924.8	924.8	9762.1	275.53	10.70	1.0E+00	0.73804	0.00126	0.74056

Table 6.9.6-56-A. Abridged results for the nbsbbm (NCT, bare, single unit, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	molfr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal, single unit, bare											
nbsbbm_12_01_01	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-20	0.81424	0.00117	0.81657
nbsbbm_12_01_02	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-05	0.81486	0.00130	0.81745
nbsbbm_12_01_03	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-04	0.81336	0.00143	0.81622
nbsbbm_12_01_04	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-03	0.81510	0.00118	0.81746
nbsbbm_12_01_05	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-02	0.81303	0.00150	0.81602
nbsbbm_12_01_06	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-01	0.82298	0.00132	0.82561
nbsbbm_12_01_08	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	3.0E-01	0.84261	0.00141	0.84543
nbsbbm_12_01_15	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E+00	0.89251	0.00150	0.89551

Table 6.9.6-57-A. Abridged results for the nbsrbm (NCT, refl., single unit, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
Broken metal, single unit, reflected											
nbsrbm_12_01_01	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-20	0.82650	0.00136	0.82923
nbsrbm_12_01_02	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-05	0.82379	0.00118	0.82615
nbsrbm_12_01_03	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-04	0.82098	0.00124	0.82346
nbsrbm_12_01_04	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-03	0.82446	0.00127	0.82700
nbsrbm_12_01_05	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-02	0.82604	0.00138	0.82880
nbsrbm_12_01_06	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-01	0.83202	0.00131	0.83464
nbsrbm_12_01_08	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	3.0E-01	0.84422	0.00123	0.84668
nbsrbm_12_01_15	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E+00	0.89255	0.00141	0.89536
nbsrbm_12_03_01	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E-20	0.81042	0.00113	0.81268
nbsrbm_12_03_02	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E-05	0.81085	0.00118	0.81321
nbsrbm_12_03_03	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E-04	0.80892	0.00121	0.81135
nbsrbm_12_03_04	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E-03	0.80773	0.00121	0.81015
nbsrbm_12_03_05	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E-02	0.80913	0.00161	0.81234
nbsrbm_12_03_06	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E-01	0.81603	0.00133	0.81868
nbsrbm_12_03_08	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	3.0E-01	0.83003	0.00128	0.83258
nbsrbm_12_03_15	1.0	100	35141.5	35141.5	7946.4	5.90	0.28	1.0E+00	0.87891	0.00138	0.88167

Table 6.9.6-58-A. Abridged results for the nbiabm (NCT, infinite array, broken metal content) calculational model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
nbiabm_12_01_09_01	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-20	1.03075	0.00151	1.03378
nbiabm_12_01_09_02	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-05	1.03457	0.00118	1.03692
nbiabm_12_01_09_03	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-04	1.03408	0.00146	1.03699
nbiabm_12_01_09_04	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-03	1.03036	0.00133	1.03302
nbiabm_12_01_09_05	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-02	1.01860	0.00137	1.02135
nbiabm_12_01_09_06	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-01	0.94569	0.00128	0.94826
nbiabm_12_01_09_08	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	3.0E-01	0.90116	0.00136	0.90389
nbiabm_12_01_09_15	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E+00	0.90951	0.00146	0.91243
nbiabm_12_01_09_03	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-04	1.03408	0.00146	1.03699
nbiabm_11_01_09_03	0.0	100	29592.8	29592.8	8626.6	7.61	0.34	1.0E-04	1.01566	0.00123	1.01812
nbiabm_10_01_09_03	0.0	100	23119.4	23119.4	8970.2	10.13	0.43	1.0E-04	0.99678	0.00127	0.99932
nbiabm_09_01_09_03	0.0	100	17570.7	17570.7	9264.6	13.76	0.57	1.0E-04	0.97570	0.00133	0.97835
nbiabm_08_01_09_03	0.0	100	14796.4	14796.4	9411.8	16.60	0.67	1.0E-04	0.96303	0.00130	0.96562
nbiabm_07_01_09_03	0.0	100	11097.3	11097.3	9608.1	22.60	0.90	1.0E-04	0.94789	0.00132	0.95052
nbiabm_06_01_09_03	0.0	100	8323.0	8323.0	9755.3	30.59	1.20	1.0E-04	0.93007	0.00143	0.93293
nbiabm_05_01_09_03	0.0	100	5548.7	5548.7	9902.5	46.58	1.80	1.0E-04	0.90451	0.00144	0.90739
nbiabm_04_01_09_03	0.0	100	2774.3	2774.3	10049.8	94.55	3.59	1.0E-04	0.85058	0.00147	0.85351
nbiabm_03_01_09_03	0.0	100	1849.6	1849.6	10098.8	142.51	5.39	1.0E-04	0.80777	0.00151	0.81080
nbiabm_02_01_09_03	0.0	100	924.8	924.8	10147.9	286.41	10.70	1.0E-04	0.70776	0.00119	0.71014
nbiabm_01_01_09_03	0.0	100	924.8	924.8	10147.9	286.41	10.70	1.0E-04	0.70776	0.00119	0.71014
nbiabm_07_01_06_03	0.0	90	11111.3	10000.2	9608.1	25.08	1.00	1.0E-04	0.92154	0.00118	0.92390
nbiabm_08_01_05_03	0.0	80	14833.9	11867.1	9411.8	20.70	0.84	1.0E-04	0.91736	0.00151	0.92038
nbiabm_10_01_04_03	0.0	70	23207.3	16245.1	8970.2	14.41	0.61	1.0E-04	0.91510	0.00130	0.91769
nbiabm_12_01_03_03	0.0	60	35319.9	21192.0	8332.2	10.26	0.47	1.0E-04	0.91757	0.00126	0.92009
nbiabm_06_03_09_03	1.0	100	8323.0	8323.0	9369.5	29.38	1.20	1.0E-04	0.90769	0.00125	0.91019

Table 6.9.6-58-A. Abridged results for the nbiabm (NCT, infinite array, broken metal content) calculational model (cont.)

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
nbiabm_07_03_07_03	1.0	95	11104.3	10549.1	9222.3	22.82	0.94	1.0E-04	0.90983	0.00136	0.91255
nbiabm_08_03_06_03	1.0	90	14815.1	13333.6	9026.0	17.67	0.75	1.0E-04	0.91388	0.00143	0.91673
nbiabm_10_03_05_03	1.0	80	23177.9	18542.4	8584.4	12.08	0.54	1.0E-04	0.91741	0.00124	0.91988
nbiabm_11_03_04_03	1.0	70	29705.4	20793.8	8240.9	10.34	0.48	1.0E-04	0.91036	0.00125	0.91287
nbiabm_12_03_03_03	1.0	60	35319.9	21192.0	7946.4	9.79	0.47	1.0E-04	0.89194	0.00118	0.89431

Table 6.9.6-59-A. Abridged results for the nbf1bm (NCT, 13x13x6 array, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal, 13x13x6 array, no spacer										
nbf1bm_09_01_06_03	0.0	90	17593.0	15833.7	9264.6	15.27	1.0E-04	0.91716	0.00145	0.92007
nbf1bm_10_01_05_03	0.0	80	23177.9	18542.4	8970.2	12.63	1.0E-04	0.91152	0.00140	0.91433
nbf1bm_12_01_04_03	0.0	70	35275.1	24692.6	8332.2	8.81	1.0E-04	0.91536	0.00133	0.91801
nbf1bm_12_01_03_03	0.0	60	35319.9	21192.0	8332.2	10.26	1.0E-04	0.89090	0.00117	0.89324
Broken metal, 13x13x6 array, 1.0-in. spacers										
nbf1bm_08_03_09_03	1.0	100	14796.4	14796.4	9026.0	15.92	1.0E-04	0.91851	0.00147	0.92144
nbf1bm_09_03_07_03	1.0	95	17581.8	16702.7	8878.8	13.87	1.0E-04	0.91044	0.00150	0.91344
nbf1bm_10_03_06_03	1.0	90	23148.6	20833.8	8584.4	10.75	1.0E-04	0.91443	0.00145	0.91733
nbf1bm_11_03_05_03	1.0	80	29667.8	23734.2	8240.9	9.06	1.0E-04	0.90943	0.00119	0.91181
nbf1bm_12_03_04_03	1.0	70	35275.1	24692.6	7946.4	8.40	1.0E-04	0.89710	0.00143	0.89996
nbf1bm_12_03_03_03	1.0	60	35319.9	21192.0	7946.4	9.79	1.0E-04	0.86840	0.00138	0.87117

Table 6.9.6-60-A. Abridged results for the nbf2bm (NCT, 9x9x4 array, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	moifr	k_{eff}	σ	k_{eff}+2σ
Broken metal, 9x9x4 array, no spacer										
nbf2bm_10_01_06_03	0.0	90	23148.6	20833.8	8970.2	11.24	1.0E-04	0.91670	0.00154	0.91978
nbf2bm_11_01_05_03	0.0	80	29667.8	23734.2	8626.6	9.49	1.0E-04	0.90809	0.00128	0.91065
nbf2bm_12_01_04_03	0.0	70	35275.1	24692.6	8332.2	8.81	1.0E-04	0.89570	0.00114	0.89797
nbf2bm_12_01_03_03	0.0	60	35319.9	21192.0	8332.2	10.26	1.0E-04	0.87187	0.00104	0.87394
Broken metal, 9x9x4 array, 1.0-in. spacer										
nbf2bm_09_03_09_03	1.0	100	17570.7	17570.7	8878.8	13.19	1.0E-04	0.90643	0.00141	0.90925
nbf2bm_10_03_07_03	1.0	95	23134.0	21977.3	8584.4	10.20	1.0E-04	0.90841	0.00157	0.91156
nbf2bm_11_03_06_03	1.0	90	29630.2	26667.2	8240.9	8.07	1.0E-04	0.91388	0.00132	0.91652
nbf2bm_12_03_05_03	1.0	80	35230.5	28184.4	7946.4	7.36	1.0E-04	0.90313	0.00162	0.90637
nbf2bm_12_03_04_03	1.0	70	35275.1	24692.6	7946.4	8.40	1.0E-04	0.87823	0.00134	0.88092
nbf2bm_12_03_03_03	1.0	60	35319.9	21192.0	7946.4	9.79	1.0E-04	0.85090	0.00123	0.85337

Table 6.9.6-61-A. Abridged results for the nbf3bm (NCT, 7x7x3 array, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	molfr	k_{eff}	σ	k_{eff}+2σ
Broken metal, 7x7x3 array, no spacer										
nbf3bm_11_01_06_03	0.0	90	29630.2	26667.2	8626.6	8.44	1.0E-04	0.91539	0.00153	0.91846
nbf3bm_12_01_05_03	0.0	80	35230.5	28184.4	8332.2	7.72	1.0E-04	0.90418	0.00120	0.90657
nbf3bm_12_01_04_03	0.0	70	35275.1	24692.6	8332.2	8.81	1.0E-04	0.87670	0.00118	0.87907
nbf3bm_12_01_03_03	0.0	60	35319.9	21192.0	8332.2	10.26	1.0E-04	0.85250	0.00121	0.85491
Broken metal, 7x7x3 array, 1.0-in. spacer										
nbf3bm_10_03_09_03	1.0	100	23119.4	23119.4	8584.4	9.69	1.0E-04	0.90754	0.00125	0.91004
nbf3bm_11_03_07_03	1.0	95	29611.5	28130.9	8240.9	7.65	1.0E-04	0.90985	0.00125	0.91235
nbf3bm_12_03_06_03	1.0	90	35185.9	31667.3	7946.4	6.55	1.0E-04	0.91172	0.00133	0.91437
nbf3bm_12_03_05_03	1.0	80	35230.5	28184.4	7946.4	7.36	1.0E-04	0.88496	0.00121	0.88737
nbf3bm_12_03_04_03	1.0	70	35275.1	24692.6	7946.4	8.40	1.0E-04	0.86109	0.00116	0.86342
nbf3bm_12_03_03_03	1.0	60	35319.9	21192.0	7946.4	9.79	1.0E-04	0.83106	0.00120	0.83345

Table 6.9.6-65-A. Abridged results for the hbiabm (HAC, infinite array, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal content, infinite array, no spacer:											
hbiabm_12_01_09_01	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-20	1.05223	0.00126	1.05475
hbiabm_12_01_09_02	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-05	1.05224	0.00120	1.05464
hbiabm_12_01_09_03	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-04	1.05086	0.00123	1.05332
hbiabm_12_01_09_04	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-03	1.05045	0.00131	1.05308
hbiabm_12_01_09_05	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-02	1.04230	0.00118	1.04467
hbiabm_12_01_09_06	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-01	0.97989	0.00116	0.98221
hbiabm_12_01_09_08	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	3.0E-01	0.93393	0.00134	0.93660
hbiabm_12_01_09_15	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E+00	0.92935	0.00133	0.93201
hbiabm_12_01_09_03	0.0	100	35141.5	35141.5	8332.2	6.19	0.28	1.0E-04	1.05086	0.00123	1.05332
hbiabm_11_01_09_03	0.0	100	29592.8	29592.8	8626.6	7.61	0.34	1.0E-04	1.03092	0.00107	1.03307
hbiabm_10_01_09_03	0.0	100	23119.4	23119.4	8970.2	10.13	0.43	1.0E-04	1.01032	0.00129	1.01290
hbiabm_09_01_09_03	0.0	100	17570.7	17570.7	9264.6	13.76	0.57	1.0E-04	0.99241	0.00123	0.99487
hbiabm_08_01_09_03	0.0	100	14796.4	14796.4	9411.8	16.60	0.67	1.0E-04	0.97865	0.00131	0.98127
hbiabm_07_01_09_03	0.0	100	11097.3	11097.3	9608.1	22.60	0.90	1.0E-04	0.96424	0.00135	0.96695
hbiabm_06_01_09_03	0.0	100	8323.0	8323.0	9755.3	30.59	1.20	1.0E-04	0.94616	0.00129	0.94875
hbiabm_05_01_09_03	0.0	100	5548.7	5548.7	9902.5	46.58	1.80	1.0E-04	0.92089	0.00178	0.92446
hbiabm_04_01_09_03	0.0	100	2774.3	2774.3	10049.8	94.55	3.59	1.0E-04	0.86566	0.00145	0.86855
hbiabm_03_01_09_03	0.0	100	1849.6	1849.6	10098.8	142.51	5.39	1.0E-04	0.81906	0.00149	0.82204
hbiabm_02_01_09_03	0.0	100	924.8	924.8	10147.9	286.41	10.70	1.0E-04	0.71947	0.00120	0.72188
hbiabm_01_01_09_03	0.0	100	924.8	924.8	10147.9	286.41	10.70	1.0E-04	0.71947	0.00120	0.72188
hbiabm_06_01_06_03	0.0	90	8333.5	7500.2	9755.3	33.95	1.33	1.0E-04	0.92087	0.00131	0.92349
hbiabm_07_01_05_03	0.0	80	11125.4	8900.3	9608.1	28.18	1.12	1.0E-04	0.91818	0.00125	0.92068
hbiabm_09_01_04_03	0.0	70	17637.6	12346.3	9264.6	19.59	0.81	1.0E-04	0.91878	0.00141	0.92160
hbiabm_10_01_03_03	0.0	60	23236.8	13942.1	8970.2	16.79	0.71	1.0E-04	0.91191	0.00125	0.91441

Table 6.9.6-65-A. Abridged results for the hbiabm (HAC, infinite array, broken metal content) calculation model (cont.)

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal content, infinite array, no spacer											
hbiabm_05_03_09_03	1.0	100	5548.7	5548.7	9516.7	44.77	1.80	1.0E-04	0.90128	0.00147	0.90422
hbiabm_07_03_07_03	1.0	95	11104.3	10549.1	9222.3	22.82	0.94	1.0E-04	0.92677	0.00141	0.92959
hbiabm_07_03_06_03	1.0	90	11111.3	10000.2	9222.3	24.07	1.00	1.0E-04	0.91186	0.00160	0.91506
hbiabm_09_03_05_03	1.0	80	17615.2	14092.2	8878.8	16.44	0.71	1.0E-04	0.91599	0.00126	0.91851
hbiabm_10_03_04_03	1.0	70	23207.3	16245.1	8584.4	13.79	0.61	1.0E-04	0.91234	0.00149	0.91532
hbiabm_12_03_03_03	1.0	60	35319.9	21192.0	7946.4	9.79	0.47	1.0E-04	0.90959	0.00132	0.91224

Table 6.9.6-67-A. Abridged results for the hbf2bm (HAC, 9x9x4 array, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal content, 9x9x4 array, no spacer											
hbf2bm_10_01_06_03	0.0	90.0	23148.6	20833.8	8970.2	11.24	0.48	1.00E-04	0.93049	0.00132	0.93313
hbf2bm_11_01_05_03	0.0	80.0	29667.8	23734.2	8626.6	9.49	0.42	1.00E-04	0.92250	0.00132	0.92515
hbf2bm_12_01_04_03	0.0	70.0	35275.1	24692.6	8332.2	8.81	0.40	1.00E-04	0.91132	0.00136	0.91405
hbf2bm_12_01_03_03	0.0	60.0	35319.9	21192.0	8332.2	10.26	0.47	1.00E-04	0.88335	0.00126	0.88588
Broken metal content, 9x9x4 array, 1.0-in. spacer											
hbf2bm_05_03_09_03	1.0	100	5548.7	5548.7	9516.7	44.77	1.80	1.00E-04	0.85663	0.00127	0.85917
hbf2bm_06_03_07_03	1.0	95	8328.2	7911.8	9369.5	30.91	1.26	1.00E-04	0.86428	0.00149	0.86725
hbf2bm_07_03_06_03	1.0	90	11111.3	10000.2	9222.3	24.07	1.00	1.00E-04	0.87028	0.00122	0.87273
hbf2bm_09_03_05_03	1.0	80	17615.2	14092.2	8878.8	16.44		1.00E-04	0.86974	0.00130	0.87234
hbf2bm_10_03_04_03	1.0	70	23207.3	16245.1	8584.4	13.79	0.61	1.00E-04	0.86611	0.00128	0.86867
hbf2bm_12_03_03_03	1.0	60	35319.9	21192.0	7946.4	9.79	0.47	1.00E-04	0.85978	0.00136	0.86250

Table 6.9.6-68-A. Abridged results for the hbf3bm (HAC, 7x7x3 array, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal content, 7x7x3 array, no spacer:											
hbf3bm_10_01_06_03	0.0	90.0	23148.6	20833.8	8970.2	11.24	0.48	1.00E-04	0.90511	0.00132	0.90775
hbf3bm_12_01_05_03	0.0	80.0	35230.5	28184.4	8332.2	7.72	0.35	1.00E-04	0.91675	0.00129	0.91933
hbf3bm_12_01_04_03	0.0	70.0	35275.1	24692.6	8332.2	8.81	0.40	1.00E-04	0.89083	0.00154	0.89392
hbf3bm_12_01_03_03	0.0	60.0	35319.9	21192.0	8332.2	10.26	0.47	1.00E-04	0.86374	0.00122	0.86617
Broken metal content, 7x7x3 array, 1.0-in. spacer:											
hbf3bm_07_03_09_03	1.0	100.0	11097.3	11097.3	9222.3	21.69	0.90	1.00E-04	0.87477	0.00129	0.87735
hbf3bm_08_03_07_03	1.0	95.0	14805.8	14065.5	9026.0	16.75	0.71	1.00E-04	0.87723	0.00133	0.87990
hbf3bm_09_03_06_03	1.0	90.0	17593.0	15833.7	8878.8	14.64	0.63	1.00E-04	0.87116	0.00148	0.87411
hbf3bm_10_03_05_03	1.0	80.0	23177.9	18542.4	8584.4	12.08	0.54	1.00E-04	0.86621	0.00153	0.86927
hbf3bm_12_03_04_03	1.0	70.0	35275.1	24692.6	7946.4	8.40	0.40	1.00E-04	0.86964	0.00136	0.87235
hbf3bm_12_03_03_03	1.0	60.0	35319.9	21192.0	7946.4	9.79	0.47	1.00E-04	0.84195	0.00107	0.84408

