71-9315

Department of Energy
Washington, DC 20585

JUN 27 2007

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

In a letter dated May 9, 2007, the Department of Energy received a request for additional information (RAI) concerning the application for air transport of the ES-3100 shipping package. These RAIs were discussed during a public meeting with the Nuclear Regulatory Commission on May 10, 2007. In a letter dated May 30, 2007, DOE submitted responses to these RAIs. This letter and enclosure is response #2 to RAI on Certificate of Compliance No.9315, Revision 4 for Model ES-3100 Package, Docket No. 71-9315, and TAC No. L24057.

Subsequent to the RAI response submittal, two additional requests were presented and discussed during a conference call between the NRC and the ES-3100 design agency on June 26, 2007. The first request was for a copy of a reference document in Section 6 of the ES-3100 Safety Analysis Report (Y/LF-717, Rev 1). The reference document, Y/DD-896/R1, was sent to the NRC via FedEx on June 26, 2007.

The second request was for criticality safety calculations for TRIGA fuel contents for infinite arrays of undamaged packages with damaged fuel contents. These calculations are needed to demonstrate compliance with 10CFR71.55(d)(2) for Normal Conditions of Transport and 10CFR71.55(e)(1) for Hypothetical Accident Conditions. These calculations have been performed and appropriate changes to the SAR have been made. SAR pages that reflect these additional calculations are attached.

The original of this letter with an attachment is being sent to the Document Control Desk. Ten copies of this letter with attachments are being delivered to Kimberly J. Hardin, Project Manager, Licensing Branch, Division of Spent Fuel Storage and Transportation, Office of Nuclear Material Safety and Safeguards.

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NMSS

If you have any questions, please contact me at 301-903-5513.

JUN 27 200[illegible]

Sincerely,

James Shuler
Manager, Packaging Certification Program
Safety Management and Operations
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Enclosures

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GUIDE TO PAGE CHANGES
Y/LF-717, Rev. 1, page change #2 - supplement

SAR SECTION	PAGE CHANGES
Volume 2, Section 6	Replace pages 6-31/6-32, 6-47 to 6-50, 6-66c/6-66d, 6-71 to 6-80 Replace pages 6-254 to 6-257

6.2.2 Convenience Cans, Teflon and Polyethylene Bottles, and 277-4 Canned Spacers

HEU fissile material to be shipped in the ES-3100 package will be placed in stainless steel, tin-plated carbon steel, or nickel alloy convenience cans or polyethylene or Teflon bottles. Can lids may be welded, press fit, slip lid, or crimp seal types; bottle lids are screw cap type. Convenience cans and bottles are used to hold the HEU for shipment in the ES-3100 package and to assure that the inside of the containment vessel does not become contaminated with HEU under NCT. The HEU metal or oxide content may be wrapped or bagged in polyethylene, and the convenience cans may also be wrapped in polyethylene to further reduce the possibility of radioactive contamination of the packaging. Nylon straps may be use used for handling the nickel alloy cans. Masses of the convenience cans and packing materials are in addition to the fissile material mass.

Three 4.25-in.-diam × 10.0-in.-tall or six 4.25-in.-diam × 4.88-in.-tall convenience cans, separated by can pads, can be placed inside the 31-in.-tall cavity of the ES-3100 containment vessel (Fig. 1.4). The convenience cans may have press-fit or crimp-seal lids. The size of solid content placed inside a convenience can is physically limited by both the can opening and the usable height of the convenience can. Other can arrangements fit inside the containment vessel, such as three 4.25-in.-diam × 8.75-in.-tall convenience cans or five 4.25-in.-diam × 4.88-in.-tall convenience cans. Both of these can arrangements include can pads and 277-4 canned spacers. Nickel alloy cans to be used exclusively for HEU oxide content are ~3-in. diam × 4.75-in. tall. Three Teflon bottles (4.69-in. diam × 9.4-in. tall) or three polyethylene bottles (4.94-in. diam × 8.76-in. tall) fit inside the containment vessel; however, 277-4 canned spacers are not used with these configurations.