Table 6.9.6-69-A. Abridged results for the hbf4bm (HAC, 5x5x2 array, broken metal content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
Broken metal content, 5x5x2 array, no spacer:											
hbf4bm_12_01_06_03	0.0	90.0	35185.9	31667.3	8332.2	6.87	0.31	1.00E-04	0.90376	0.00122	0.90620
hbf4bm_12_01_05_03	0.0	80.0	35230.5	28184.4	8332.2	7.72	0.35	1.00E-04	0.88118	0.00123	0.88364
hbf4bm_12_01_04_03	0.0	70.0	35275.1	24692.6	8332.2	8.81	0.40	1.00E-04	0.85509	0.00119	0.85747
hbf4bm_12_01_03_03	0.0	60.0	35319.9	21192.0	8332.2	10.26	0.47	1.00E-04	0.82849	0.00147	0.83144
Broken metal content, 5x5x2 array, 1.0-in. spacer:											
hbf4bm_09_03_09_03	1.0	100.0	17570.7	17570.7	8878.8	13.19	0.57	1.00E-04	0.86637	0.00164	0.86964
hbf4bm_10_03_07_03	1.0	95.0	23134.0	21977.3	8584.4	10.2	0.45	1.00E-04	0.86912	0.00118	0.87148
hbf4bm_11_03_06_03	1.0	90.0	29630.2	26667.2	8240.9	8.07	0.37	1.00E-04	0.86989	0.00152	0.87293
hbf4bm_12_03_05_03	1.0	80.0	35230.5	28184.4	7946.4	7.36	0.35	1.00E-04	0.85957	0.00111	0.86180
hbf4bm_12_03_04_03	1.0	70.0	35275.1	24692.6	7946.4	8.40	0.40	1.00E-04	0.83566	0.00109	0.83784
hbf4bm_12_03_03_03	1.0	60.0	35319.9	21192.0	7946.4	9.79	0.47	1.00E-04	0.80691	0.00120	0.80930

Table 6.9.6-70-A. Abridged results for the cvrox (HEU Oxide content in CV) calculation model

case name	np277-4 thickness (in)	U (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	mocfr	k_{eff}	σ	$k_{eff}+2σ$
cvrox_01_11_01_01	0.0	24000.0	21124.9	0.0	0.00	0.47	1.0E-20	0.68061	0.00104	0.68268
cvrox_01_11_01_06	0.0	24000.0	21124.9	653.4	0.81	0.47	1.0E-01	0.69751	0.00105	0.69962
cvrox_01_11_01_07	0.0	24000.0	21124.9	1306.8	1.61	0.47	2.0E-01	0.71649	0.00111	0.71872
cvrox_01_11_01_08	0.0	24000.0	21124.9	1960.2	2.42	0.47	3.0E-01	0.73326	0.00132	0.73591
cvrox_01_11_01_09	0.0	24000.0	21124.9	2613.5	3.23	0.47	4.0E-01	0.75313	0.00123	0.75560
cvrox_01_11_01_10	0.0	24000.0	21124.9	3266.9	4.04	0.47	5.0E-01	0.77223	0.00118	0.77459
cvrox_01_11_01_11	0.0	24000.0	21124.9	3920.3	4.84	0.47	6.0E-01	0.79100	0.00107	0.79315
cvrox_01_11_01_12	0.0	24000.0	21124.9	4573.7	5.65	0.47	7.0E-01	0.81175	0.00116	0.81406
cvrox_01_11_01_13	0.0	24000.0	21124.9	5227.1	6.46	0.47	8.0E-01	0.83112	0.00117	0.83347
cvrox_01_11_01_14	0.0	24000.0	21124.9	5880.5	7.27	0.47	9.0E-01	0.85120	0.00121	0.85362
cvrox_01_11_01_15	0.0	24000.0	21124.9	6533.9	8.07	0.47	1.0E+00	0.86964	0.00158	0.87280

Table 6.9.6-71-A. Abridged results for the nbsbox (NCT, bare, single unit, HEU Oxide content) calculation model

case name	np277-4 thickness (in)	Oxide (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
HEU Oxide, single unit, bare										
nbsbox_01_11_03_01	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-20	0.70619	0.00099	0.70817
nbsbox_01_11_03_02	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-05	0.70528	0.00112	0.70753
nbsbox_01_11_03_03	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-04	0.70687	0.00118	0.70924
nbsbox_01_11_03_04	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-03	0.70727	0.00106	0.70939
nbsbox_01_11_03_05	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-02	0.70596	0.00126	0.70847
nbsbox_01_11_03_06	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-01	0.71636	0.00107	0.71851
nbsbox_01_11_03_08	1.0	24000.0	21124.9	6148.1	9.42	0.47	3.0E-01	0.73506	0.00111	0.73727
nbsbox_01_11_03_15	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E+00	0.78907	0.00119	0.79145

Table 6.9.6-72-A. Abridged results for the nbsrox (NCT, refl., single unit, HEU Oxide content) calculation model

case name	np277-4 thickness (in)	Oxide (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
HEU Oxide, single unit, reflected										
nbsrox_01_11_03_01	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-20	0.71587	0.00099	0.71784
nbsrox_01_11_03_02	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-05	0.71393	0.00102	0.71598
nbsrox_01_11_03_03	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-04	0.71397	0.00118	0.71632
nbsrox_01_11_03_04	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-03	0.71359	0.00108	0.71575
nbsrox_01_11_03_05	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-02	0.71443	0.00115	0.71674
nbsrox_01_11_03_06	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-01	0.72143	0.00133	0.72409
nbsrox_01_11_03_08	1.0	24000.0	21124.9	6148.1	9.42	0.47	3.0E-01	0.73586	0.00106	0.73799
nbsrox_01_11_03_15	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E+00	0.78734	0.00112	0.78959
nbsrox_01_11_01_15	0.0	24000.0	21124.9	6533.9	9.90	0.47	1.0E+00	0.78872	0.00120	0.79113
nbsrox_01_10_01_15	0.0	21000.0	18484.3	6991.7	11.70	0.54	1.0E+00	0.77346	0.00113	0.77571
nbsrox_01_09_01_15	0.0	18000.0	15843.7	7449.6	14.10	0.63	1.0E+00	0.75320	0.00122	0.75564
nbsrox_01_08_01_15	0.0	15000.0	13203.0	7907.5	17.46	0.75	1.0E+00	0.72836	0.00109	0.73053
nbsrox_01_07_01_15	0.0	12000.0	10562.4	8365.4	22.50	0.94	1.0E+00	0.68955	0.00115	0.69184
nbsrox_01_06_01_15	0.0	9000.0	7921.8	8823.3	30.90	1.26	1.0E+00	0.63714	0.00120	0.63954
nbsrox_01_05_01_15	0.0	6000.0	5281.2	9281.2	47.69	1.89	1.0E+00	0.55749	0.00106	0.55960
nbsrox_01_04_01_15	0.0	3000.0	2640.6	9739.1	98.09	3.77	1.0E+00	0.43369	0.00091	0.43552
nbsrox_01_03_01_15	0.0	1998.0	1758.6	9892.0	148.64	5.66	1.0E+00	0.37198	0.00088	0.37375
nbsrox_01_02_01_15	0.0	1500.0	1320.3	9968.0	198.88	7.54	1.0E+00	0.33289	0.00096	0.33481
nbsrox_01_01_01_15	0.0	999.0	879.3	10044.5	299.98	11.30	1.0E+00	0.28974	0.00090	0.29154

Table 6.9.6-73-A. Abridged results for the nbiaox (NCT, infinite array, HEU Oxide content) calculation model

case name	np277-4 thickness (in)	Oxide (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	molfr	k_{eff}	σ	k_{eff}+2σ
nbiaox_01_11_03_01	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-20	0.84309	0.00114	0.84536
nbiaox_01_11_03_02	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-05	0.84589	0.00116	0.84820
nbiaox_01_11_03_03	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-04	0.84582	0.00118	0.84818
nbiaox_01_11_03_04	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-03	0.84389	0.00124	0.84637
nbiaox_01_11_03_05	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-02	0.83774	0.00109	0.83992
nbiaox_01_11_03_06	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-01	0.80679	0.00120	0.80920
nbiaox_01_11_03_08	1.0	24000.0	21124.9	6148.1	9.42	0.47	3.0E-01	0.78311	0.00114	0.78540
nbiaox_01_11_03_15	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E+00	0.79893	0.00116	0.80124
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
nbiaox_01_11_03_03	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-04	0.84582	0.00118	0.84818
nbiaox_01_10_03_03	1.0	21000.0	18484.3	6606.0	11.15	0.54	1.0E-04	0.82028	0.00111	0.82250
nbiaox_01_09_03_03	1.0	18000.0	15843.7	7063.8	13.46	0.63	1.0E-04	0.79033	0.00123	0.79278
nbiaox_01_08_03_03	1.0	15000.0	13203.0	7521.7	16.69	0.75	1.0E-04	0.75720	0.00115	0.75949
nbiaox_01_07_03_03	1.0	12000.0	10562.4	7979.6	21.54	0.94	1.0E-04	0.71111	0.00116	0.71343
nbiaox_01_06_03_03	1.0	9000.0	7921.8	8437.5	29.63	1.26	1.0E-04	0.64824	0.00101	0.65027
nbiaox_01_05_03_03	1.0	6000.0	5281.2	8895.4	45.79	1.89	1.0E-04	0.55838	0.00123	0.56084
nbiaox_01_04_03_03	1.0	3000.0	2640.6	9353.3	94.28	3.77	1.0E-04	0.41886	0.00112	0.42110
nbiaox_01_03_03_03	1.0	1998.0	1758.6	9506.2	142.91	5.66	1.0E-04	0.34882	0.00098	0.35077
nbiaox_01_02_03_03	1.0	1500.0	1320.3	9582.2	191.26	7.54	1.0E-04	0.30823	0.00090	0.31003
nbiaox_01_01_03_03	1.0	999.0	879.3	9658.7	288.52	11.30	1.0E-04	0.25790	0.00073	0.25936

Table 6.9.6-78-A. Abridged results for the hbsrox (HAC, refl., single unit, HEU Oxide content) calculation model

case name	np277-4 thickness (in)	Oxide (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	k_{eff}+2σ
hbsrox_01_11_03_01	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-20	0.71377	0.00115	0.71607
hbsrox_01_11_03_02	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-05	0.71273	0.00108	0.71488
hbsrox_01_11_03_03	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-04	0.71336	0.00129	0.71593
hbsrox_01_11_03_04	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-03	0.71352	0.00133	0.71619
hbsrox_01_11_03_05	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-02	0.71580	0.00115	0.71811
hbsrox_01_11_03_06	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-01	0.72041	0.00106	0.72253
hbsrox_01_11_03_08	1.0	24000.0	21124.9	6148.1	9.42	0.47	3.0E-01	0.73479	0.00128	0.73735
hbsrox_01_11_03_15	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E+00	0.78792	0.00129	0.79050
hbsrox_01_11_01_15	0.0	24000.0	21124.9	6533.9	9.90	0.47	1.0E+00	0.78844	0.00112	0.79069
hbsrox_01_10_01_15	0.0	21000.0	18484.3	6991.7	11.70	0.54	1.0E+00	0.77255	0.00131	0.77517
hbsrox_01_09_01_15	0.0	18000.0	15843.7	7449.6	14.10	0.63	1.0E+00	0.75523	0.00125	0.75773
hbsrox_01_08_01_15	0.0	15000.0	13203.0	7907.5	17.46	0.75	1.0E+00	0.72754	0.00106	0.72966
hbsrox_01_07_01_15	0.0	12000.0	10562.4	8365.4	22.50	0.94	1.0E+00	0.69066	0.00113	0.69292
hbsrox_01_06_01_15	0.0	9000.0	7921.8	8823.3	30.90	1.26	1.0E+00	0.63846	0.00119	0.64083
hbsrox_01_05_01_15	0.0	6000.0	5281.2	9281.2	47.69	1.89	1.0E+00	0.56199	0.00098	0.56395
hbsrox_01_04_01_15	0.0	3000.0	2640.6	9739.1	98.09	3.77	1.0E+00	0.43831	0.00090	0.44011
hbsrox_01_03_01_15	0.0	1998.0	1758.6	9892.0	148.64	5.66	1.0E+00	0.37844	0.00098	0.38040
hbsrox_01_02_01_15	0.0	1500.0	1320.3	9968.0	198.88	7.54	1.0E+00	0.34193	0.00091	0.34376
hbsrox_01_01_01_15	0.0	999.0	879.3	10044.5	299.98	11.30	1.0E+00	0.29669	0.00086	0.29841
hbsrox_02_11_03_01	1.0	24000.0	20313.7	6148.1	8.90	0.49	1.0E-20	0.60318	0.00119	0.60556
hbsrox_02_11_03_02	1.0	24000.0	20313.7	6148.1	8.90	0.49	1.0E-05	0.60230	0.00103	0.60437
hbsrox_02_11_03_03	1.0	24000.0	20313.7	6148.1	8.90	0.49	1.0E-04	0.60216	0.00090	0.60396
hbsrox_02_11_03_04	1.0	24000.0	20313.7	6148.1	8.90	0.49	1.0E-03	0.60115	0.00096	0.60306
hbsrox_02_11_03_05	1.0	24000.0	20313.7	6148.1	8.90	0.49	1.0E-02	0.60328	0.00093	0.60514
hbsrox_02_11_03_06	1.0	24000.0	20313.7	6148.1	8.90	0.49	1.0E-01	0.61032	0.00099	0.61229
hbsrox_02_11_03_08	1.0	24000.0	20313.7	6148.1	8.90	0.49	3.0E-01	0.62977	0.00108	0.63194
hbsrox_02_11_03_15	1.0	24000.0	20313.7	6148.1	8.90	0.49	1.0E+00	0.68714	0.00106	0.68925

Table 6.9.6-78-A. Abridged results for the hbsrox (HAC, refl., single unit, HEU Oxide content) calculation model (cont.)

case name	np277-4 thickness (in)	Oxide (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
hbsrox_03_11_03_01	1.0	24000.0	19931.0	6148.1	8.54	0.50	1.0E-20	0.54120	0.00090	0.54301
hbsrox_03_11_03_02	1.0	24000.0	19931.0	6148.1	8.54	0.50	1.0E-05	0.53953	0.00085	0.54122
hbsrox_03_11_03_03	1.0	24000.0	19931.0	6148.1	8.54	0.50	1.0E-04	0.53970	0.00095	0.54160
hbsrox_03_11_03_04	1.0	24000.0	19931.0	6148.1	8.54	0.50	1.0E-03	0.54030	0.00088	0.54205
hbsrox_03_11_03_05	1.0	24000.0	19931.0	6148.1	8.54	0.50	1.0E-02	0.54211	0.00080	0.54372
hbsrox_03_11_03_06	1.0	24000.0	19931.0	6148.1	8.54	0.50	1.0E-01	0.54873	0.00083	0.55039
hbsrox_03_11_03_08	1.0	24000.0	19931.0	6148.1	8.54	0.50	3.0E-01	0.56707	0.00092	0.56891
hbsrox_03_11_03_15	1.0	24000.0	19931.0	6148.1	8.54	0.50	1.0E+00	0.62601	0.00108	0.62817

Table 6.9.6-79-A. Abridged results for the hbiaox (HAC, infinite array, HEU Oxide content) calculation model

case name	np277-4 thickness (in)	Oxide (g)	^{235}U (g)	H_2O (g)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
hbiaox_01_11_03_01	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-20	0.85723	0.00103	0.85929
hbiaox_01_11_03_02	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-05	0.85659	0.00098	0.85854
hbiaox_01_11_03_03	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-04	0.85702	0.00106	0.85914
hbiaox_01_11_03_04	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-03	0.85554	0.00106	0.85766
hbiaox_01_11_03_05	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-02	0.85446	0.00117	0.85681
hbiaox_01_11_03_06	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-01	0.82927	0.00137	0.83202
hbiaox_01_11_03_08	1.0	24000.0	21124.9	6148.1	9.42	0.47	3.0E-01	0.80352	0.00123	0.80598
hbiaox_01_11_03_15	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E+00	0.81661	0.00120	0.81900
hbiaox_01_11_03_03	1.0	24000.0	21124.9	6148.1	9.42	0.47	1.0E-04	0.85702	0.00106	0.85914
hbiaox_01_10_03_03	1.0	21000.0	18484.3	6606.0	11.15	0.54	1.0E-04	0.83401	0.00103	0.83607
hbiaox_01_09_03_03	1.0	18000.0	15843.7	7063.8	13.46	0.63	1.0E-04	0.80354	0.00103	0.80560
hbiaox_01_08_03_03	1.0	15000.0	13203.0	7521.7	16.69	0.75	1.0E-04	0.76845	0.00111	0.77067
hbiaox_01_07_03_03	1.0	12000.0	10562.4	7979.6	21.54	0.94	1.0E-04	0.72101	0.00106	0.72313
hbiaox_01_06_03_03	1.0	9000.0	7921.8	8437.5	29.63	1.26	1.0E-04	0.65517	0.00117	0.65750
hbiaox_01_05_03_03	1.0	6000.0	5281.2	8895.4	45.79	1.89	1.0E-04	0.56445	0.00096	0.56637
hbiaox_01_04_03_03	1.0	3000.0	2640.6	9353.3	94.28	3.77	1.0E-04	0.42306	0.00083	0.42471
hbiaox_01_03_03_03	1.0	1998.0	1758.6	9506.2	142.91	5.66	1.0E-04	0.35492	0.00087	0.35667
hbiaox_01_02_03_03	1.0	1500.0	1320.3	9582.2	191.26	7.54	1.0E-04	0.31295	0.00086	0.31468
hbiaox_01_01_03_03	1.0	999.0	879.3	9658.7	288.52	11.30	1.0E-04	0.26079	0.00089	0.26256

Table 6.9.6-82-A. Abridged results for the cvrunhc (UNH Crystals content in CV) calculation model

case name	np277-4 thickness (in)	UNH (g)	^{235}U (g)	^{235}U conc (g/L)	H_2O (g)	h/x	mocfr	k_{eff}	σ	$k_{eff}+2σ$
cvrunhc_11_01_01	0.0	24000.0	11303.1	1106.48	0.0	12.00	1.0E-20	0.72617	0.00152	0.72920
cvrunhc_11_01_06	0.0	24000.0	11303.1	1106.48	162.0	12.37	1.0E-01	0.73893	0.00149	0.74192
cvrunhc_11_01_07	0.0	24000.0	11303.1	1106.48	324.1	12.75	2.0E-01	0.74806	0.00142	0.75090
cvrunhc_11_01_08	0.0	24000.0	11303.1	1106.48	486.1	13.12	3.0E-01	0.75747	0.00134	0.76015
cvrunhc_11_01_09	0.0	24000.0	11303.1	1106.48	648.2	13.50	4.0E-01	0.76653	0.00139	0.76931
cvrunhc_11_01_10	0.0	24000.0	11303.1	1106.48	810.2	13.87	5.0E-01	0.77413	0.00148	0.77709
cvrunhc_11_01_11	0.0	24000.0	11303.1	1106.48	972.3	14.25	6.0E-01	0.78428	0.00115	0.78658
cvrunhc_11_01_12	0.0	24000.0	11303.1	1106.48	1134.3	14.62	7.0E-01	0.78898	0.00129	0.79155
cvrunhc_11_01_13	0.0	24000.0	11303.1	1106.48	1296.3	14.99	8.0E-01	0.80109	0.00140	0.80390
cvrunhc_11_01_14	0.0	24000.0	11303.1	1106.48	1458.4	15.37	9.0E-01	0.81148	0.00123	0.81394
cvrunhc_11_01_15	0.0	24000.0	11303.1	1106.48	1620.4	15.74	1.0E+00	0.82007	0.00128	0.82262
cvrunhc_11_01_15	0.0	24000.0	11303.1	1106.48	1620.4	15.74	1.0E+00	0.82007	0.00128	0.82262
cvrunhc_10_01_15	0.0	21000.0	9890.2	968.17	2692.5	19.11	1.0E+00	0.82938	0.00118	0.83174
cvrunhc_09_01_15	0.0	18000.0	8477.3	829.86	3764.6	23.59	1.0E+00	0.83622	0.00128	0.83878
cvrunhc_08_01_15	0.0	15000.0	7064.4	691.55	4836.6	29.87	1.0E+00	0.84402	0.00133	0.84667
cvrunhc_07_01_15	0.0	12000.0	5651.5	553.24	5908.7	39.29	1.0E+00	0.85138	0.00159	0.85456
cvrunhc_06_01_15	0.0	9000.0	4238.7	414.93	6980.8	54.99	1.0E+00	0.85423	0.00147	0.85718
cvrunhc_05_01_15	0.0	6000.0	2825.8	276.62	8052.8	86.38	1.0E+00	0.83915	0.00151	0.84218
cvrunhc_04_01_15	0.0	3000.0	1412.9	138.31	9124.9	180.57	1.0E+00	0.78282	0.00120	0.78522
cvrunhc_03_01_15	0.0	1998.0	941.0	92.11	9483.0	275.04	1.0E+00	0.73030	0.00110	0.73250
cvrunhc_02_01_15	0.0	1500.0	706.4	69.15	9660.9	368.94	1.0E+00	0.68580	0.00132	0.68844
cvrunhc_01_01_15	0.0	999.0	470.5	46.06	9840.0	557.88	1.0E+00	0.60693	0.00098	0.60889

Table 6.9.6-83-A. Abridged results for the nbsbunhc (NCT, bare, single unit, UNH Crystals content) calculation model

case name	np277-4 thickness (in)	UNH crystals (g)	^{235}U (g)	H_2O (g)	U conc (g/l)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
UNH Crystals content, single unit, homogenized over convenience can volume, bare											
nbsbunhc_11_01_01	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-20	0.60596	0.00120	0.60835
nbsbunhc_11_01_02	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-05	0.60627	0.00129	0.60885
nbsbunhc_11_01_03	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-04	0.60730	0.00157	0.61044
nbsbunhc_11_01_04	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-03	0.60511	0.00139	0.60789
nbsbunhc_11_01_05	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-02	0.60424	0.00116	0.60655
nbsbunhc_11_01_06	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-01	0.61552	0.00119	0.61790
nbsbunhc_11_01_08	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	3.0E-01	0.63821	0.00123	0.64067
nbsbunhc_11_01_15	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E+00	0.70515	0.00138	0.70791

Table 6.9.6-84-A. Abridged results for the nbsrunhc (NCT, refl., single unit, UNH Crystals content) calculation model

case name	np277-4 thickness (in)	UNH crystals (g)	^{235}U (g)	H_2O (g)	U conc (g/l)	h/x	wrapped, dry cc h/x	molfr	k_{eff}	σ	$k_{eff}+2σ$
UNH Crystals content, single unit, homogenized over convenience can volume, reflected											
nbsrunhc_11_01_01	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-20	0.61525	0.00127	0.61778
nbsrunhc_11_01_02	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-05	0.61490	0.00147	0.61783
nbsrunhc_11_01_03	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-04	0.61827	0.00128	0.62083
nbsrunhc_11_01_04	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-03	0.61467	0.00135	0.61738
nbsrunhc_11_01_05	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-02	0.61678	0.00119	0.61915
nbsrunhc_11_01_06	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-01	0.62509	0.00115	0.62738
nbsrunhc_11_01_08	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	3.0E-01	0.64403	0.00119	0.64641
nbsrunhc_11_01_15	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E+00	0.70534	0.00124	0.70783
nbsrunhc_11_01_15	0.0	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E+00	0.70534	0.00124	0.70783
nbsrunhc_10_01_15	0.0	21000.0	9890.2	2692.5	968.17	19.11	1.01	1.0E+00	0.71594	0.00137	0.71868
nbsrunhc_09_01_15	0.0	18000.0	8477.3	3764.6	829.86	23.59	1.18	1.0E+00	0.72779	0.00148	0.73074
nbsrunhc_08_01_15	0.0	15000.0	7064.4	4836.6	691.55	29.87	1.41	1.0E+00	0.73814	0.00145	0.74104
nbsrunhc_07_01_15	0.0	12000.0	5651.5	5908.7	553.24	39.29	1.76	1.0E+00	0.74788	0.00156	0.75100
nbsrunhc_06_01_15	0.0	9000.0	4238.7	6980.8	414.93	54.99	2.35	1.0E+00	0.74609	0.00134	0.74877
nbsrunhc_05_01_15	0.0	6000.0	2825.8	8052.8	276.62	86.38	3.53	1.0E+00	0.74133	0.00154	0.74441
nbsrunhc_04_01_15	0.0	3000.0	1412.9	9124.9	138.31	180.57	7.05	1.0E+00	0.69473	0.00121	0.69715
nbsrunhc_03_01_15	0.0	1998.0	941.0	9483.0	92.11	275.04	10.50	1.0E+00	0.64780	0.00130	0.65040
nbsrunhc_02_01_15	0.0	1500.0	706.4	9660.9	69.15	368.94	14.10	1.0E+00	0.60820	0.00112	0.61043
nbsrunhc_01_01_15	0.0	999.0	470.5	9840.0	46.06	557.88	21.10	1.0E+00	0.54048	0.00114	0.54275

Table 6.9.6-85-A. Abridged results for the nbiaunhc (NCT, infinite array, UNH Crystals content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	UNH crystals (g)	^{235}U (g)	H_2O (g)	U conc (g/l)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
UNH Crystal content, infinite array, homogenized over convenience can volume:												
nbiaunhc_10_11_01_01	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-20	0.81652	0.00143	0.81938
nbiaunhc_10_11_01_02	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-05	0.81818	0.00124	0.82067
nbiaunhc_10_11_01_03	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-04	0.81670	0.00127	0.81923
nbiaunhc_10_11_01_04	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-03	0.81430	0.00127	0.81683
nbiaunhc_10_11_01_05	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-02	0.80241	0.00119	0.80479
nbiaunhc_10_11_01_06	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-01	0.73298	0.00125	0.73549
nbiaunhc_10_11_01_08	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	3.0E-01	0.70032	0.00120	0.70272
nbiaunhc_10_11_01_15	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E+00	0.72408	0.00127	0.72662
nbiaunhc_10_11_01_03	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-04	0.81670	0.00127	0.81923
nbiaunhc_10_10_01_03	0.0	100	21000.0	9890.2	2692.5	968.17	19.11	1.01	1.0E-04	0.82609	0.00126	0.82862
nbiaunhc_10_09_01_03	0.0	100	18000.0	8477.3	3764.6	829.86	23.59	1.18	1.0E-04	0.83017	0.00129	0.83274
nbiaunhc_10_08_01_03	0.0	100	15000.0	7064.4	4836.6	691.55	29.87	1.41	1.0E-04	0.83825	0.00156	0.84137
nbiaunhc_10_07_01_03	0.0	100	12000.0	5651.5	5908.7	553.24	39.29	1.76	1.0E-04	0.83584	0.00141	0.83866
nbiaunhc_10_06_01_03	0.0	100	9000.0	4238.7	6980.8	414.93	54.99	2.35	1.0E-04	0.83566	0.00145	0.83857
nbiaunhc_10_05_01_03	0.0	100	6000.0	2825.8	8052.8	276.62	86.38	3.53	1.0E-04	0.81604	0.00143	0.81889
nbiaunhc_10_04_01_03	0.0	100	3000.0	1412.9	9124.9	138.31	180.57	7.05	1.0E-04	0.75748	0.00126	0.76000
nbiaunhc_10_03_01_03	0.0	100	1998.0	941.0	9483.0	92.11	275.04	10.50	1.0E-04	0.69898	0.00157	0.70213
nbiaunhc_10_02_01_03	0.0	100	1500.0	706.4	9660.9	69.15	368.94	14.10	1.0E-04	0.65026	0.00109	0.65243
nbiaunhc_10_01_01_03	0.0	100	999.0	470.5	9840.0	46.06	557.88	21.10	1.0E-04	0.56953	0.00108	0.57169

Table 6.9.6-86-A. Abridged results for the obsrunhc (NCT, refl., single unit, UNH Crystals content) calculation model

case name	np277-4 thickness (in)	UNH crystals (g)	^{235}U (g)	H_2O (g)	U conc (g/l)	h/x	wrapped, dry cc h/x	molfr	k_{eff}	σ	k_{eff}+2σ
UNH Crystals content, single unit, homogenized over containment vessel volume, reflected											
obsrunhc_11_01_01	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-20	0.79566	0.00150	0.79866
obsrunhc_11_01_02	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-05	0.79398	0.00146	0.79691
obsrunhc_11_01_03	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-04	0.79272	0.00135	0.79542
obsrunhc_11_01_04	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-03	0.79469	0.00129	0.79727
obsrunhc_11_01_05	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-02	0.79519	0.00155	0.79829
obsrunhc_11_01_06	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-01	0.79677	0.00127	0.79932
obsrunhc_11_01_08	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	3.0E-01	0.79633	0.00146	0.79924
obsrunhc_11_01_15	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E+00	0.79933	0.00143	0.80218
obsrunhc_11_01_15	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E+00	0.79933	0.00143	0.80218
obsrunhc_10_01_15	0.0	21000.0	9890.2	5540.2	600.79	35.56	1.01	1.0E+00	0.80787	0.00139	0.81066
obsrunhc_09_01_15	0.0	18000.0	8477.3	6205.4	514.96	42.79	1.18	1.0E+00	0.80995	0.00160	0.81316
obsrunhc_08_01_15	0.0	15000.0	7064.4	6870.7	429.13	52.91	1.41	1.0E+00	0.80988	0.00144	0.81276
obsrunhc_07_01_15	0.0	12000.0	5651.5	7535.9	343.31	68.09	1.76	1.0E+00	0.80594	0.00148	0.80889
obsrunhc_06_01_15	0.0	9000.0	4238.7	8201.2	257.48	93.38	2.35	1.0E+00	0.79575	0.00150	0.79875
obsrunhc_05_01_15	0.0	6000.0	2825.8	8866.5	171.65	143.98	3.53	1.0E+00	0.77006	0.00152	0.77309
obsrunhc_04_01_15	0.0	3000.0	1412.9	9531.7	85.83	295.76	7.05	1.0E+00	0.68984	0.00137	0.69258
obsrunhc_03_01_15	0.0	1998.0	941.0	9753.9	57.16	448.00	10.50	1.0E+00	0.61945	0.00113	0.62171
obsrunhc_02_01_15	0.0	1500.0	706.4	9864.3	42.91	599.32	14.10	1.0E+00	0.56605	0.00141	0.56888
obsrunhc_01_01_15	0.0	999.0	470.5	9975.4	28.58	903.80	21.10	1.0E+00	0.47980	0.00083	0.48146

Table 6.9.6-87-A. Abridged results for the obiaunhc (NCT, infinite array, UNH Crystals content) calculation model

case name	np277-4 thickness (in)	enrichment (wt%)	UNH crystals (g)	^{235}U (g)	H_2O (g)	U conc (g/l)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
UNH Crystal content, infinite array, homogenized over containment vessel volume:												
obiaunhc_10_11_01_01	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-20	1.02465	0.00137	1.02738
obiaunhc_10_11_01_02	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-05	1.02418	0.00131	1.02680
obiaunhc_10_11_01_03	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-04	1.02373	0.00128	1.02628
obiaunhc_10_11_01_04	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-03	1.02218	0.00134	1.02486
obiaunhc_10_11_01_05	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-02	1.01214	0.00130	1.01474
obiaunhc_10_11_01_06	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-01	0.94728	0.00146	0.95019
obiaunhc_10_11_01_08	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	3.0E-01	0.88141	0.00121	0.88384
obiaunhc_10_11_01_15	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E+00	0.82831	0.00130	0.83091
obiaunhc_10_11_01_03	0.0	100	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-04	1.02373	0.00128	1.02628
obiaunhc_10_10_01_03	0.0	100	21000.0	9890.2	5540.2	600.79	35.56	1.01	1.0E-04	1.02297	0.00126	1.02549
obiaunhc_10_09_01_03	0.0	100	18000.0	8477.3	6205.4	514.96	42.79	1.18	1.0E-04	1.02016	0.00133	1.02282
obiaunhc_10_08_01_03	0.0	100	15000.0	7064.4	6870.7	429.13	52.91	1.41	1.0E-04	1.00719	0.00147	1.01014
obiaunhc_10_07_01_03	0.0	100	12000.0	5651.5	7535.9	343.31	68.09	1.76	1.0E-04	0.99540	0.00162	0.99863
obiaunhc_10_06_01_03	0.0	100	9000.0	4238.7	8201.2	257.48	93.38	2.35	1.0E-04	0.97357	0.00123	0.97602
obiaunhc_10_05_01_03	0.0	100	6000.0	2825.8	8866.5	171.65	143.98	3.53	1.0E-04	0.92385	0.00138	0.92662
obiaunhc_10_04_01_03	0.0	100	3000.0	1412.9	9531.7	85.83	295.76	7.05	1.0E-04	0.81217	0.00137	0.81491
obiaunhc_10_03_01_03	0.0	100	1998.0	941.0	9753.9	57.16	448.00	10.50	1.0E-04	0.72620	0.00118	0.72855
obiaunhc_10_02_01_03	0.0	100	1500.0	706.4	9864.3	42.91	599.32	14.10	1.0E-04	0.65589	0.00102	0.65793
obiaunhc_10_01_01_03	0.0	100	999.0	470.5	9975.4	28.58	903.80	21.10	1.0E-04	0.55446	0.00114	0.55673

Table 6.9.6-90-A. Abridged results for the hbiaunhc (HAC, infinite array, UNH Crystals content) calculational model

case name	np277-4 thickness (in)	enrichment (wt%)	UNH crystals (g)	^{235}U (g)	H_2O (g)	U conc (g/l)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2σ$
hbiaunhc_10_11_01_01	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-20	0.83501	0.00125	0.83752
hbiaunhc_10_11_01_02	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-05	0.83291	0.00115	0.83521
hbiaunhc_10_11_01_03	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-04	0.83187	0.00130	0.83446
hbiaunhc_10_11_01_04	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-03	0.83518	0.00139	0.83796
hbiaunhc_10_11_01_05	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-02	0.82196	0.00146	0.82488
hbiaunhc_10_11_01_06	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-01	0.76849	0.00132	0.77112
hbiaunhc_10_11_01_08	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	3.0E-01	0.72923	0.00132	0.73187
hbiaunhc_10_11_01_15	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E+00	0.74364	0.00130	0.74625
hbiaunhc_10_11_01_03	0.0	100	24000.0	11303.1	1620.4	1106.48	15.74	0.88	1.0E-04	0.83187	0.00130	0.83446
hbiaunhc_10_10_01_03	0.0	100	21000.0	9890.2	2692.5	968.17	19.11	1.01	1.0E-04	0.84258	0.00109	0.84475
hbiaunhc_10_09_01_03	0.0	100	18000.0	8477.3	3764.6	829.86	23.59	1.18	1.0E-04	0.84717	0.00173	0.85062
hbiaunhc_10_08_01_03	0.0	100	15000.0	7064.4	4836.6	691.55	29.87	1.41	1.0E-04	0.85136	0.00136	0.85408
hbiaunhc_10_07_01_03	0.0	100	12000.0	5651.5	5908.7	553.24	39.29	1.76	1.0E-04	0.85449	0.00131	0.85712
hbiaunhc_10_06_01_03	0.0	100	9000.0	4238.7	6980.8	414.93	54.99	2.35	1.0E-04	0.84769	0.00123	0.85015
hbiaunhc_10_05_01_03	0.0	100	6000.0	2825.8	8052.8	276.62	86.38	3.53	1.0E-04	0.83047	0.00160	0.83367
hbiaunhc_10_04_01_03	0.0	100	3000.0	1412.9	9124.9	138.31	180.57	7.05	1.0E-04	0.76605	0.00140	0.76885
hbiaunhc_10_03_01_03	0.0	100	1998.0	941.0	9483.0	92.11	275.04	10.50	1.0E-04	0.71090	0.00128	0.71345
hbiaunhc_10_02_01_03	0.0	100	1500.0	706.4	9660.9	69.15	368.94	14.10	1.0E-04	0.66202	0.00158	0.66518
hbiaunhc_10_01_01_03	0.0	100	999.0	470.5	9840.0	46.06	557.88	21.10	1.0E-04	0.58137	0.00114	0.58364

Table 6.9.6-91-A. Abridged results for the ibsrunhc (HAC, refl., UNH crystals content) calculation model

case name	np277-4 thickness (in)	UNH crystals (g)	^{235}U (g)	H_2O (g)	U conc (g/l)	h/x	wrapped, dry cc h/x	moifr	k_{eff}	σ	$k_{eff}+2\sigma$
ibsrunhc_11_01_01	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-20	0.79582	0.00136	0.79854
ibsrunhc_11_01_02	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-05	0.79132	0.00145	0.79421
ibsrunhc_11_01_03	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-04	0.79489	0.00143	0.79774
ibsrunhc_11_01_04	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-03	0.79297	0.00181	0.79658
ibsrunhc_11_01_05	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-02	0.79572	0.00148	0.79868
ibsrunhc_11_01_06	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E-01	0.79349	0.00132	0.79612
ibsrunhc_11_01_08	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	3.0E-01	0.79847	0.00145	0.80136
ibsrunhc_11_01_15	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E+00	0.79947	0.00154	0.80256
ibsrunhc_11_01_15	0.0	24000.0	11303.1	4874.9	686.61	30.14	0.88	1.0E+00	0.79947	0.00154	0.80256
ibsrunhc_10_01_15	0.0	21000.0	9890.2	5540.2	600.79	35.56	1.01	1.0E+00	0.80584	0.00159	0.80902
ibsrunhc_09_01_15	0.0	18000.0	8477.3	6205.4	514.96	42.79	1.18	1.0E+00	0.80900	0.00149	0.81197
ibsrunhc_08_01_15	0.0	15000.0	7064.4	6870.7	429.13	52.91	1.41	1.0E+00	0.81004	0.00158	0.81320
ibsrunhc_07_01_15	0.0	12000.0	5651.5	7535.9	343.31	68.09	1.76	1.0E+00	0.80637	0.00140	0.80917
ibsrunhc_06_01_15	0.0	9000.0	4238.7	8201.2	257.48	93.38	2.35	1.0E+00	0.79894	0.00137	0.80168
ibsrunhc_05_01_15	0.0	6000.0	2825.8	8866.5	171.65	143.98	3.53	1.0E+00	0.76933	0.00143	0.77220
ibsrunhc_04_01_15	0.0	3000.0	1412.9	9531.7	85.83	295.76	7.05	1.0E+00	0.68665	0.00130	0.68925
ibsrunhc_03_01_15	0.0	1998.0	941.0	9753.9	57.16	448.00	10.50	1.0E+00	0.62039	0.00107	0.62254
ibsrunhc_02_01_15	0.0	1500.0	706.4	9864.3	42.91	599.32	14.10	1.0E+00	0.56386	0.00096	0.56578
ibsrunhc_01_01_15	0.0	999.0	470.5	9975.4	28.58	903.80	21.10	1.0E+00	0.48055	0.00089	0.48233