The can pad and 277-4 canned spacer have overall dimensions of 4.25-in. diam × 1.82-in. height. (Drawing M2E801580A026, Appendix 1.4.8) A stainless-steel spacer can with a lid has a usable cavity with dimensions of 4.13-in. diam × 1.37-in. height, which nominally allows for ~510 g of neutron poison material.

6.2.3 Packing Materials

Polyethylene bags may be used for contamination control. Realistically, the number of polyethylene bags used to bag content and wrap a convenience can would be six bags at most. Given that each bag weighs ~28 g, this results in a maximum of ~510 g of polyethylene per ES-3100 package. Possible additional sources of hydrogenous material inside the containment vessel include can pads, vinyl tape, and polyethylene (~85 g) or Teflon (~303 g) bottles.

For the criticality calculations, the sources of hydrogen contained in packing materials are not distinguished from other sources of hydrogen inherent in the fissile material content. Therefore, packing material mass is defined as all sources of hydrogenous packing materials inside the containment vessel plus the actual moisture in the content as constituent (the bonded hydrogen in UNX crystals or impurities in the oxide.) Given content moisture is not to exceed 6 wt %, the actual amount of hydrogenous material inside the containment vessel is not expected to exceed 2,400 g.

Normally, the H/X ratio inside the containment vessel is specified as an administrative control used to restrict both the amount of hydrogenous packing material normally used inside the containment vessel and other sources of moisture present in the fissile content. The total amount of hydrogen inside the containment vessel is used in the determination of package H/X ratio (i.e., the ratio of the number of hydrogen atoms "H" to the number of fissile atoms "X," where the hydrogen atoms are those of the content, including absorbed moisture and of the packing material both inside and outside of the convenience cans.) However, containment vessel flooding is assumed in calculations performed for the derivation of fissile material loading limits. Even though both the NCT tests under 10 CFR 71.71 and the HAC tests under 10 CFR 71.73 demonstrate that containment is not breached, this simulated condition produces more reactive package configurations in the criticality calculations than the actual package configurations. The 7.1–10.1 kg quantities of evaluation water required in both the NCT and HAC criticality calculations bound reasonable amounts of hydrogenous material and inherent moisture of fissile material (primarily HEU oxides) present inside the containment vessel. Thus, an administrative criticality control is not needed to restrict either the amount of hydrogenous material normally present inside the containment vessel or other sources of moisture present in the fissile content.

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, tin-plated carbon steel or nickel-plated carbon steel convenience cans or polyethylene or Teflon bottles. The can lids may be welded, press fit, slip lid, or crimp seal types; bottle lids are screw cap type.

(2) The content shall not exceed the "per package" fissile material mass loading limits specified in Tables 6.2a and 6.2b, and 277-4 canned spacers shall be used as indicated for criticality control.

(3) Where 277-4 canned spacers are required, not greater than one-third of the permissible package content for that category indicated in Tables 6.2a or 6.2b shall be loaded in any vacancy between or adjacent to canned spacers inside the containment vessel. The content mass loading may be further restricted based on structural, mechanical, and practical considerations (see Sects. 1 and 2).

(4) As shown in Fig. 1.4, the ES-3100 package may carry up to six loaded convenience cans. In situations where the plan for loading the containment vessel calls for the use of empty convenience cans to fill the containment vessel, the heavier cans shall be loaded into the bottom of the upright shipping container, and the empty cans shall be placed above them.

(5) 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.

(6) With the exception of slug content and unirradiated TRIGA reactor fuel element content, solid HEU metal or alloy content of specified geometric shapes shall be one item per loaded convenience can. HEU bulk metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, billet, slug, or unirradiated TRIGA fuel element contents) will be in the HEU broken metal category, and so limited.