APPENDIX 6.9.7

INPUT LISTINGS OF ES-3100 CALCULATION MODELS FOR SELECT CASES IDENTIFIED IN TABLES 6.1a-c

This appendix contains selected input listing for calculations identified Tables 6.1a, 6.1b and 6.1c and Sects. 6.4, 6.5, and 6.6 of this document. These listings are a few taken from Y/LF-718.

```
=csas25    parm=size=3000000
cvrsp 6sph,0.0in thk np,32938.2gU(32938.2g235,8449.1gH2O hx=  6.70),fr=1.0e+00
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.30'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000                  end
'np277-4: spacer'
'min.den.= 1.6819 = (105 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
arbm2774s  1.6819  11 0 0 0        1001    4.6190
                                   5000    4.2330
                                   6012    1.5060
                                   8016   59.9960
                                  11023    0.1300
                                  12000    0.3860
                                  13027   21.1600
                                  14000    1.3200
                                  16000    0.1500
                                  20000    6.1800
                                  26000    0.3200    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
'np277-4: confinement -- neutron poison inner liner 4 wt% boron'
'See np277-4 spacer. Regarding H2O loss, H2 (4.6190wt%) removes O (36.6541wt%)'
'Residual O bound to other constituents is (23.3419wt%). Wt%'s are normalized by'
'sumTi/100.0 = 0.587269, where sumTi are wt%s for 10 remaining consistituents.'
'density is normalized by 100.0/sumTi.  0.9877 =(density)(sumTi/100.0)'
'density = 1.6800 = (den.mult)(min.den.) = 0.99889*1.6819 where'
'den.mult = 1.32561e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'actual vol.= 1.32561e4 cm3 = (28316.84 cm3/ft3)(49.15423 lb)/(105 lb/ft3)'
'min.den.= 1.6819 = (105 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
arbmnp277  0.9877  10 0 0 0    5000    7.2080
                               6012    2.5644
                               8016   39.7463
                              11023    0.2214
                              12000    0.6573
                              13027   36.0313
                              14000    2.2477
                              16000    0.2554
                              20000   10.5233
                              26000    0.5449   11  1.0000  293  end
arbmnph2o  0.6942   2 0 0 0    1001   11.1913
                               8016   88.8087   11  1.0000  293  end
'kaolite 1600 body'
'array densities are s.u.dens. multiplied by a volume ratio 1.34888/1.10336'
'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    1.16235  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
cvrsp 6sph,0.0in thk np,32938.2gU(32938.2g235, 8449.1gH2O,hx=  6.70),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
'bottom of cv to bottom of 1st step [Elev=35.270 in.]'
' 4.11480            radius of sphere'
```

```
' 4.74980            axial location of sphere 1'
 array 1  -4.361180  -4.361180  4.74980        com='stack in cv'
 cylinder  3  1    6.426200   77.72400   0.63500 com='cv well cavity'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv below 1st step'
 cuboid    21 1 4p24.587200   77.72400   0.0     com='drum chine outer radius'
unit 1004
'sphere content, --  spacerless'
 sphere    1  1    4.114800                      com='spherical content'
 cuboid    3  1  4p4.361180   2p 4.11480         com='void space in cv'
unit 1005
'sphere content, --  sphere plus square half-spacer on top'
' 4.11480 half thickness of cell'
 sphere    1  1    4.114800                      com='spherical content'
 cuboid    3  1  4p4.361180   2p 4.11480         com='void space in cv'
 cuboid    2  1  4p4.361180    4.11480  -4.11480 com='sngl-end np half-spacer'
unit 1006
'sphere content, --  sphere plus square half-spacer on bottom'
 sphere    1  1    4.114800                      com='spherical content'
 cuboid    3  1  4p4.361180   2p 4.11480         com='void space in cv'
 cuboid    2  1  4p4.361180    4.11480  -4.11480 com='sngl-end np half-spacer'
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 2        2r-24.587200     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 4p22.889718    110.5048  0.0    com='interstital array space'
'global
'unit 1021
'array 3   3r0.0
'reflector  21 2  6r3.0  10
```

```
end geometry
read array
ara=1 nux=1 nuy=1 nuz=6                                 fill
1004 1005 1006 1005 1006 1004                       end fill
ara=2 nux=1 nuy=1 nuz=13                                fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
'ara=3 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


=csas25    parm=size=3000000
nbsrcy 3cyl,0.0in thk np,18000.0gU(18000.0g235, 9241.8gH2O hx= 13.40),fr=1.0e+00
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.55'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000               end
'np277-4: spacer'
'min.den.= 1.6819 = (105 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
arbm2774s  1.6819  11 0 0 0     1001     4.6190
                                5000     4.2330
                                6012     1.5060
                                8016    59.9960
                               11023     0.1300
                               12000     0.3860
                               13027    21.1600
                               14000     1.3200
                               16000     0.1500
                               20000     6.1800
                               26000     0.3200   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 4 wt% boron'
'See np277-4 spacer. Regarding H2O loss, H2 (4.6190wt%) removes O (36.6541wt%)'
'Residual O bound to other constituents is (23.3419wt%). Wt%'s are normalized by'
'sumTi/100.0 = 0.587269, where sumTi are wt%s for 10 remaining consistituents.'
'density is normalized by 100.0/sumTi.  0.9877 =(density)(sumTi/100.0)'
'density = 1.6800 = (den.mult)(min.den.) = 0.99889*1.6819 where'
'den.mult = 1.32561e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'actual vol.= 1.32561e4 cm3 = (28316.84 cm3/ft3)(49.15423 lb)/(105 lb/ft3)'
'min.den.= 1.6819 = (105 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 7.1195e-2 1 0 0 0     5000   100.0000   11  0.7500  293  end
arbmnp277  0.9165   9 0 0 0     6012     2.7636
                                8016    42.8337
                               11023     0.2386
                               12000     0.7083
                               13027    38.8302
                               14000     2.4223
                               16000     0.2753
                               20000    11.3408
                               26000     0.5872   11  1.0000  293  end
arbmnph2o  0.6942   2 0 0 0     1001    11.1913
                                8016    88.8087   11  1.0000  293  end
'kaolite 1600 body'
'array densities are s.u.dens. multiplied by a volume ratio 1.34888/1.10336'
```

```
'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    1.16235  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
nbsrcy 3cyl,0.0in thk np,18000.0gU(18000.0g235, 9241.8gH2O,hx= 13.40),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
'bottom of cv to bottom of 1st step [Elev=35.270 in.]'
' 4.11480          radius of cylinder'
' 5.99639          height of HEU cylinder'
' 0.63550          axial location of cylinder 1'
 array 1  -4.361180  -4.361180   0.63550         com='stack in cv'
 cylinder  3  1    6.426200   77.72400   0.63500 com='cv well cavity'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv below 1st step'
 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 1004
'cylinder content, --  spacerless'
 cylinder  1  1    4.114800  2p 2.99820          com='cylindrical content'
 cuboid    3  1  4p4.361180   2p 2.99820          com='void space in cv'
unit 1005
'cylinder content, --  cylinder plus spacer on top'
' 2.99820          half thickness of cell'
 cylinder  1  1    4.114800  2p 2.99820          com='cylindrical content'
 cuboid    3  1  4p4.361180   2p 2.99820          com='void space in cv'
 cuboid    2  1  4p4.361180     2.99820  -2.99820 com='sngl-end np spacer'
unit 1006
'cylinder content, --  cylinder plus spacer on bottom'
 cylinder  1  1    4.114800  2p 2.99820          com='cylindrical content'
 cuboid    3  1  4p4.361180   2p 2.99820          com='void space in cv'
 cuboid    2  1  4p4.361180     2.99820  -2.99820 com='sngl-end np spacer'
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 2          2r-24.587200     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 4p22.889718    110.5048  0.0     com='interstital array space'
'global
'unit 1021
'array 3   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=1 nuy=1 nuz=3 fill 1005 1004 1006 end fill
ara=2 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019      end fill
'ara=3 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


=csas25    parm=size=3000000
hbsrsq, 0.0in thk np,36000.0gU(36000.0g235, 8286.7gH2O hx=  6.01),fr=1.0e+00
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.28'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238   0.000              end
'np277-4: spacer'
'min.den.= 1.6819 = (105 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
arbm2774s  1.6819  11 0 0 0     1001     4.6190
                                5000     4.2330
                                6012     1.5060
                                8016    59.9960
                               11023     0.1300
                               12000     0.3860
                               13027    21.1600
                               14000     1.3200
                               16000     0.1500
                               20000     6.1800
                               26000     0.3200    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 4 wt% boron'
'See np277-4 spacer. Regarding H2O loss, H2 (4.6190wt%) removes O (36.6541wt%)'
'Residual O bound to other constituents is (23.3419wt%). Wt%'s are normalized by'
'sumTi/100.0 = 0.587269, where sumTi are wt%s for 10 remaining consistituents.'
'density is normalized by 100.0/sumTi.  0.9877 =(density)(sumTi/100.0)'
'density = 1.6800 = (den.mult)(min.den.) = 0.99889*1.6819 where'
'den.mult = 1.32561e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'actual vol.= 1.32561e4 cm3 = (28316.84 cm3/ft3)(49.15423 lb)/(105 lb/ft3)'
'min.den.= 1.6819 = (105 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 7.1195e-2 1 0 0 0    5000  100.0000   11  0.7500  293  end
arbmnp277  0.9165    9 0 0 0    6012    2.7636
                                8016   42.8337
                               11023    0.2386
                               12000    0.7083
                               13027   38.8302
                               14000    2.4223
                               16000    0.2753
                               20000   11.3408
                               26000    0.5872   11  1.0000  293  end
arbmnph2o  0.6942    2 0 0 0    1001   11.1913
                                8016   88.8087   11  0.9000  293  end
'kaolite 1600 body'
'array densities are s.u.dens. multiplied by a volume ratio 1.34888/1.10336'
'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 vol.=1.34888e5 cm3'
'hac.s.u.dens= (hac.mult)(nct.den)'
' for arbmh2ok = 1.20172*0.52294,   for rest = 1.20172*0.34864'
'hac.mult= 1.34888e5 cm3 (nct vol.)/ 9.84895e4 cm3 (model vol.)'
arbmh2ok    0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  1        293  end
arbmal2o3   0.41897  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096    293  end
arbmsio2    0.41897  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367    293  end
arbmfe2o3   0.41897  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067    293  end
arbmtio2    0.41897  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012    293  end
arbmcao     0.41897  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307    293  end
arbmmgo     0.41897  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131    293  end
arbmna2o    0.41897  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
nbsrsq 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   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
'bottom of cv to bottom of 1st step [Elev=35.270 in.]'
' 2.90960            half length-width of block'
'18.83826            height of HEU block'
' 0.63550            axial location of block 1'
 array 1  -4.361180  -4.361180   0.63550          com='stack in cv'
 cylinder  3  1.    6.426200   77.72400   0.63500 com='cv well cavity'
 cylinder  8  1.    6.680200   77.72400   0.0      com='cv below 1st step'
 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 1004
'block content, --  spacerless'
 cuboid    1  1  4p2.909600  2p 9.41913          com='block content'
 cuboid    3  1  4p4.361180   2p 9.41913          com='void space in cv'
unit 1005
'block content, --  block plus spacer on top'
' 9.41913            half thickness of cell'
 cuboid    1  1  4p2.909600  2p 9.41913          com='block content'
 cuboid    3  1  4p4.361180   2p 9.41913          com='void space in cv'
 cuboid    2  1  4p4.361180     9.41913  -9.41913 com='sngl-end np spacer'
unit 1006
'block content, --  block plus spacer on bottom'
 cuboid    1  1  4p2.909600  2p 9.41913          com='block content'
 cuboid    3  1  4p4.361180   2p 9.41913          com='void space in cv'
 cuboid    2  1  4p4.361180     9.41913  -9.41913 com='sngl-end np spacer'
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 2         2r-21.838092     0.0
'cuboid     0  1 4p21.838092    110.4900  0.0     com='bare package'
 cuboid    21  1 4p52.318092   140.9700 -30.48    com='reflected package'
'cuboid    20  1 4p21.838092    110.4900  0.0     com='interstital array space'
'global
'unit 1021
'array 3   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=1 nux=1 nuy=1 nuz=3 fill 1005 1004 1006 end fill
ara=2 nux=1 nuy=1 nuz=13 fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019       end fill
'ara=3 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


=csas25    parm=size=3000000
nbiaox 1.0in np,disp.24000.0gUO2 (21124.9g235, 6148.1gH2O hx=  9.42),fr=1.0e+00
238groupndf5 infhommedium
'HEU oxide, bulk density of oxide in cans=  6.54000 g/cm3'
'wrapped dry content can hx=0.47'
'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'
'min.den.= 1.6819 = (105 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
arbm2774s  1.6819  11 0 0 0     1001    4.6190
                                5000    4.2330
                                6012    1.5060
                                8016   59.9960
                               11023    0.1300
                               12000    0.3860
                               13027   21.1600
                               14000    1.3200
                               16000    0.1500
                               20000    6.1800
```

```
                                26000    0.3200    2  1.0000  293  end
'flooded containmment vessel and content cans -- 10 CFR 71.55(d)(3)'
arbmwicv  9.3926e-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 4 wt% boron'
'See np277-4 spacer. Regarding H2O loss, H2 (4.6190wt%) removes O (36.6541wt%)'
'Residual O bound to other constituents is (23.3419wt%). Wt%'s are normalized by'
'sumTi/100.0 = 0.587269, where sumTi are wt%s for 10 remaining consistituents.'
'density is normalized by 100.0/sumTi: 0.9877 =(density)(sumTi/100.0)'
'density = 1.6800 = (den.mult)(min.den.) = 0.99889*1.6819 where'
'den.mult = 1.32561e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'actual vol.= 1.32561e4 cm3 = (28316.84 cm3/ft3)(49.15423 lb)/(105 lb/ft3)'
'min.den.= 1.6819 = (105 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 7.1195e-2 1 0 0 0    5000  100.0000    11  0.7500  293  end
arbmnp277  0.9165   9 0 0 0    6012    2.7636
                               8016   42.8337
                              11023    0.2386
                              12000    0.7083
                              13027   38.8302
                              14000    2.4223
                              16000    0.2753
                              20000   11.3408
                              26000    0.5872    11  1.0000  293  end
arbmnph2o  0.6942   2 0 0 0    1001   11.1913
                               8016   88.8087    11  1.0000  293  end
'kaolite 1600 body'
'array densities are s.u.dens. multiplied by a volume ratio 1.34888/1.10336'
'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
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                                        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
nbiaox 1.0in np,disp.24000.0gUO2 (21124.9g235, 6148.1gH2O,hx=  9.42),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
'bottom of cv 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 below 1st step'
 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'
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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.]'
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 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 2          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 3   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=2 nux=1 nuy=1 nuz=13                          fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019      end fill
'ara=3 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


=csas25    parm=size=3000000
ibiaunhc 1.0innp,disp. 6000.0gUNHc( 2825.8g235, 8500.2gH2O hx=140.41),fr=1.0e-04
238groupndf5 infhommedium
'U(enr)O2(NO3)2+6H2O [2.81 g/cc for U(nat)], gU/L= 175.7800 dispersed'
'UNH crystals in cans  2.79329 g/cm3. wrapped dry content can hx=3.53'
'UNHc in cv   3668.49250 g.'
'water in cv  8500.22749 g.'
arbmunh    2.79329  5 0 0 0   92235   47.0962
                              92238    0.0000
                               1001    2.4232
                               7014    5.6116
                               8016   44.8690    1  0.12856 293  end
arbmh2oc   0.99820  2 0 0 0    1001   11.1913
                               8016   88.8087    1  0.83360 293  end
'np277-4: spacer'
'min.den.= 1.6819 = (105 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
arbm2774s  1.6819  11 0 0 0    1001    4.6190
                               5000    4.2330
                               6012    1.5060
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                                     8016   59.9960
                                    11023    0.1300
                                    12000    0.3860
                                    13027   21.1600
                                    14000    1.3200
                                    16000    0.1500
                                    20000    6.1800
                                    26000    0.3200    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 4 wt% boron'
'See np277-4 spacer. Regarding H2O loss, H2 (4.6190wt%) removes O (36.6541wt%)'
'Residual O bound to other constituents is (23.3419wt%). Wt%'s are normalized by'
'sumTi/100.0 = 0.587269, where sumTi are wt%s for 10 remaining consistituents.'
'density is normalized by 100.0/sumTi.  0.9877 =(density)(sumTi/100.0)'
'density = 1.6800 = (den.mult)(min.den.) = 0.99889*1.6819 where'
'den.mult = 1.32561e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'actual vol.= 1.32561e4 cm3 = (28316.84 cm3/ft3)(49.15423 lb)/(105 lb/ft3)'
'min.den.= 1.6819 = (105 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 7.1195e-2 1 0 0 0    5000  100.0000   11  0.7500  293  end
arbmnp277  0.9165   9 0 0 0    6012    2.7636
                                8016   42.8337
                               11023    0.2386
                               12000    0.7083
                               13027   38.8302
                               14000    2.4223
                               16000    0.2753
                               20000   11.3408
                               26000    0.5872   11  1.0000  293  end
arbmnph2o  0.6942   2 0 0 0    1001   11.1913
                                8016   88.8087   11  0.9000  293  end
'kaolite 1600 body'
'array densities are s.u.dens. multiplied by a volume ratio 1.34888/1.10336'
'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 vol.=1.34888e5 cm3'
'hac.s.u.dens= (hac.mult)(nct.den)'
' for arbmh2ok = 1.20172*0.52294,    for rest = 1.20172*0.34864'
'hac.mult= 1.34888e5 cm3 (nct vol.)/ 9.84895e4 cm3 (model vol.)'
arbmh2ok   0.62843  2 0 0 0    1001   11.1913
                                8016   88.8087   12  0.0287  293  end
arbmal2o3  0.41897  2 0 0 0   13027   52.9390
                                8016   47.0610   12  0.096   293  end
arbmsio2   0.41897  2 0 0 0   14000   46.7570
                                8016   53.2430   12  0.367   293  end
arbmfe2o3  0.41897  2 0 0 0   26000   69.9540
                                8016   30.0460   12  0.067   293  end
arbmtio2   0.41897  2 0 0 0   22000   59.9535
                                8016   40.0465   12  0.012   293  end
arbmcao    0.41897  2 0 0 0   20000   71.4815
                                8016   28.5185   12  0.307   293  end
arbmmgo    0.41897  2 0 0 0   12000   60.3169
                                8016   39.6831   12  0.131   293  end
arbmna2o   0.41897  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'
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```
'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'
'UNHc in cv well   2331.50750 g.'
'water in cv well  5402.31286 g.'
arbmunh     2.79329  5 0 0 0    92235    47.0962
                                92238     0.0000
                                 1001     2.4232
                                 7014     5.6116
                                 8016    44.8690    15  0.13362 293  end
arbmh2oc    0.99820  2 0 0 0     1001    11.1913
                                 8016    88.8087    15  0.86638 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  1.0e-20 293  end
end comp
ibiaunhc 1.0innp,disp. 6000.0gUNHc( 2825.8g235, 8500.2gH2O,hx=140.41),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.]'
'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    20 1 4p21.838092   11.59510   0.0     com='drum(chine)outer radius'
unit 1003
'bottom of cv 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 below 1st step'
 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.]'
'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    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.]'
'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    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.]'
'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    20 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    20 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    20 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    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.]'
'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    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.]'
'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    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.]'
'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    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 2        2r-21.838092     0.0
'cuboid    0  1 4p21.838092    110.4900  0.0     com='bare package'
'cuboid   21  1 4p52.318092   140.9700 -30.48    com='reflected package'
 cuboid   20  1 4p21.838092    110.4900  0.0     com='interstital array space'
'global
'unit 1021
'array 3   3r0.0
'reflector  21 2  6r3.0  10
end geometry
read array
ara=2 nux=1 nuy=1 nuz=13                                  fill
1001 1002 1003 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019          end fill
'ara=3 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

=csas25    parm=size=3000000
nbf15slg,1.0in np,32684.3gU(32684.3g235, 8076.8gH2O hx=  6.45),fr=1.0e-04
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.30'
uranium  1 den=18.81109 1.0 293      92235  100.00
                                     92238    0.000                end
'np277-4: spacer'
'min.den.= 1.6819 = (105 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
arbm2774s  1.6819  11 0 0 0    1001     4.6190
                               5000     4.2330
                               6012     1.5060
                               8016    59.9960
                              11023     0.1300
                              12000     0.3860
                              13027    21.1600
                              14000     1.3200
                              16000     0.1500
                              20000     6.1800
                              26000     0.3200   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 4 wt% boron'
'See np277-4 spacer. Regarding H2O loss, H2 (4.6190wt%) removes O (36.6541wt%)'
'Residual O bound to other constituents is (23.3419wt%). Wt%'s are normalized by'
'sumTi/100.0 = 0.587269, where sumTi are wt%s for 10 remaining consistituents.'
'density is normalized by 100.0/sumTi.  0.9877 =(density)(sumTi/100.0)'
'density = 1.6800 = (den.mult)(min.den.) = 0.99889*1.6819 where'
'den.mult = 1.32561e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'actual vol.= 1.32561e4 cm3 = (28316.84 cm3/ft3)(49.15423 lb)/(105 lb/ft3)'
'min.den.= 1.6819 = (105 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 7.1195e-2 1 0 0 0    5000   100.0000  11  0.7500  293  end
arbmnp277  0.9165   9 0 0 0    6012     2.7636
                               8016    42.8337
                              11023     0.2386
                              12000     0.7083
                              13027    38.8302
                              14000     2.4223
                              16000     0.2753
                              20000    11.3408
                              26000     0.5872  11  1.0000  293  end
arbmnph2o  0.6942   2 0 0 0    1001    11.1913
                               8016    88.8087  11  1.0000  293  end
'kaolite 1600 body'
'array densities are s.u.dens. multiplied by a volume ratio 1.34888/1.10336'
'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
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                                          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
nbf15slg,1.0in np,32684.3gU(32684.3g235, 8076.8gH2O,hx=  6.45),fr=1.0e-04
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= 0.111 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
'bottom of cv to top of 1st cc [Elev= 8.926 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'
' 1.90500 half of side of pentagon'
' 3.24098 radius of circumscribed circle'
' 2.62200 radius of inscribed circle'
' 3.08236 x axis location of 2nd cyl in cc'
' 1.00153 y axis location of 2nd cyl in cc'
 cylinder  3  1    6.426200   10.79500   0.63500 com='cv well cavity'
 hole  1020    0.0        3.24098  0.63500       com='cy1 (0,ccrpent)'
 hole  1020    3.08236    1.00153  0.63500       com='cy2 (xtwo,ytwo)'
 hole  1020    1.90500   -2.62200  0.63500       com='cy3 (hspent,-icrpent)'
 hole  1020   -1.90500   -2.62200  0.63500       com='cy4 (-hspent,-icrpent)'
 hole  1020   -3.08236    1.00153  0.63500       com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200   10.79500   0.0     com='cv at top of 1st cc'
 cylinder  15 1    7.924800   10.79500   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   10.79500   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   10.79500   0.0     com='np277_4'
 cylinder  16 1   11.074400   10.79500   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   10.79500   0.0     com='kaolite'
 cylinder  19 1   21.722275   10.79500   0.0     com='drum'
 cuboid    20 1 4p22.866096   10.79500   0.0     com='drum chine outer radius'
unit 1004
'cv at np277-4 can spacer [Elev=10.046 in.]'
 cylinder  2  1    4.921250    2.69290   0.15240 com='np277-4 thickness'
 cylinder  3  1    6.426200    2.84530   0.0     com='cv well cavity'
 cylinder  8  1    6.680200    2.84530   0.0     com='cv top of np can spacer'
 cylinder  15 1    7.924800    2.84530   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200    2.84530   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000    2.84530   0.0     com='np277_4'
 cylinder  16 1   11.074400    2.84530   0.0     com='kaolite liner'
 cylinder  12 1   21.555075    2.84530   0.0     com='kaolite'
 cylinder  19 1   21.722275    2.84530   0.0     com='drum'
 cuboid    20 1 4p22.866096    2.84530   0.0     com='drum chine outer radius'
unit 1005
'bottom to top of 2nd cc [Elev=14.046 in.]'
 cylinder  3  1    6.426200   10.16000   0.0     com='cv well cavity'
 hole  1021    0.0        3.24098  0.00000       com='cy1 (0,ccrpent)'
 hole  1021    3.08236    1.00153  0.00000       com='cy2 (xtwo,ytwo)'
 hole  1021    1.90500   -2.62200  0.00000       com='cy3 (hspent,-icrpent)'
 hole  1021   -1.90500   -2.62200  0.00000       com='cy4 (-hspent,-icrpent)'
 hole  1021   -3.08236    1.00153  0.00000       com='cy5 (-xtwo,ytwo)'
 cylinder  8  1    6.680200   10.16000   0.0     com='cv st top of 2nd cc'
 cylinder  15 1    7.924800   10.16000   0.0     com='void btw cv-np liner'
 cylinder  16 1    8.077200   10.16000   0.0     com='np277_4 liner'
 cylinder  11 1   10.922000   10.16000   0.0     com='np277_4'
 cylinder  16 1   11.074400   10.16000   0.0     com='kaolite liner'
 cylinder  12 1   21.555075   10.16000   0.0     com='kaolite'
 cylinder  19 1   21.722275   10.16000   0.0     com='drum'
 cuboid    20 1 4p22.866096   10.16000   0.0     com='drum chine outer radius'
unit 1006
'cv at np277-4 can spacer [Elev=15.166 in.]'
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```
 cylinder  2  1      4.921250     2.69290    0.15240 com='np277-4 thickness'
 cylinder  3  1      6.426200     2.84530    0.0     com='cv well cavity'
 cylinder  8  1      6.680200     2.84530    0.0     com='cv top of np can spacer'
 cylinder  15 1      7.924800     2.84530    0.0     com='void btw cv-np liner'
 cylinder  16 1      8.077200     2.84530    0.0     com='np277_4 liner'
 cylinder  11 1     10.922000     2.84530    0.0     com='np277_4'
 cylinder  16 1     11.074400     2.84530    0.0     com='kaolite liner'
 cylinder  12 1     21.555075     2.84530    0.0     com='kaolite'
 cylinder  19 1     21.722275     2.84530    0.0     com='drum'
 cuboid    20 1 4p22.866096     2.84530    0.0     com='drum chine outer radius'
unit 1007
'bottom of 3rd cc to bottom of 1st step [Elev=14.046 in.]'
 cylinder  3  1      6.426200    51.07840    0.0     com='cv well cavity'
 hole  1022      0.0         3.24098   0.00000       com='cy1 (0,ccrpent)'
 hole  1022      3.08236     1.00153   0.00000       com='cy2 (xtwo,ytwo)'
 hole  1022      1.90500    -2.62200   0.00000       com='cy3 (hspent,-icrpent)'
 hole  1022     -1.90500    -2.62200   0.00000       com='cy4 (-hspent,-icrpent)'
 hole  1022     -3.08236     1.00153   0.00000       com='cy5 (-xtwo,ytwo)'
 cylinder  8  1      6.680200    51.07840    0.0     com='cv below 1st step'
 cylinder  15 1      7.924800    51.07840    0.0     com='void btw cv-np liner'
 cylinder  16 1      8.077200    51.07840    0.0     com='np277_4 liner'
 cylinder  11 1     10.922000    51.07840    0.0     com='np277_4'
 cylinder  16 1     11.074400    51.07840    0.0     com='kaolite liner'
 cylinder  12 1     21.555075    51.07840    0.0     com='kaolite'
 cylinder  19 1     21.722275    51.07840    0.0     com='drum'
 cuboid    20 1 4p22.866096    51.07840    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, 3.81000cm diameter by 10.16000cm height'
 cylinder  1  1    1.904500  10.1600   0.0      com='cyl'
unit 1021
'HEU cylinder content, 3.81000cm diameter by 10.16000cm height'
 cylinder  1  1    1.904500  10.1600   0.0      com='cyl'
unit 1022
'HEU cylinder content, 3.81000cm diameter by 10.16000cm height'
 cylinder  1  1    1.904500  10.1600   0.0      com='cyl'
'global
unit 1023
'es3100 drum [Elev=43.512 in.]'
array 2       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 3   3r0.0
reflector  21 2  6r3.0  10
end geometry
```

```
read array
ara=2 nux=1 nuy=1 nuz=17 fill
1001 1002 1003 1004 1005 1006 1007 1010
1011 1012 1013 1014 1015 1016 1017 1018 1019        end fill
ara=3 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


=csas25    parm=size=3000000
nbf2bm hocv,1.0in thk np,17570.7gU(17570.7g235, 8878.8gH2O hx= 13.19),fr=1.0e-04
238groupndf5 infhommedium
'HEU wrapped dry content can hx=0.57'
uranium  1 den=18.81109 0.09503 293      92235  100.00
                                        92238   0.000                end
arbmh2oi    0.90334  2 0 0 0   1001    11.1913
                               8016    88.8087    1  1.0000  293   end
'np277-4: spacer'
'min.den.= 1.6819 = (105 lb/ft3)(453.59 g/lb)/(28316.84 cm3/ft3)'
arbm2774s  1.6819  11 0 0 0    1001     4.6190
                               5000     4.2330
                               6012     1.5060
                               8016    59.9960
                              11023     0.1300
                              12000     0.3860
                              13027    21.1600
                              14000     1.3200
                              16000     0.1500
                              20000     6.1800
                              26000     0.3200    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 4 wt% boron'
'See np277-4 spacer. Regarding H2O loss, H2 (4.6190wt%) removes O (36.6541wt%)'
'Residual O bound to other constituents is (23.3419wt%). Wt%'s are normalized by'
'sumTi/100.0 = 0.587269, where sumTi are wt%s for 10 remaining consistituents.'
'density is normalized by 100.0/sumTi.  0.9877 =(density)(sumTi/100.0)'
'density = 1.6800 = (den.mult)(min.den.) = 0.99889*1.6819 where'
'den.mult = 1.32561e4 cm3 (actual vol.) / 1.32708e4 cm3 (model vol.)'
'actual vol.= 1.32561e4 cm3 = (28316.84 cm3/ft3)(49.15423 lb)/(105 lb/ft3)'
'min.den.= 1.6819 = (105 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 7.1195e-2 1 0 0 0    5000   100.0000   11  0.7500  293   end
arbmnp277  0.9165   9 0 0 0    6012     2.7636
                               8016    42.8337
                              11023     0.2386
                              12000     0.7083
                              13027    38.8302
                              14000     2.4223
                              16000     0.2753
                              20000    11.3408
                              26000     0.5872   11  1.0000  293   end
arbmnph2o  0.6942   2 0 0 0    1001    11.1913
                               8016    88.8087   11  1.0000  293   end
'kaolite 1600 body'
'array densities are s.u.dens. multiplied by a volume ratio 1.34888/1.10336'
'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
nbf2bm hocv,1.0in thk np,17570.7gU(17570.7g235, 8878.8gH2O,hx= 13.19),fr=1.0e-04
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= 0.111 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
'bottom of cv to bottom of 1st step [Elev=35.276 in.]'
' 0.63550   bottom location of variable height stack'
'32.34336             height collapsed cc plus spacer      CALCULATED
 array 2  -4.54386  -4.54386   0.63550           com='array of content'
 cuboid    1  1  4p4.54386    32.97936   0.63550 com='array of content'
 cylinder  1  1    6.426200   77.72400   0.63500 com='cv well cavity'
 cylinder  8  1    6.680200   77.72400   0.0     com='cv below 1st step'
 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 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'
'    19                   number of HEU cubes per can'
'  5856.91155             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'
'     3    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=3   fill 19r1004  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
'   750.52419             lattice volume in cc                   CALCULATED
'   439.16998             moderator volume in lattice in cc      CALCULATED
'   311.35422             HEU volume in lattice in cc            CALCULATED
'     0.09503             volume fraction of HEU in CV           CALCULATED
'     0.90334             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
'array of cubical contents, --  spacerless'
```

```
' 4.54386     1.78892 half width-depth lattice          CALCULATED'
' 9.08772             height lattice                    CALCULATED'
'array 1           2r-4.54386      0.0'
 cuboid    1  1  4p4.54386      9.08772    0.0     com='homog. content-array'
unit 1007
'np277_4 spacer'
 cuboid    2  1  4p4.36118      2.54010    0.0     com='sngl-end np spacer'
 cuboid    1  1  4p4.54386      2.54010    0.0     com='void space in cv'
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=3   fill 19r1004  8r1005      end fill
ara=2 nux=1 nuy=1 nuz=5 fill 1006 1007 1006 1007 1006      end fill
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=04 fill f1020                 end fill
end array
read bias id=500 2  11  end bias
read start nst=0
end start
end data
end
```

SECTION 6 REFERENCES

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7. PACKAGE OPERATIONS

Shipping packages used to transport radioactive materials shall be operated in accordance with applicable U.S. Department of Energy (DOE) orders and 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 Y-12's quality assurance plan.

Applicable DOE orders and federal regulations containing the policies for the management of hazardous materials transportation activities includes DOE Order 461.1A The applicable NRC regulations for packaging and transportation of radioactive materials are given in Title 10, Code of Federal Regulations (CFR), Part 71 (10 CFR 71) and 10 CFR 830 Subpart A. The applicable DOT requirements for shipments and packaging of hazardous materials are given in 49 CFR.

Specific criteria for operating the ES-3100 package with highly enriched uranium (HEU) contents are presented in this section. The packaging user shall develop detailed operating procedures based on these criteria and on the NRC-issued Certificate of Compliance (CoC). These procedures shall be in accordance with DOE orders; 10 CFR 20.1101; Subparts A, G, and H of 10 CFR 71; and other NRC, DOT, federal, state, and local regulations as cited above. The package operations should be consistent with maintaining occupational radiation exposures as low as reasonably achievable (ALARA) as required by 10 CFR 20.1101(b) of 10 CFR Part 20, "Standards for Protection Against Radiation."

This section is presented in the format provided by Draft Regulatory Guide DG-7003 (Proposed Revision 2 of Regulatory Guide 7.9).

7.1 PACKAGE LOADING

The user of the packaging shall have the following:

1. authorization to acquire, package, transport, or transfer radioactive, fissile, or special nuclear material;
2. the latest NRC CoC for the ES-3100 package with HEU contents;
3. the latest copy of the Safety Analysis Report (SAR) for the ES-3100 package with HEU contents;
4. compliance with all actions and restrictions specified in both documents described in Items 2 and 3 above (written procedures);
5. registration as a user of the packaging with Y-12; and
6. Y-12's quality assurance program that meets the requirements of 10 CFR 71, Subpart H.

7.1.1 Preparation for Loading

Detailed, written operating procedures shall include, at a minimum, the process steps listed below before the contents are placed in the ES-3100 package. These steps, initiated by the operating personnel and their supervisor, ensure that:

1. all appropriate documents have been reviewed by operating personnel and are available for further review, if necessary.

2. the radioactive material contents are authorized by the CoC and the SAR, and the use of the package complies with all conditions in the CoC and the SAR.

3. the packaging has been properly maintained and is in unimpaired condition. (All required periodic maintenance shall have been performed and documented within the scheduled requirements of the CoC, the SAR, and the maintenance program.)

4. the packaging is free of surface corrosion and moisture as noted by a visual inspection.

5. A valid leak-test sticker must be present on the containment vessel to ensure that the required acceptance leak test or the annual leak test has been performed.

6. packaging interior, nonfixed surface contamination levels are not high enough to significantly contaminate the contents. Nonfixed surface contamination limit requirements are given in 10 CFR 20.1906, 10 CFR 71.87(I), and 49 CFR 173.443 for alpha, beta, and gamma-emitting radionuclides.

7. all closure fasteners are those furnished with the packaging or are certified replacements and are acceptable for use.

   Note: The threads on the containment vessel body and closure nut are to be visually inspected for damage and wear. A damaged closure nut (evidence of cross-threading or flattened threads) or excessive wear (visible rounding of the fastener threads) must be replaced with certified replacement. Contact Y-12 Packaging Engineering to report containment vessel body thread damage.

8. all required parts of the packaging and all necessary equipment are available and ready for use.

9. the silicone rubber pads (3 in number) have been inspected prior to use to verify that:

   - there is no moisture between the pad and drum inner cavity;
   - there is no pad swelling due to moisture absorption;
   - there are no gouges, cuts, tears, or nondesign voids in the pad;
   - there are no unauthorized modifications to the pad; and
   - there is no substitution of the pad with unauthorized replacements.

Package preparations should be made to reduce the potential to contaminate the packaging. Special precautions should be taken to protect the packaging from inadvertent contamination by radioactive materials during content loading.

Other package preparations should be made to minimize damage or loss of packaging and packaging components. Nuts, washers, O-rings, lids, and pads are removed from the package during loading, unloading, and refurbishment. Care should be exercised to control the packaging components when they are removed from the package to ensure that parts are kept with the packaging and not co-mingled with others. Loose parts (washers, nuts, O-rings) may be reused if it can be shown that they are the parts that were removed and that no damage to the parts has occurred. Otherwise, they shall be discarded and replaced with certified parts.

The user may replace certain certified parts during loading. Parts that may be replaced by the user are identified in Table 7.1. The certification of all replacement parts must be traceable. The user must document the replacement and forward a copy of the document to Y-12.

Table 7.1. Certified replacement parts for the ES-3100 packaging

Part	Description	Material	Specification/Drawing
Containment vessel inner O-ring	5.359-in. inner diam (ID) by 0.139-in. diam stock	Ethylene propylene	ASTM D-2000 M2E801580A013
Containment vessel outer O-ring	5.859-in. ID by 0.139-in. diam stock	Ethylene propylene	ASTM D-2000 M2E801580A013
Drum lid washer	0.844-in. ID by 1.375-in. outer diam (OD) × 0.25-in.-thick	Stainless steel	ASTM A240 or ASTM A276 M2E801580A005
Drum lid hex nut	⅝-in.-11 unified coarse thread (UNC)	Silicon bronze	ASTM F467 per ANSI B18.2.2 M2E801580A005
Plug	(Plastic plug around circumference of drum assembly and top of top plug)	Nylon 6/6	62MP0312 Micro Plastic, Inc. M2E801580A002 M2E801580A008
Modified VCO Threaded Plug	Leak-test port plug	Brass	P/N 04-2126 M2E801580A011
Containment vessel closure nut	Closure nut	Nitronic 60 SST	M2E801580A016 ASME SA-479
External Retaining Ring	Spiral retaining ring	302 SST	P/N WSM-400-502 M2E801580A014
Silicone rubber pads		Silicone rubber 22 ± 5 Shore A	M2E801580-A009-1 M2E801580-A009-2 M2E801580-A009-3

7.1.2 Loading of Contents

The operating procedures for the ES-3100 package with HEU contents shall be specific regarding handling of all package components. They shall also clearly state all safety aspects or activities such as personnel protection (radiation, chemical, physical); surface contamination or radiation surveys; nuclear criticality safety; and environment temperature.

The detailed operating procedures for inserting the content into the packaging shall include, at a minimum, the process steps listed below. The operating personnel and their supervisor shall ensure that:

1. the appropriate containment vessel is ready for packing and verify that the vessel was loaded according to these steps. Verify that the Cat 277-4 liner is intact and there is no evidence of damage or leakage of Cat 277-4 material.

2. the HEU material has been verified as being within the limits specified in this SAR and the NRC CoC for material mass, material dimension, uranium content, and ^{235}U enrichment as required in Sect. 1.2.3. The content shall be verified using accountability records and weight measurements.

3. all contents and their associated packing material are weighed and are within the allowable weights specified in Sect. 1.2.3.6.

4. the HEU material and associated packing material (convenience cans, spacers, bagging, pads, etc.) have been inserted as required by Sect. 1.2.3.

The detailed operating procedures should also describe interim activities to be followed if the package is to be temporarily stored prior to shipment.

7.1.2.1 Closure Placement, Package Assembly, and Leak Testing

The detailed operating procedures shall describe activities to prepare the packaging for final closure and shipment. They shall include, at a minimum, the process steps listed below when preparing the containment vessels for closure. Operating personnel and their supervisor shall ensure that:

1. the containment vessel O-ring grooves and sealing surfaces are visually checked for scratches that may have occurred during insertion. If scratches are found, Sect. 8.2.2 should be reviewed for criteria for evaluating surface scratches, possible repair methods for minor scratches, and rejection criteria for significant scratches.