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

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

Table 6.3. Deformation of 18.37-in.-diam ES-3100 drum projected by finite element analysis Case "3100 RUN1HL Lower Bound Kaolite May 2004"

Deformation point	FEA node	Diameter at 90° (in.)	Diameter at 180° (in.)	Equivalent circular diameter (in.)
UR	098194	20.02	15.60	17.67
MUR	100238	20.74	15.07	17.68
MR	101589	20.74	14.18	17.15
MLR	103012	22.00	13.44	17.20
LR	105786	20.92	12.92	16.44

Physical damage is significant in terms of criticality safety when the amount of volatile hydrogenous material available for interstitial moderation is reduced. Conversely, the package could be saturated with water during water immersion conditions. Both possibilities affect only the amount of interstitial moderation. The representation of the changes to material composition from temperature extremes and water intrusion is addressed in Sect. 6.3.2.

In the case of broken metal content, the ETP geometry specification using the "MLR" package model (diameter = 17.20 in.) produces a 16×3 package configuration having a correspondingly higher CSI value than a 5×5×2 package arrangement. This allows for a greater fissile payload.

6.3.1.4 Calculation models for catastrophically-damaged packages (air-transport)

It is possible for accidents to be substantially more severe in the air transport mode than in the surface transport mode. Thus, the performance requirements for packages designed to be transported by air are more stringent. Regulatory Guide 7.9 states that the criticality evaluation should evaluate a single package under the expanded accident conditions specific in 10 CFR 71.55(f).

For a fissile material package designed to be transported by air, 10 CFR 71.55(f) requires the criticality evaluation demonstrate that the package be subcritical, assuming no water inleakage and reflection by 20 cm (7.9 in.) of water, when subjected to the sequential application of the HAC free drop and crush tests of 10 CFR 71.73(c)(1 and 2) and the modified puncture and thermal tests of 10 CFR 71.55(f)(1)(iii and iv).

Physical testing of Type-B fissile material packages transported by air was not conducted for the ES-3100. In lieu of testing, criticality calculations are performed using calculation models that conform to the basic requirements of 10 CFR 71.55(f) regarding both the reflection of the package by 20 cm of water and the absence of water inleakage. In addition, the air-transport calculation models incorporate features exhibiting the worst-case assumptions made regarding the geometric arrangement of the packaging and package contents. No credit is taken for the geometric form of the package content. Spherical geometry is used to represent the ultimate configuration of the ES-3100 package which undergoes catastrophic destruction.

The criticality analysis for air transport does not credit the ES-3100 for maintaining the geometry configuration of the packaged content. Fissile material is configured spherical in shape for optimization of neutron multiplication. Also, the criticality analysis does not credit the ES-3100 packaging for structural integrity of the containment and the confinement. The reactivity "enhancing" materials of the packaging and of the accident environment may be interspersed with the fissile material content. However, selective removal of the neutron absorbing material of the package (i.e., Kaolite and stainless steel) accompanied by retention of the moderating constituents of the neutron absorbing material (i.e., bound water in the Kaolite) is not a credible condition. Moreover, a calculation model where the fissile material is homogenized with moderating material, is only an appropriate representation when the fissile material content being shipped consists of numerous solid pieces uranium ("broken metal"), oxide, or crystals. Homogenization of fissile material with moderating material is not performed with exclusive preference given to specific constituents of the moderating material.

A set of six calculation models are constructed in order to determine the worst case or most reactive configuration with consideration given to the efficiency of moderators, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes, and temperature effects. The fissile material component is dry in each case.

Model 1 (Fig. 6.11) represents the fissile material content configured into a spherical core with a 20.0-cm thick water reflector. All ES-3100 packaging material (Kaolite, stainless steel, 277-4 neutron poison, etc.) is excluded from Model 1. The fissile material content considered in the calculation model consists of a specific material form: solid HEU metal (7 – 10 kg ^{235}U); TRIGA fuel (10 kg $UZrH_x$ having 921 g ^{235}U); or broken HEU metal ($\leq$ 7 kg ^{235}U). The presence of hydrogenous packing material inside the containment vessel is also addressed in this calculation model. 513 g of polyethylene is used to represent a maximum amount of hydrogenous packing material in the ES-3100. For 7 kg ^{235}U HEU homogenized with 513 g of polyethylene, the radius of the core is 6.0547 cm. The parametric variation of both the ^{235}U mass and the enrichment in Model 1 is used to establish a reference point for the evaluation neutron reflection and absorption effects on k_{eff} provided by the stainless steel and Kaolite packaging material, addressed separately in Models 2 and 3.