2. the O-rings and the containment vessel sealing surfaces are free from debris and have not been damaged during loading operations. Isopropyl alcohol and lint-free cotton cloth or swabs should be used to clean the grooves and sealing surfaces. The O-rings may be wiped with lint-free gloves, cloth, or swabs. **Note that the O-rings shall be lubricated with a thin coat of Super O-Lube.**

3. the containment vessel sealing lid is positioned over the containment vessel body with the notches aligned.

4. the containment vessel sealing lid is lowered into position.

5. the containment vessel sealing lid is secured to the containment vessel body by the containment vessel closure nut.

6. the closure nut is tightened to 162.7 ± 6.78 N·m (120 ± 5 ft-lb) of torque as specified in Drawing M2E801580A011 (Appendix 1.4.1). No impact wrench shall be used.

7. the assembled and loaded containment vessel is prepared for leak testing.

8. the annulus between the O-rings shall be leak tested to an acceptable leak rate of 1×10^{-4} atm-cm³/s (or lower) in accordance with the requirements in American National Standards Institute (ANSI) N14.5-1997, Sect. 7.6, "Preshipment leakage rate test."

9. the vacuum coupling is removed.

10. the modified VCO threaded brass plug is tightened into the leak-test port opening.

The procedure in Appendix 7.5.1 (Y-12 Plant Procedure Y51-01-B2-R-074, *DT-Type Shipping Container Leak Test*) is an example of a leak-test procedure that can be used with the ES-3100 package. Use of this procedure is not mandatory; however, the user must ensure that his or her procedure meets the requirements of ANSI N14.5-1997.

The leak-test equipment used for this test should be calibrated with a known leak. The leak tests are to be performed indoors in a temperature-controlled environment where the temperature is nominally 21 °C (70 °F). As such, there are no active controls on the temperature of the leak-test equipment or the leak (known and unknown), nor are the temperatures recorded.

The following measures should be taken if the containment vessel assembly leak test fails to reach the required vacuum pressure:

1. review the operating procedures,

2. check the leak-test equipment,

3. check the vacuum couplings and connections,

4. check the test gauges, and

5. check all equipment certifications.

The containment vessel lid assembly shall be removed if the above measures do not uncover the root cause. Care shall be taken to control the lid assembly parts on removal. The O-rings shall be visually inspected for roughness, porosity, scratches, and foreign matter. The sealing surfaces on both the containment vessel sealing lid and body shall be visually examined for surface scratches. Review Sect. 8.2.2 for criteria for evaluating O-rings and sealing surfaces.

The O-rings shall be replaced with certified O-rings if none of the measures described above properly identify a possible cause of the failure to pass the leak test. After examining the new O-rings, the closure steps cited above shall be repeated. The assembly must be retested to a leak rate of 1×10^{-4} atm-cm³/s of air. If the leak test fails again, then the contents shall be removed using the unloading procedures (beginning with step 13, Sect. 7.2.2). The containment vessel, along with both sets of O-rings, shall be tagged as "potential" nonconforming parts and returned for closer examination and disposition.

Following a successful leak test, the containment vessel with its content is ready to be loaded into the drum assembly for closure and sealing.

7.1.2.2 Closing and Sealing

The containment vessel shall be inserted into the drum body cavity prior to drum closing. A radiation check of the contents may be conducted prior to loading to measure the content dose rate. The measured dose rate should be compared with known values for such a test. This is not a requirement and should generally only be performed if there are ALARA concerns. After loading is complete, radiation measurements shall be taken to determine the package dose rate, which establishes the transport index (TI).

The detailed operating procedures shall include, at a minimum, the process steps listed below when preparing the drum assembly for closing and sealing. The operating personnel and their supervisor shall ensure that:

1. the containment vessel assembly with content is ready for loading into the drum assembly.
2. the drum assembly (with top plug removed) is ready to receive the containment vessel assembly and that the containment vessel assembly, silicone rubber pads, drum lid, drum-lid nuts and washers, and tamper-indicating devices (TIDs) are available.
3. the approved lifting equipment is available and in place. For lifting equipment restrictions, see Sect. 7.1.3.1.
4. the containment vessel bottom pad is placed in the drum assembly cavity.
5. the containment vessel is lifted by the swivel hoist ring and placed into the drum assembly cavity in a manner that minimizes damage to the packaging and Cat 277-4 liner. The swivel hoist ring is removed.
6. the CV flange pad is placed on top of the containment vessel and the plug pad is placed on the inner liner shelf.
7. the top plug is placed into position over the containment vessel using eye bolts attached to the threaded holes provided on the top plug.
8. the eye bolts are removed from the top plug.
9. the drum lid is placed in position.
10. the drum washers and bronze drum nuts are installed.
11. the nuts are tightened to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) of torque with no sequence specified. No impact wrench shall be used.
12. the TIDs are attached through both TID lugs.
13. the gross package weight does not exceed 190.5 kg (420 lb).

14. surveys for nonfixed surface contamination and radiation dose rate measurements are conducted. The nonfixed surface contamination survey shall be conducted in accordance with the user's facility procedures. The survey shall use criteria that are derived from the surface radioactivity guidance of 10 CFR 20.1906, 10 CFR 71.87(i), 49 CFR 173.443, or the user's site-specific criteria, whichever is the most stringent.

15. nonfixed surface contamination is removed as applicable.

16. all "empty" or inappropriate labels or tags are removed from the exterior surface of the package.

17. the package is labeled with the appropriate material description, nuclides, activity/mass, and TI in accordance with 49 CFR 172.403.

18. the package is marked with the minimum marking "Radioactive Material, Type B(U), Fissile, UN3328" in accordance with 49 CFR 172.310.

19. the package radiation dose rate at the surface is measured. The package radiation dose rate at 1 m from the surface shall be measured to establish the TI for the package and to ensure that content does not exceed the expected or allowable dose rates (see Sect. 5). The analysis presented in the containment evaluation (Sect. 4) has determined that this is a Type B, fissile material package.

7.1.3 Preparation for Transport

7.1.3.1 Package Transfer or Handling

The transfer of a package on-site to storage or to a staging area prior to off-site shipment shall be accomplished in accordance with the user's approved on-site transport safety manual. Criticality Safety Index (CSI) values for the ES-3100 package with various payloads can be found in Table 6.2.

The ES-3100 is handled using industry-standard drum-handling equipment. Operating procedures shall include requirements to limit clamping pressures on forklift drum-handling equipment to prevent damage to the ES-3100 drum body (see Sect. 1.2.1.1 for limits on forklift gripping forces).

The detailed operating procedures shall include, at a minimum, the process steps listed below for preparing the package for transfer or handling. Operating personnel and their supervisor shall ensure that:

1. the package nonfixed surface contamination is below the minimum off-site and on-site transportation requirements,

2. all appropriate package labels are affixed to the package's exterior surface,

3. all lifting and handling equipment is available and certified for use, and

4. all transfer equipment is available and certified for use.

The user shall identify placement restrictions associated with the handling, transfer, or shipping of radioactive materials as they relate to persons and animals for off-site and on-site operations. The minimum acceptable distance between a package and a human or animal is a function of the TI in accordance with 49 CFR 177.842 for carriage on public highways. When shipping off-site, such restrictions shall be identified to the carrier.

7.1.3.2 Decontamination

The reference to nonfixed surface contamination is repeated throughout the various operating procedure steps. It is essential that radiation exposure to the worker and the workplace be minimized. As the package is being prepared to enter the public domain, it is very important that the nonfixed surface contamination level of the package and the transport medium [Safe-Secure Trailer/Safeguards Transporter (SST/SGT) or other approved conveyance] be maintained at ALARA levels.

The package may be placed onto areas that are covered by disposable covering, such as plastic or paper, to reduce the nonfixed surface contamination of physical structures.

The package must be shipped in an enclosed conveyance. Generally, the exterior surfaces of the package will remain relatively clean. However, each user shall prepare written procedures to clean dirty packages. These procedures shall, at a minimum, consider the following:

1. The drum is austenitic stainless steel.
2. The drum nut is silicon bronze.
3. The drum vent holes are covered with plastic push-in plugs.
4. The labels and markings on the drum must remain legible.
5. The cleaning solution must be checked for contamination.

7.1.3.3 Requirements Prior to Shipment

The shipper shall ensure that the quality control requirements of 49 CFR 173.475 and the routine determination requirements of 10 CFR 71.87 have been satisfied prior to each shipment. Detailed operating procedures [10 CFR 71.87(f)], initiated by the operators and their supervisor, shall provide evidence that these requirements are met and ensure that:

1. the package is proper for the content shipped and verified with the appropriate records by the user prior to content loading [10 CFR 71.87(a)];
2. the package is in unimpaired physical condition [10 CFR 71.87(b)];
3. the closure devices of the package are properly installed, secured, and free of defects [10 CFR 71.87(c)];
4. the containment vessel has been loaded properly and preparation for shipment has been followed, witnessed, and checked;
5. the internal pressure of the containment system does not exceed the design pressure during transportation [10 CFR 71.85(b)] as demonstrated by analysis (Appendix 2.10.1) and that there are no pressure-relief devices [10 CFR 71.87(e)] in the package;
6. the external radiation levels for all transport conditions are within the allowable limits as demonstrated by analysis (Sect. 5) and as measured for Normal Conditions of Transport (NCT) [10 CFR 71.87(j)];

7. the nonfixed external contamination levels are within the allowable limits as demonstrated by surface wipes prior to content insertion, containment vessel loading, package closure, on-site transfers, and off-site shipment [10 CFR 71.87(i)];

8. the contents are adequately sealed and have adequate space for expansion [10 CFR 71.87(d)];

9. all records for shipment are prepared and maintained; and

10. all lifting attachment features are either inoperative during transport [10 CFR 71.87(h)] or meet the requirements of 10 CFR 71.45(a).

7.1.3.4 Testing

Leak tests shall be conducted following the content loading and the containment vessel closure. The annulus between the O-rings shall be leak tested to an acceptable leak rate of 1×10^{-4} atm-cm^3/s of air (or equivalent) or lower in accordance with ANSI N14.5-1997, Subclause 7.6.

All operations involving the use of the packaging shall emphasize safety and radiological control for the operator. Package loading and unloading shall be preceded and followed by surface radiation surveys to control radioactive contamination.

The radiation (gamma, neutron) emanating from the radionuclide in the package shall be measured before the package is released for transport [10 CFR 71.47 and 71.87(j)]. The package radiation dose rate at the surface is measured to ensure that the content does not exceed the expected or allowable dose rates. The package radiation dose rate at 1 m from the surface is measured to establish the TI for the package.

7.1.3.5 Surveying

Radiation surveys shall be conducted before the package is released for final shipment preparation to control radioactive contamination and to protect the worker (10 CFR 71.47). The package exterior surface contamination level limits are found in 10 CFR 71.87(i) and 49 CFR 173.443. The regulations present both fixed and nonfixed surface contamination level limits for the various radionuclides for DOE facilities. The test methodology is also given in these references. In addition to these limits, the user may have more stringent surface contamination levels that shall also be followed.

A final visual survey of the package and loading paperwork shall be conducted to ensure that the package was assembled correctly and that it is ready for final shipment preparation. This survey may include a thorough review of the loading checklists by someone other than those who filled out the list to verify the loading operations. The area immediately surrounding the assembly operations should be surveyed, and all spare or extra parts should be identified. A final package survey may include weighing the package, hand-testing the closure nuts on the drum lid, and flexing the TIDs. The loading checklist should include a place for this final quality check to be properly recorded—including a signature and date—as being successfully completed.

7.1.3.6 Marking

The user shall ensure detailed marking procedures are consistent with 10 CFR 71.85 and the applicable subsections of 49 CFR 172, Subpart D. Each shipper shall ensure that each package containing radioactive material is marked in the manner required.

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. Data plate M2E801580A010-1 provides the owner's return address, container model, container serial number, and the trefoil symbol. Data plate M2E801580A010-2 provides the required DOT marking—certificate number, maximum gross weight, and "Type B" designation.

The packaging components (drum assembly, containment vessel body, lid, and closure nut) are also marked with their serial numbers. The numbers are used to control these parts and to accumulate their respective histories.

7.1.3.7 Labeling

The user shall prepare detailed labeling procedures that are consistent with the applicable subsections of 49 CFR 172, Subpart E. The procedures should include the following steps, to ensure that:

1. the proper label is affixed to the package and the TI is determined at the time of loading;

2. the correct label (White—I, Yellow—II, or Yellow-III) is determined using the table from 49 CFR 172.403(c);

3. the appropriate label is affixed to two places on opposite sides of the drum;

4. the content name, nuclides and activity/mass (49 CFR 173.435), and the TI are entered in the blank spaces on the radioactive label; and

5. the information is entered legibly using a durable, weather-resistant means of marking.

Additionally, two Fissile labels are required per 49 CFR 172.402(d)(2). These labels must be affixed two places on opposite sides of the drum adjacent to the radioactive labels. The CSI must be legibly entered on the Fissile label using a durable, weather-resistant means of marking.

The user should be advised that DOE Order 470.1 for safeguards and security of special nuclear material may require that the content and activity or weight information be omitted from the exterior surface of the package. However, such information shall be provided indirectly through the proper security channels and referenced to the particular package by the package serial numbers. The detailed operating procedures shall consider such methods.

7.1.3.8 Securing to Vehicle

The package shall be secured against movement within the vehicle in which it is being transported under conditions normally incident to transportation [49 CFR 177.834 and 177.842(d)]. The loading procedures shall include the following measures, at a minimum, to ensure that:

1. only a SST/SGT or other approved conveyance is used,

2. all reasonable precautions are taken to prevent motion of the vehicle during loading,

3. no tampering with packages occurs during transit,

4. no vehicle is loaded or unloaded unless a qualified person is in attendance at all times, and

5. no radioactive material package is loaded onto a vehicle also carrying Div. 1.1 or 1.2 explosives (49 CFR 177.848).

The following represents acceptable loading practices that shall, at a minimum, be applied:

1. Before a shipment is loaded onto a transport vehicle, the user shall visually survey the equipment to determine its general operating conditions, its capability to transport the shipment, the existence of appropriate restraint devices in good condition, and that the gross weight of the shipment does not exceed the authorized carrying capacity of the conveyance.

2. Reasonable precautions such as wheel chocking are taken to prevent motion of the conveyance during the loading operations.

3. The loading devices used to load the packages are appropriate for the dimensions and weight of the packages.

4. The shipment is positioned on the conveyance 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 heavy loads.

The following represents acceptable blocking, bracing, and tie-down practices that shall, at a minimum, be applied to ensure that:

1. packages are prevented from shifting or changing position in the conveyance during NCT (the cargo is restrained in accordance with the provisions of 49 CFR 393.100–102), and

2. packages remain stable after the restraints are removed.

All loading, blocking, bracing, and tie-down practices for loaded ES-3100 packages in a SST/SGT must be in accordance with requirements in the current release of the technical manual *Tiedown Procedures for Type-B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)*.

7.2 PACKAGE UNLOADING

7.2.1 Receipt of Package from Carrier

Prior to shipment, the user shall verify that the receiver can accept the special nuclear material. The user (shipper) shall ensure that appropriate documentation is submitted to the receiver to ensure that the physical characteristics and hazards of the material are conveyed to the receiver.

The user shipping the package 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. These instructions shall include special actions in the event that TIDs are not intact, or if surface contamination or radiation surveys are too high.

The receiver shall accept the radioactive material by surveying the conveyance and package surface for contamination and external radiation levels. The receiver's procedures shall clearly indicate that the contamination and radiation surveys and inspections be conducted upon receipt of the package. The receiver shall, at a minimum, include the following in their procedures (in compliance with 10 CFR 71.111):

1. receive the package when offered by the carrier for delivery and,

2. monitor external surfaces of the conveyance and package for radioactive contamination and radiation levels.

Surface contamination and radiation-level monitoring shall be accomplished within 3 hours of receipt. If the package is received after normal work hours, then the monitoring must be done no later than 3 hours from the beginning of the next work day.

All users shall include provisions in their operating procedures for reporting safety concerns associated with the packaging or its use. The user shall notify DOE in accordance with DOE Order 231.1A and 10 CFR 20.2202. Although 10 CFR 20.2202 provides a graduated reporting period based on the severity of the incident, DOE Order 231.1A delineates specific reporting periods in accordance with the category of the occurrence. Incidents requiring notification include:

1. removable radioactive surface contamination in excess of the limits provided by 10 CFR 71.87, and

2. external radiation levels in excess of the limits provided by 10 CFR 71.47.

At a minimum, the user shall maintain the records outlined below of the radiation protection program and of dosimetry records for all monitored individuals.

1. ALARA plans and programs and their implementation;

2. individual occupational dose records;

3. monitoring and area control records;

4. monitoring methods records;

5. training records of plant employees, radiation workers, and radiation safety personnel; and

6. records of exposure (provided to all workers).

The receiver shall compare the cargo with the list provided by the shipper. If a discrepancy appears between the cargo and the list, the receiver shall notify DOE in accordance with DOE Order 231.1A.

7.2.1.1 Inspections and Surveys

A radiological survey of the conveyance and the package shall be conducted to determine if nonfixed contamination has been picked up during shipping. The receiver shall include the following instructions, at a minimum, in written procedures for surface contamination and radiological inspections and surveys to ensure that:

1. surveys are made,

2. instruments and equipment are calibrated periodically for the radiation measured,

3. persons performing surveys use personal dosimeters that are routinely processed and evaluated, and

4. persons performing surveys are properly trained and their records are kept.

The receiver's written procedures shall also include general inspections of the conveyance and package. The following inspections that provide an indication of the condition of the package from shipping shall be included, at a minimum, to ensure that:

1. the conveyance is examined for entrapped moisture (water or moisture);

2. such moisture is identified, surveyed for contamination, and removed;

3. the general appearance and condition of the conveyance and the package are noted;

4. labeling and placarding of the package and conveyance are checked for compliance;

5. TIDs on the conveyance and the package are examined for signs of tampering; and

6. the package tie-downs were properly used and have no visible signs of wear.

The receiver shall notify DOE in accordance with DOE Order 231.1A if moisture, surface contamination, noncompliant items, visible damage, or wear is found.

7.2.1.2 Removal from Vehicle

The package shall be removed from the conveyance prior to unloading the content. Unloading procedures shall, at a minimum, ensure that:

1. the package nonfixed surface contamination is below the minimum on-site or off-site requirements,

2. all appropriate package labels are affixed to the package exterior surface,

3. all lifting and handling equipment is available and certified for use,

4. all transfer equipment is available and certified for use,

5. the package is visually examined to ascertain surface damage that may have occurred during shipping or handling, and

6. the TIDs are examined to ensure that the package has not been tampered with during shipment.

If the package surface was damaged during handling or shipping, a nonconformance tag shall be completed and attached to the package for subsequent refurbishment (10 CFR 71.131). If the TIDs are found to be compromised, DOE shall be notified in accordance with DOE Order 231.1A.

7.2.2 Removal of Contents

Transfer of the package from an on-site storage or staging area or from the conveyance prior to unloading shall be in accordance with the user's approved on-site transport safety manual.

When a package is prepared for transfer or handling, the detailed unloading procedures shall include, at a minimum, the process steps listed below. The appropriate steps, initiated by the operating personnel and their supervisor, shall ensure that:

1. the package nonfixed surface contamination is below the minimum on-site and appropriate off-site transportation requirements;

2. all appropriate package labels are affixed to the package;

3. certified equipment (such as visual inspection gauges, scales, and radiation detection gauges) is used (no impact wrenches shall be used);

4. segregated work stations, curtains, lead blankets, or other such equipment is used to protect workers or nearby personnel from hazards associated with radioactive materials; and

5. appropriate material-handling equipment (forklifts, hoists, drum handlers, etc.) is available.

Detailed operating procedures shall describe activities required for content removal. These procedures shall identify any safety and health measures required to protect workers and the environment. The procedures shall include, at a minimum, the process steps listed below. The appropriate steps, initiated by the operating personnel and their supervisor, shall ensure that:

1. All appropriate labels for the material shipped are affixed to the exterior surface of the drum body.

2. Surveys for nonfixed surface contamination and radiation dose rate measurements are conducted.

3. As applicable, nonfixed surface contamination is removed before the contents are removed.

4. The TIDs remain intact until removal. (Notify Safeguards and Security if they have been tampered with.)

5. The weld stud nuts and washers are removed and controlled.

6. The drum lid is removed.

7. Visible portions of the interior of the drum body and top plug are still in good condition—no visible signs of damage, water damage, or tears.

8. The top plug is removed using eye bolts that can be attached to the threaded holes provided on the top plug.

9. The silicone rubber CV flange pad and plug pad are removed from above the containment vessel.

10. The containment vessel top is in good condition—no visible signs of damage or loose closure nut.

11. A surface contamination check is conducted to discover any leak of radioactive material.

12. The containment vessel is removed from the drum assembly. The containment vessel is placed onto the work area. (This step may not be required.)

13. The external retaining ring, containment vessel closure nut, and containment vessel sealing lid are removed and controlled. (No pressure buildup is expected under NCT.) Hand force may be required to disengage the sealing lid because of the slight vacuum.

14. The O-rings and the O-ring grooves on the containment vessel flange are protected from damage during unloading.

15. The HEU content (convenience cans) and associated packing materials (can spacers, stainless-steel scrubbers, or silicone can pads) are removed from the containment vessel using the cable lanyard in accordance with site-specific HEU material-handling procedures.

16. The items removed and the inside of the containment vessel are checked for nonfixed surface contamination.

7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

The user shall develop detailed procedures to prepare an empty package for storage or transport. These procedures shall, at a minimum, ensure that:

1. The package has been emptied of all radioactive contents.

2. The radiation level at any point on the external surface of the package does not exceed 0.5 mrem/h.

3. The nonfixed radioactive surface contamination on the external surface of the packaging does not exceed the limits specified in 49 CFR 173.443(a), and the internal contamination level does not exceed 100 times the limits in 49 CFR 173.443(a).

4. The package is not damaged, and there is no visible internal or external surface moisture or corrosion.

5. The packaging is closed. Steps 1–11 from Sect. 7.1.2.2 should be performed.

6. No leakage of radioactive material under conditions normally incident to transportation can occur.

7. Any labels previously affixed in accordance with Subpart E of 49 CFR 172 are removed, obliterated, or covered. Leak-test labels should not be removed from the drum body.

8. The "EMPTY" label prescribed in 49 CFR 172.450 is affixed to the drum.

9. An appropriate notice is provided giving the name of the consignor or consignee and the statement: For example, "This package conforms to the conditions and limitations specified in 49 CFR 173.428 for radioactive material, excepted package—empty packaging, UN2908."

7.4 OTHER OPERATIONS

All shipments involving the ES-3100 packages on an SST/SGT will be subject to special operational controls (e.g., route, weather restrictions, time restrictions, etc.) that are imposed by the Office of Secure Transportation.

7.5 APPENDIX

Appendix	Description
7.5.1	Y-12 PLANT PRODUCT SPECIFICATION PROCEDURE Y51-01-B2-R-074, *DT-TYPE SHIPPING CONTAINER LEAK TEST*

APPENDIX 7.5.1

Y-12 PLANT PRODUCT SPECIFICATION PROCEDURE Y51-01-B2-R-074, *DT-TYPE SHIPPING CONTAINER LEAK TEST*

PRODUCT SPECIFICATION PROCEDURE

Lockheed Martin Energy Systems, Inc.	Oak Ridge Y-12 Plant	Number:	Y51-01-B2-R-074
		Revision:	A.0
		Supersedes:	New
		Page:	1 of 10

USE CATEGORY II

Subject: DT-Type Shipping Container Leak Test

Effective Date: 6-13-97

Approvals:

Dennis Nabors / Dennis Nabors / 6/10/97
Operations Manager Signature — Print Name — Date

Stephen T. Holder / Stephen T. Holder / 6/10/97
Defense Programs (Nuclear Packaging Systems) — Print Name — Date

G. W. Eckert / G. W. Eckert / 6/10/97
Quality Systems (Quality Engineering) — Print Name — Date

PRT
CC Review

CONCURRENCE BY THE FOLLOWING ORGANIZATIONS IS DOCUMENTED IN THE PROCEDURE HISTORY FILE:

Radiological Control (RADCON)
Safety and Health Organization

This procedure has been reviewed by an Authorized Derivative Classifier and has been determined to be UNCLASSIFIED. This review does not constitute clearance for public release.

Wendell Jones 6/10/97
Name and Date

MODIFICATION LOG

Revision	Effective Date	Modification Description	Affected Page(s)
A.0	6-13-97	**PMR-96-0228** New Y51 Series procedure.	All

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Purpose

To provide instructions for operating the DT-type shipping container leak test station. The leak test station consists of a mechanical vacuum pump, pressure gauges, chart recorder, flow orifice, and the connecting valve manifold.

1.2 Scope

[1] Applies to leak test of the O-ring seal found in the DT-Type leak testable inner containers. The equipment is capable of determining a leak rate of 1.0×10^{-4} cc/sec.

[2] The system correlates the pressure drop across an orifice as compared to the pressure drop across the orifice when a calibrated leak is installed. When the pressure readings have stabilized at predetermined calculated values, the leak rate of the container being tested should be less than 1×10^{-4} cc/sec.

[3] Program: WC

1.3 General Information

[1] Use of standard tools and equipment as needed is acceptable without being listed in the tooling/equipment list.

[2] It is acceptable to turn off the chart recorder during long pumping periods to minimize the use of chart paper.

2. PRECAUTIONS AND LIMITATIONS

2.1 Safety and Health Organization

In case of liquid nitrogen spill, ensure personnel in area back away from the spill and allow the liquid nitrogen to evaporate. DO NOT attempt to clean up a liquid nitrogen spill.

3. ACCEPTANCE CRITERIA

The container has passed the leak test when:

[a] P1 is less than 5 mtorr.
[b] P2 is less than 330 mtorr.
[c] P2 pressure trace has stabilized or is declining.

4. PREREQUISITE ACTIONS

4.1 Special Tools, Test Equipment, Parts, and Supplies

Supervisor

Ensure the following equipment is available to perform this procedure:

- Container Leak Test Adapter
- Container Leak Test Plug
- Leak Test Manifold (Appendix A)
- Liquid Nitrogen

4.2 Field Preparations

Assemblyperson

[1] Ensure power on to leak test manifold.

[2] IF system is started from power off condition,
THEN ensure MKS Baratron transducer is allowed at least four (4) hours warm up time.

[3] Ensure the chart recorder has:

- At least 50 cm of chart paper
- Channel pens have ink
- Channel pens are in contact with the paper.

[4] Ensure that all equipment, fixtures, and accessories are:

- Operable
- Current on required inspection and/or maintenance
- Determined to be in good condition

[5] Ensure certification stickers are attached and NOT expired on the following:

- Pressure gauges
- Chart recorder

4.3 Approvals and Notifications

Supervisor

Obtain permission from the Shift Manager to start the Performance Section of this procedure.

5. PERFORMANCE

5.1 System Set Up

Assembly person

[1] Ensure the following valves are OPEN:

- Valve 1
- Valve 2

[2] Ensure Valve 3 is CLOSED:

[3] Set the chart recorder switches to the following positions:

CH A	DWN
CH B	DWN
CHART SPEED	1
SPEED	CM/MIN
RANGE CH A	1 VOLT
x 5 MULTIPLIER CH A	DEPRESSED
RANGE CH B	1 VOLT
x 5 MULTIPLIER CH B	PULLED OUT
POWER	ON
CHART	STOP

[4] Zero the chart recorder as follows:

[a] Latch IN the ZERO/RECORD CH A and ZERO/RECORD CH B switches.

[b] Align the pens with the zero line on the chart paper.

[c] Release the ZERO/RECORD CH A and ZERO/RECORD CH B switches.

[5] Ensure that the Granville- Phillips gauge (P1) reads less than 5 mtorr.

[6] Ensure that the MKS Baratron gauge (P2) reads less than 5 mtorr.

5.2 Leak Testing

Assembly person

[1] Ensure the leak test plug has been removed from the test port on the container to be tested.

[2] Connect the flexible hose from the Leak Test Station to the container test port.

[3] Place the chart recorder CHART switch to START.

[4] Open Valve 3 to begin evacuating the test volume.

[5] ONCE P1 pressure is less than 20 mtorr,
THEN wait approximately five minutes
AND close Valve 2.

Warning

Failure to wear apron, facesheild, and insulated gloves when handling liquid nitrogen may result in personnel injury.

[6] Ensure the cold trap vacuum flask is filled with liquid nitrogen.

NOTE 1 *P2 pressure is considered stabilized when the chart recorder P2 pressure trace shows a flat line for four centimeters.*

NOTE 2 *When all the following conditions are true, the container has passed the leak test.*

[7] Monitor P1, P2, and the chart recorder paper for the following conditions:

[a] P1 is less than 5 mtorr.

[b] P2 is less than 330 mtorr.

[c] P2 pressure trace has stabilized or is declining.

[8] IF ALL three of the conditions in Step 5.2 [7] are NOT met,
THEN

[a] Contact Supervisor.

[b] Refer to Appendix B "Troubleshooting Instructions" for possible causes.

5.2 Leak Testing (cont.)

[9] AFTER All three of the conditions in Step 5.2 [7] are met, THEN

[a] Close Valve 3.

[b] Open Valve 2.

[c] Place the chart recorder CHART switch to STOP.

[d] Disconnect flexible hose from shipping container.

6. POST-PERFORMANCE ACTIVITIES

6.1 Extended Shutdown

Assembly person
Turn off all power to leak test manifold.

7. RECORDS

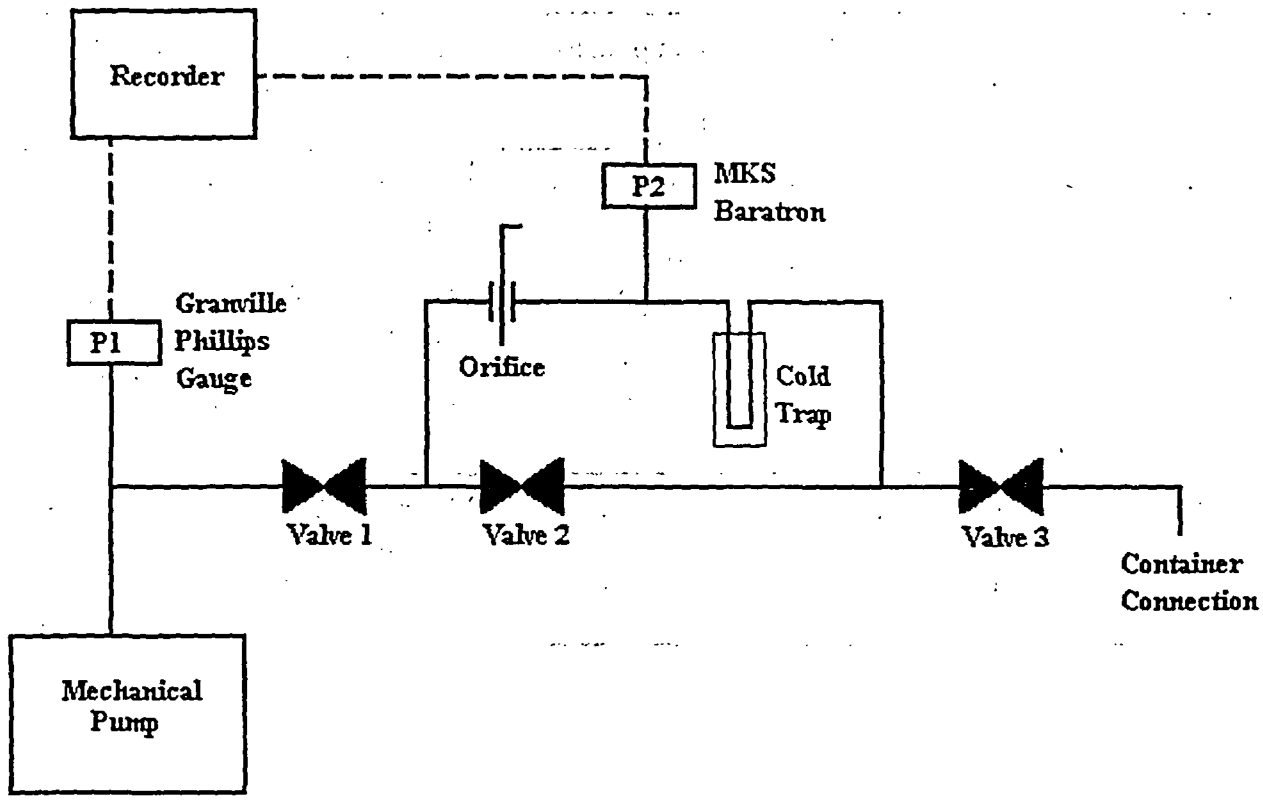
None

8. SOURCE REQUIREMENTS

None

Appendix A

Leak Test Manifold



Appendix B

Troubleshooting Instructions

CONDITION	POSSIBLE CAUSE(S)	CORRECTIVE ACTIONS
P1 pressure still greater than 5 mtorr, after 15 minutes of pumping	Mechanical Pump faulty Valve 2 faulty	Repair faulty equipment and restart test from Section 5.2.
P2 pressure still greater than 330 mtorr, after 20 minutes of pumping	Container leaking Fittings leaking	Restart test from Section 5.1 without venting container. Disconnect flexible hose from container, plug flexible hose and evacuate. Repair hose if found to be leaking. Restart test from Section 5.2.
P2 pressure is not stable, or is increasing, after 20 minutes of pumping		Monitor P2 pressure until stable or declining, or until P2 pressure reaches 330 mtorr.

SECTION 7 REFERENCES

10 CFR 71, *Packaging and Transportation of Radioactive Material*, Jan. 1, 2005.

10 CFR 830, Subpart A, *Nuclear Safety Management*, 2003.

49 CFR Pts. 100–180 and 393, *Transportation*, Oct. 1, 2004.

ANSI N14.5-1997, *Radioactive Materials—Leakage Tests on Packages for Shipment*, American Natl. Standards Institute, Feb. 5, 1998.

DG 7003 (Proposed Revision 2 of Regulatory Guide 7.9), *Standard Format and Content of Part 71 Applications for Approval of Packaging for Radioactive Material*, U.S. NRC, December 2003.

DOE Order 231.1A, Administrative Change 1, *Environment, Safety, and Health Reporting*, June 3, 2004.

DOE Order 461.1A, *Packaging and Transfer or Transportation of Materials of National Security Interest*, April 26, 2004.

DOE Order 470.1, Change 1, *Safeguards and Security Programs*, June 1996.

Tie-down Procedures for Type-B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT), DOE-Sandia Natl. Labs., Albuquerque, N.M., current revision. OFFICIAL USE ONLY.

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Shipping packages used to transport radioactive materials shall be fabricated, procured, and maintained in accordance with applicable U.S. Department of Energy (DOE) orders and 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. Furthermore, the packages shall be fabricated, procured, and maintained according to Y-12's quality assurance (QA) plan.

DOE Order 461.1A contains the policies and directives for the management of hazardous materials transportation activities associated with radioactive materials. The NRC regulations for packaging and transporting radioactive materials are given in Title 10 of the Code of Federal Regulations (CFR) (10 CFR 71). The DOT requirements for shipping and packaging hazardous materials are given in Title 49 CFR.

Minimum requirements for fabricating, procuring, and maintaining the packaging are presented in this section. The owner and user shall develop detailed procedures based on criteria contained herein and on the Certificate of Compliance (CoC). These procedures shall be in accordance with DOE orders, Subparts G and H of 10 CFR 71, and other NRC, DOT, federal, state, and local regulations as cited.

Fabrication specifications for ES-3100 components are listed on fabrication drawings (Appendix 1.4.1) and equipment specifications (Appendices 1.4.2 – 1.4.5). The containment vessel is designed and built to meet American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code*, Sect. III, Division I, Subsection NB (ASME B&PVC, Sect. III, Div. 1).

This section is presented in the format provided by Draft Regulatory Guide DG-7003 (Proposed Revision 2 of Regulatory Guide 7.9 (DG-7003).

8.1 ACCEPTANCE TESTS

The owner shall determine that the packaging has been fabricated in accordance with the approved design [10 CFR 71.85(c)]. The owner may use the inspection guidance provided by the NRC in NUREG/CR-5717 for conducting QA inspections of packaging suppliers. An exploded view of the packaging design is presented in Fig. 1.2. The package drawings are in Appendix 1.4.1. The packaging includes:

1. a reinforced 30-gal stainless-steel drum, inner liner, lid, weld studs, Kaolite 1600; Cat 277-4; drum flat cover plate; nylon vent hole plugs; top plug (consisting of sheet steel and Kaolite 1600); hex nuts; washers; paint; and

2. a containment vessel body, sealing lid, closure nut, and retaining ring; O-rings; swivel hoist ring; modified VCO threaded brass plug.

Quality certification and procurement instructions (QCPIs) are used by the BWXT Y-12 (Y-12), Quality Division to establish the minimum requirements for records and reports for the packaging. These requirements are derived from the packaging drawings. Although these procurement documents may be unique to Y-12, the requirements included shall be considered as minimum requirements, and their information shall be present in the owner's fabrication records. QCPIs for the ES-3100 are available upon request.

The containment vessel procurement specification is presented in Appendix 1.4.3. This specification indicates the records and reports required to properly document the quality of the containment vessel fabricated by a vendor in accordance with the QA requirements.

If any acceptance inspection or test identifies a nonconforming condition for a packaging, the packaging is segregated and tagged, and the appropriate manager evaluates and approves final disposition of the item. Any one of the following actions may be taken:

1. Return the item to the vendor or shop; reject the item outright.

2. Return the item to the vendor or shop; repair the item to a usable condition, record the repair, and prepare a deviation report.

3. Return the item to the vendor or shop; rework the item to specification and record the rework.

4. Accept the item as is; prepare a deviation report.

The minimum acceptance inspection and test requirements for the packaging components (Tables 8.1 and 8.2) are presented in the following sections. Prior to first use of the package, these requirements must be met.

8.1.1 Visual Inspections and Measurements

Visual inspections with the unaided eye of all pertinent features on the package shall be performed during fabrication. These inspections include paint color; surface condition; marking content; gauging (toleranced dimensions, positioning, edge breaks, surface finish); and welding. The required inspections, as described in Tables 8.1 and 8.2, are provided in the QCPIs, which are available upon request.

8.1.1.1 Paint color

Paint color, which is not a safety item, is used to identify, segregate, and document packages and packaging. The acceptance criteria for paint color are given in the respective federal specifications referenced by the drawings (Appendix 1.4.1). Incorrect or incomplete application of paint is cause for rejection. An application of incorrect letters or misspelled words is also cause for rejection. The item may be reworked to meet the specification.

8.1.1.2 Surface condition

The surfaces of the drum assembly and containment vessel 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 containment vessel surfaces must be in accordance with the dimensional requirements on the drawings. Penetrations will be cause for the component to be reworked, including dye-penetrant and radiographic testing.