Model 2 (Fig. 6.12) represents a spherical core of Model 1 blanketed by a variable-thickness shell of stainless steel, and a 20.0 cm thick water reflector external to the shell. The shell at maximum thickness corresponds to the 66,133 g stainless steel of the containment vessel and the liner and drum assembly. For 7 kg ^{235}U HEU metal, the radius of the core is 6.0547 cm while the outer radius of the stainless steel shell is 13.0264 cm.

Model 3 (Fig. 6.13) is configured the same as Model 2 with the exception that the variable-thickness shell is composed of the Kaolite instead of stainless steel. At maximum shell thickness, the 128,034 g of Kaolite corresponds to the mass of water-saturated Kaolite inside the drum body weldment and the drum top plug. The 76,819 g of saturation water corresponds to the amount of water in the Kaolite cast-slurry prior to baking. For 7 kg ^{235}U HEU metal, the radius of the core is 6.0547 cm while the outer radius of the Kaolite shell is 31.0814 cm. The parametric variation of shell thickness in Models 2 and 3 is performed for the purpose of evaluating the effect on k_{eff} of neutron reflection and absorption provided by each packaging material.

Models 1–3 are applicable for establishing loading limits for air transport packages having a single piece or several pieces of solid HEU metal where the integrity of the content can be established based on package tests or dynamic impact simulations per Type-C test criteria. Otherwise, the criticality evaluation of additional accident models is required for those situations where: (1) data is not available or is inadequate for discounting fragmentation of the fissile content in the air transport accident, or (2) the fissile material is in a physical form (crystals, oxide, or multiple pieces of solids) having the potential to blend with the other material of the package in the air transport accident.

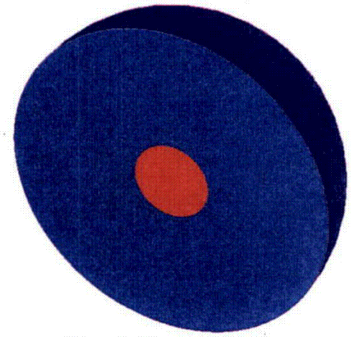

Fig. 6.11. Model 1.
7 kg ^{235}U (red) reflected by 20 cm of water (blue).

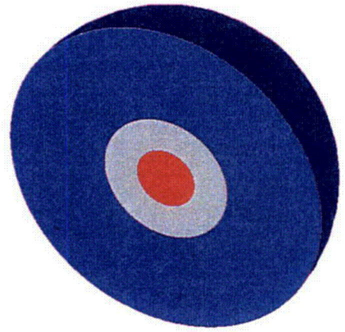

Fig. 6.12. Model 2.
7 kg ^{235}U (red) blanketed by a stainless-steel shell (gray), reflected by 20 cm of water (blue).

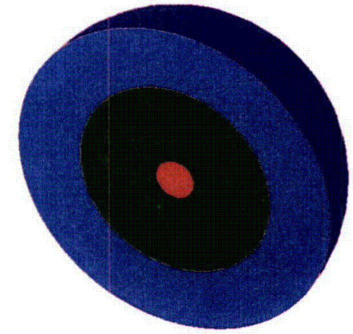

Fig. 6.13. Model 3.
7 kg ^{235}U (red) blanketed by a Kaolite shell (green), reflected by 20 cm of water (blue).

Model 4 (Fig. 6.14) depicts a spherical core of broken metal homogenized with water-saturated Kaolite and hydrogenous packing materials inside the containment vessel represented by 513 g of polyethylene. A 20-cm thick water reflector blankets the spherical core. All other ES-3100 packaging material (stainless steel, 277-4 neutron poison, etc.) is excluded from Model 4. For 25 kg of HEU (5 kg of ^{235}U), the radius of the homogenized core ranges from 31.4499 cm with dry Kaolite to 39.1608 cm with water saturated Kaolite. Model 4 also applies to TRIGA fuel content.