The ES-3100 components shall be stored in indoor facilities. However, before acceptance of any ES-3100 component, all surfaces shall be inspected for corrosion. The presence of surface corrosion (rust) on any component will be cause for further inspection. If the rust can be easily wiped off and no pitting is apparent beneath it, the component is acceptable. If the rust cannot be easily wiped off, or if scaling is present or pitting is observed, then the surface will be repaired and the component must undergo a

Table 8.1. Acceptance tests for the drum assembly

Packaging[a]	Visual inspection	Structural and pressure tests	Leak tests
Drum, 30-gal modified, including lid, drum flat cover	Material certification, gauging,[b] marking, liquid penetrant, weld repair, corrosion, dents	Tensile, percent elongation, impact, yield point, chemistry	Pressure test (10 psig for 5 min)
Weld stud, ARC FT 5/8-11UNC × 7/8 LG, 304/304L stainless steel	Part certifications, gauging	Tensile, percent elongation, impact, yield point, chemistry	NA[c]
Inner liner weldment and top plug, 304/304L stainless-steel	Material certifications, gauging	Tensile, percent elongation, yield point, chemistry	NA
304/304L stainless-steel 0.25-in. internal flange	Material certifications, gauging	Tensile, percent elongation, yield point, chemistry	NA
Nut, ⅝-in.-11UNC silicon bronze	Material certifications, damage	NA	NA
Tamper-indicating device	Material certification, damage	NA	NA
Data plates, 4.00 × 7.50 × 0.0625 in. and 4.75 × 9.00 × 0.0625 in.	Material certification, gauging, marking	NA	NA
Paint: black enamel	Material certification, color comparison	NA	NA
Cat 277-4	Material certification, sample pour	NA	NA
Kaolite 1600 castable refractory-cured thermal insulation	Material certification, sample pour	NA	NA
Flat washer, 0.812-in. ID × 1.375-in. OD × 0.250-in.-thick stainless steel	Material certification, damage	NA	NA
Lid TID lug, modified 304L stainless steel chain 3/16-in trade size, .20 diam	Material certification, damage	NA	NA
Plug, plastic push-in, Micro Plastic Inc., 62MP0312	Material certification	NA	NA
Silicone Rubber Pads 22 ± 5 Shore A Parts M2E801580A009-1 Parts M2E801580A009-2 Parts M2E801580A009-3	Material certification, damage, marking	NA	NA

[a] Appendix 1.4.1.
[b] Gauging refers to dimensional inspections for height, width, thickness, diameter, position, and surface finish.
[c] NA—Not applicable.

Table 8.2. Acceptance tests for the containment vessel assembly

Packaging[a]	Visual inspections	Structural and pressure tests	Leak tests
Body assembly, lid assembly (as applicable)	Material certification, gauging,[b] marking, radiography, liquid penetrant, weld repair, qualification tests, corrosion, scratches	Hydrotest	Helium leak test
O-ring (inner), 5.359-in. ID, 0.139-in. diameter stock	Material certification, gauging, packaging, marking	Shore A durometer, elongation	NA[c]
O-ring (outer), 5.859-in. ID, 0.139-in. diameter stock	Material certification, gauging, packaging, marking	Shore A durometer, elongation	NA
Closure nut Nitronic 60 SST, ASME SA-479	Part certifications, gauging,	Tensile, percent elongation, impact, yield, chemistry	NA
External Retaining Ring	Material certification, damage	NA	NA
Swivel hoist ring	Material certification, gauging	Load test	NA
Modified VCO threaded brass plug for leak-test port	Material certification, damage	NA	NA
4.25-in. can pad, M2E801580A024, silicone rubber A50-83B, hardness 75 ± 5 Shore A	Material certification, damage	NA	NA
Heavy can spacer assembly	Material certification, damage	NA	NA

[a] Appendix 1.4.1.
[b] Gauging refers to dimensional inspections for height, width, thickness, diameter, position, and surface finish.
[c] NA—Not applicable.

dimensional inspection and dye-penetrant and/or radiographic testing to determine the extent of the damage. In the case of the containment vessel, a hydrostatic test shall be performed. All acceptance criteria for a newly fabricated component (Appendices 1.4.1, 1.4.2, and 1.4.3) shall apply to the repaired component. If the rust has compromised the structural integrity of the component [i.e., the component no longer meets dimensional criteria for a new part as specified on the drawings], then the component shall be rejected.

8.1.1.3 Marking package components

Markings on the package components identify the hazardous content and provide traceability to the fabrication and past use of the package. All markings (serial numbers, model numbers, instructions, identification) shall be compared with the drawings' requirements for correct content. The acceptance criteria (paint color and dimensions) for markings are given in the drawings in Appendix 1.4.1. Incorrect or incomplete marking is cause for rejection. The item may be reworked to meet the specification.

8.1.1.4 Gauging

The drawings list the dimensions/tolerances (height, width, thickness, diameter); positions (bolt holes, grooves, leak-test port); edge break; and surface finishes (smoothness, passivation, coating, bonding, plating, cleanliness). Inspection of gauging features shall be performed to ensure that each component meets dimensional tolerances, which are provided on the drawings. Gauging outside the tolerance is cause for rejection. The item may be reworked to meet the specification, or the specification may be deviated from and accepted.

8.1.2 Weld Examinations

All welded or weld-repair surfaces shall be visually inspected for indications of inclusions, cracks, or porosity. *ASME Boiler and Pressure Vessel Code,* Sect. II, Part C, and Sect. IX is the applicable requirement for welds (ASME B&PVC, Sect. II and Sect. IX). Any indication of inclusions, cracks, or porosity in the weld is cause for rejection. The item may be reworked to meet the specification, or the specification may be deviated from and accepted.

8.1.3 Structural and Pressure Tests

Structural tests for the drum and containment vessel include load, mechanical properties, and chemical tests to ensure that the correct materials are used. The containment vessel is hydrotested (pressure tested) to ensure that the vendor fabrication meets the requirements. These tests are discussed below. The drum body is mechanically tested (handling test) and pressure tested in accordance with the QA provisions in Military Specification, *Drum, Metal—Shipping and Storage*, MIL-D-6054F.

8.1.3.1 Mechanical Property Tests

Material mechanical property tests shall be performed to determine the ultimate tensile strength, yield strength, percent elongation, percent reduction in area, and hardness of the containment vessel materials. Their acceptance criteria at operating temperature are provided in the appropriate material national standard referenced by the drawings (Appendix 1.4.1). 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 material national standard referenced by the drawings (Appendix 1.4.1). 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 containment vessel shall be pressure tested following the load test per *ASME Boiler and Pressure Vessel Code,* Sect. III, Div. 1. The vessel shall be subjected to an internal water pressure of 150% of design pressure (Sect. 2.1.2). Visible indication of a leak on the exterior surface of the containment vessel is cause for rejection. All containment vessels will undergo such testing.

8.1.4 Leakage Tests

The fabrication vacuum leak test of the containment boundary shall be performed after the pressure test in accordance with ANSI N14.5-1997, Sect. 7.3, "Fabrication Leakage Rate Test" with a test flange assembly (Drawing M2E801580A021) installed. (Note: Periodic and maintenance leak tests are discussed in Sect. 8.2.2.) The fabrication vacuum leak test demonstrates that the containment vessel is fabricated properly and that the containment boundary is "leaktight." An integrated leak rate exceeding 1.9×10^{-7} atm-cm^3/s of helium (or equivalent) is cause for rejection. Per ANSI N14.5-1997, the test procedure should have a sensitivity of one-half the reference air leakage rate (L_R).

The procedure in Appendix 8.3.1 (Y-12 Plant Product Specification Procedure Y51-01-B2-R-140, *Leak Testing Using LT-285 and LT-283*) is an example of a leak-test procedure that can be used with the ES-3100 package for the fabrication leak test. Use of this procedure is not mandatory; however, the user must ensure that his or her procedure meets the requirements of ANSI N14.5-1997.

Following the successful completion of the leak test, the original test date and signature shall be entered on two copies of the label shown in Fig. 8.1, and these labels shall be attached to the exterior surface of the containment vessel and to the drum. Section 8.2.2 addresses the acceptance vacuum leak test during refurbishment. All containment vessels shall undergo such testing.

All containment vessel leakage rate tests will be performed using certified equipment. All containment vessels will be tested when they are initially received from the manufacturer, or Y-12 personnel will witness final testing at the vendor.

Y-12 PLANT ASSEMBLY
DIVISION
LEAK TEST APPROVED

DO NOT REMOVE

___/___/___
EXPIRATION DATE

____
NAME

Fig. 8.1. Label for use on the exterior surface of the containment vessel and the drum.

8.1.5 Component and Material Tests

8.1.5.1 O-Ring Tests

The O-ring visual and mechanical tests are described below. Additionally, the fabrication leak test required in Sect. 8.1.4, the periodic and maintenance leak tests required in Sect. 8.2.2, and the preshipment leak test required in Sect. 7.1.2.1 test the functionality of the O-rings within the package.

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, and compound number. 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.

Mechanical properties

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

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

2. elongation of 100%, minimum.

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

8.1.6 Shielding Tests

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

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

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

8.1.7 Thermal Tests

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

8.1.8 Miscellaneous Tests

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

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

8.2 MAINTENANCE PROGRAM

When the package is being loaded or unloaded, it shall be examined to ensure that all parts are present and functional. A record shall be generated of this examination activity with the affected part numbers, personnel doing the work, and the date of the activity being recorded. This examination activity and the activities associated with the periodic and maintenance leak tests are considered refurbishment activities. The refurbishment requirements are given below.

8.2.1 Structural and Pressure Tests

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

8.2.2 Leakage Tests

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

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

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

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

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

8.2.3 Component and Material Tests

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

8.2.4 Thermal Tests

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

8.2.5 Miscellaneous Tests

8.2.5.1 Visual Inspection for Corrosion

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

8.2.5.2 Visual Inspection of Containment Vessel

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

8.2.5.3 Subsystem Maintenance

Defects in the drum (tears, broken welds, or dents >1-in. deep) are cause for rejection. Failure of the drum seam weld or bottom end-to-body weld shall be recorded as a failure and compared to others. If a statistically significant quantity of drum-weld failures from a single lot exist, then all drums from that lot shall be examined for weld failures. Those with failures shall be repaired; those without failures shall be released for use.

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

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

8.2.5.4 Fastener Inspection

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

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

8.2.5.5 Valves, Rupture Disks, and Gaskets on Containment Vessel

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

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

There are no valves or rupture disks in the packaging.

8.2.5.6 Miscellaneous

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

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

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

8.3 APPENDIX

Appendix	Description
8.3.1	SAMPLE LEAK TEST PROCEDURE
	Y-12 PLANT PRODUCT SPECIFICATION PROCEDURE Y51-01-B2-R-140, *LEAK TESTING USING LT-285 AND LT-283*

APPENDIX 8.3.1

Y-12 PLANT PRODUCT SPECIFICATION PROCEDURE Y51-01-B2-R-140, *LEAK TESTING USING LT-285 AND LT-283*

PRODUCT SPECIFICATION PROCEDURE

BWXT Y-12, L.L.C.
Management Requirements

Number:	Y51-01-B2-R-140
Revision:	A.2
Supersedes:	A.1
Page:	1 of 13

USE CATEGORY II

Subject: *Leak Testing Using LT-285 and LT-283*

Verified to be the latest revision ______________
Initials

Effective Date: 6/27/03

Approvals:

Dennis Nabors	Dennis Nabors	6/5/03
9204-2/2E Operations Manager / Signature	Print Name	Date
Stephen T. Holder	Stephen T. Holder	6/10/03
Product Engineering (Nuclear Packaging Programs)	Print Name	Date
M W Shreeve	M. W. Shreeve	6/12/03
Product Quality Assurance (Quality Engineering)	Print Name	Date

6/16/03
CC Review

CONCURRENCE BY THE FOLLOWING ORGANIZATIONS IS DOCUMENTED IN THE PROCEDURE HISTORY FILE:

Industrial Safety
Radiological Control

Distribution by:
Product Engineering Transmittal
#047546 Rev 1
06/16/2003

This procedure has been reviewed by an Authorized Derivative Classifier and an UNCI Reviewing Official and has been determined to be UNCLASSIFIED and contain no UNCI. This review does not constitute clearance for public release.

5/28/03
Name and Date

MODIFICATION LOG

Revision	Effective Date	Modification Description	Affected Page(s)
A.0	02/07/02	PMR-2002-001, New Y51 Series procedure.	All
A.1	04/12/02	PMR-B2E-2002-037, Non-intent Immediate Modification to delete a redundant step.	11
A.2	04/23/03	PMR -B2E-2003-007, Immediate Modification to include LT-283.	4, 6, 9, 10, 12, 13

TABLE OF CONTENTS

1. INTRODUCTION

1.1. Purpose

To provide instructions for operating the LT-285 and LT-283 Leak Test Stations. The LT-285 and LT-283 Leak Test Stations consists of Veeco MS-50 leak detectors, mechanical vacuum pumps, pressure gauges, and the connecting valve manifold.

1.2 Scope

[1] 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. Although intended primarily to perform leak testing on the DT-Type inner container, this equipment may to used to leak test any component which can be mechanically fitted to the test port hookups.

[2] 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.

[3] Program: WC

1.3 General Information

[1] 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.

[2] 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 four roughing pump valves, four manifold valves, and two vacuum gauges, during Section 5.2 "Leak Testing," NO valve number 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.

1.3 General Information (cont.)

[3] Use of standard tools and equipment as needed is acceptable without being listed in the tooling/equipment list.

[4] For Drum Type containers, this test is performed using an appropriate test ring as specified.

[5] Leak test may be repeated as directed by supervisor.

[6] Leaks may be repaired as directed by the supervisor and the test repeated.

2. PRECAUTIONS AND LIMITATIONS

2.1 Industrial Safety

[1] Safety shoes shall be worn while performing material activities detailed in this procedure.

[2] General purpose gloves will be worn, as needed.

2.2 Radiological Control

RADCON SHALL perform any surveys requested or surveys that are deemed necessary by RADCON.

3. ACCEPTANCE CRITERIA

None

4. PREREQUISITE ACTIONS

4.1 Performance Documents

None

4.2 Special Tools, Test Equipment, Parts, and Supplies

Supervisor

Ensure the following equipment is available to perform this procedure:

- LT-285 OR LT-283 Leak Test Station
- Helium supply bottle with regulator and tubing

4.3 Field Preparations

Assemblyperson

[1] Ensure that 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:
- Vacuum gauges
- Internal Standard Leak
- Internal Thermistor
- Leak Test Station

[4] Ensure printer is on, and "On Line" is displayed, and Leak Test results forms are in the paper tray.

4.4 Approvals and Notifications

Supervisor

Obtain permission from the Shift Manager to start the Performance Section of this procedure.

5. PERFORMANCE

NOTE *A Veeco operational check is required before each day's run.*

5.1 Veeco Operational Check

Assemblyperson

[1] Ensure the following Vacuum Manifold (VM) and Vacuum Pump (VP) valves are CLOSED:

- VM-A
- VM-B
- VM-C
- VM-D
- VP-A
- VP-B
- VP-C
- VP-D

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].

[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.

[6] Find the green FIL ON/OFF soft-key under MASS SPEC.

[7] IF the FIL "ON/OFF" LED is off,
THEN press the FIL ON/OFF key,
AND wait 15 seconds.

5.1 Veeco Operational Check (cont.)

[8] Perform calibration check.

[a] Find the green CAL CHECK key under the SYSTEM.

[b] Press the CAL CHECK key.

[c] When the Cathode Ray Tube (CRT) reads "Leak Rate Should Read," THEN compare the TEST PORT reading to the value of the LEAK RATE reading.

[9] 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.

[10] IF reading is within ± 15% of the leak rate reading,
THEN press 1 CALIBRATE.

[11] IF reading is now within ± 10% of the LEAK RATE reading,
THEN press 3 END CAL CHECK,
AND GO TO Section 5.2.

[12] IF reading is greater than ± 15% of the leak rate reading,
THEN press 2 FINE TUNE,
AND repeat Step [8], [9], and [10], once.

[13] IF the CAL Check is not within ± 10% of the internal leak rate standard;
THEN notify Supervisor.

5.2 Leak Testing

Assemblyperson

[1] Ensure the following valves are CLOSED:

- VM-A
- VM-B
- VM-C
- VM-D
- VP-A
- VP-B
- VP-C
- VP-D

[2] Connect part(s) to be leak tested to station hookup(s).

[3] Open all VP valve(s) associated with the parts under test to evacuate parts.

NOTE *The bottom of the plastic bag must be below the bottom of the part (or section of part) being tested.*

[4] Ensure the part (or section of part) to be leak tested is fully enclosed with a plastic bag.

NOTE *A vacuum source may be used to aid in collapsing the bag and removing air pockets.*

[5] Collapse the plastic bag around the part,
AND secure with tape or by placing weights on the bag touching the floor as appropriate, ensuring that the part is fully encapsulated.

[6] Seal the opening in the side of the plastic bag with tape where the vacuum hose is inserted.

5.2 Leak Testing (cont.)

NOTE *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.*

[7] Insert the helium fill tube,
AND secure to the plastic bag with tape.

NOTE *To ensure a helium atmosphere, a slight purge of helium may be necessary during testing.*

[8] WHEN Granville Phillips (GP) vacuum gauge associated with the part under test reads 15 mTorr or less,
THEN close VP valve associated with the part under test.

[9] Verify the CRT shows "READY TO TEST" and the appropriate REJECT POINT is displayed.

[10] IF the appropriate REJECT POINT is not displayed,
THEN perform the following steps:
[a] From READY TO TEST screen Press 5 SETTINGS/HELP.

[b] From HELP/SETTINGS menu press 3 SELECT UP
OR 4 SELECT DOWN 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.

[11] Open VM valve associated with the part under test.

NOTE *Pressing START a second time after testing begins will halt testing.*

[12] Press START button to begin leak test,

5.2 Leak Testing (cont.)

[13] (Deleted)

[14] IF leak rate is less than REJECT set point,
THEN "ACCEPT" is displayed,
AND end test by,
[a] Closing VM valve.

[b] Pressing VENT key.

[15] IF "LEAK TESTING ACCEPT" is not displayed after 5 minutes,
THEN end test by,
[a] Closing VM valve.

[b] Pressing VENT key.

[16] Print leak test results by pressing the following keys on the connected printer:
[a] On line.

[b] Form feed.

[c] On line.

[17] Write part number and expirations date on the leak test results,
AND attach to the part card.

[18] IF another part has been attached, and the part has been roughed down for testing,
THEN GO TO Steps 5.2 [4] through 5.2 [16].

[19] Ensure the following valves are CLOSED:
- VP-A
- VP-B
- VP-C
- VP-D
- VM-A
- VM-B
- VM-C
- VM-D

[20] Disconnect part(s) from leak test station hookup(s).

5.2 **Leak Testing (cont.)**

[21] IF additional part(s) are to be leak tested,
THEN repeat Section 5.2, "Leak Testing."

6. POST-PERFORMANCE ACTIVITIES

None

7. RECORDS

Print outs

8. SOURCE REQUIREMENTS

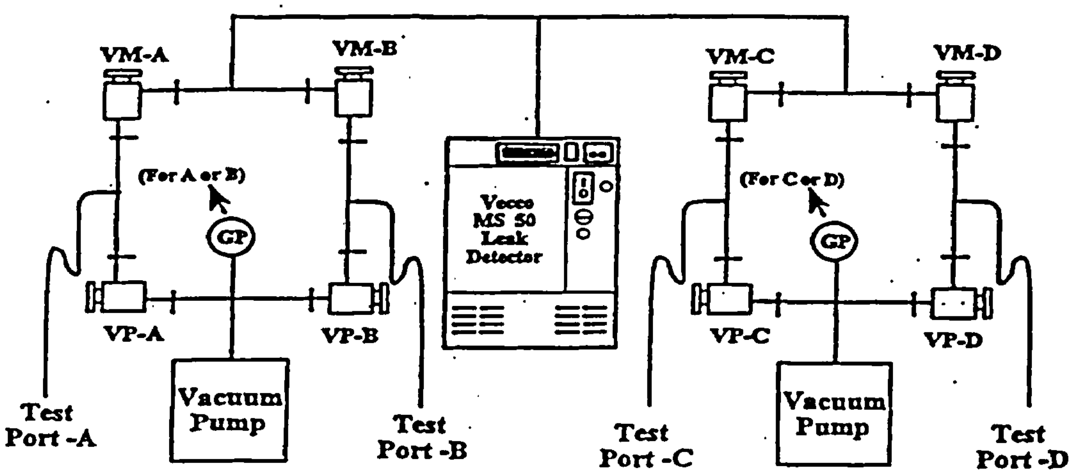
"VIC Leak Detection, MS-50 Automatic Leak Detector, Operation and Maintenance Manual," Vacuum Instrument Corporation, Vacuum Metrology Division, New York.

9. APPENDIX

LT-285 and LT-283 Leak Test Stations

Appendix

LT-285 and LT-283 Leak Test Stations



SECTION 8 REFERENCES

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