Model 5 (Fig. 6.15) is an extension of Model 3 applied to the case of TRIGA fuel and broken metal contents. Excess water from saturated Kaolite is homogenized with the fissile material in the core. For 25 kg of HEU where 5 kg of ^{235}U is homogenized with 513 g of polyethylene and 7,461 g of excess water from water saturated Kaolite, the radius of the spherical core is 13.0681 cm. The exterior Kaolite shell containing 69,357.9 g of water and the 51,214.9 g of vermiculite-cement constituents, has an outer radius of 31.7599 cm. At the extreme condition where the entire 74,614.0 g of excess water excess from the water saturated Kaolite is homogenized with the core, the radius of the spherical core is 26.3485 cm. The exterior shell of dry Kaolite, containing 2204.7 g of bound water and 51,214.9 g of vermiculite cement constituents, has an outer radius of 36.3668 cm. Although an unlimited amount of moderator could be imparted from the environment, the amount of moderator interspersed with pieces of fissile material does not exceed the excess moisture absorbed by the Kaolite.

Model 6 (Fig. 6.16) is configured similarly to Model 4 with the exception that only a partial amount of broken metal resides in the homogenized core. The remainder of the fissile material is modeled as a shell external to the spherical core and internal to the 20.0 cm thick water reflector. The amount of fissile material in the homogenized core is varied in 500 g increments from the full amount of Model 5 minus 500 g to a minimum amount of 500 g HEU. In the case of 25 kg of broken metal where 4.5 kg of ^{235}U is homogenized with 513 g of polyethylene and water-saturated Kaolite, the radius of the core is 39.1539 cm while the outer radius of the exterior 0.5 kg shell of ^{235}U is 39.1609 cm. In the case where 0.5 kg of ^{235}U is homogenized with 513 g of polyethylene and water-saturated Kaolite, the radius of core is 39.0992 cm while the outer radius of the exterior 4.5 kg shell of ^{235}U is 39.1609 cm. Model 6 addresses potential redistribution of fissile material consisting of multiple pieces, specifically the broken metal content. The parametric variation of shell thickness in Model 6 is performed for the purpose of evaluating the effect on k_{eff} of moderation efficiency of the core and enhanced neutron multiplication of the shell.

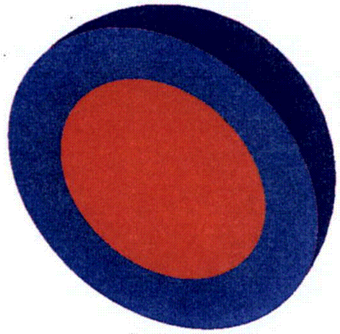

Fig. 6.14. Model 4. Homogenized sphere of 5 kg ^{235}U, polyethylene, and water saturated Kaolite (red), reflected by 20 cm of water (blue).

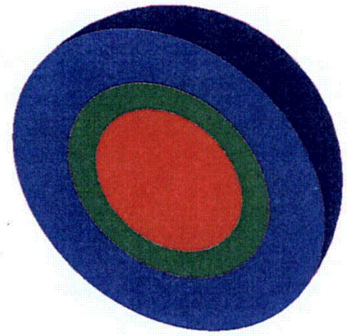

Fig. 6.15. Model 5. Homogenized sphere of 5 kg ^{235}U and excess moisture from Kaolite (red), blanketed by Kaolite shell (lt. green), reflected by 20 cm of water (blue).

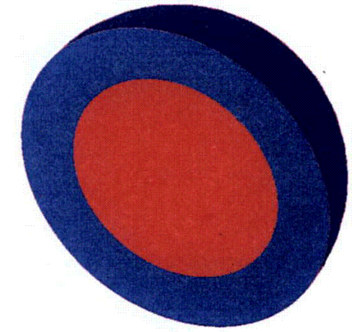

Fig. 6.16. Model 6. Homogenized sphere of 4.5 kg ^{235}U, polyethylene, and water saturated Kaolite (red); blanketed by shell of 0.5 kg ^{235}U (not visible), reflected by 20 cm of water (blue).

Models 1–6 are applicable to air transport of the ES-3100 package given that the physical integrity of the fissile content following the air transport accident can not be established, or that the physical form of fissile material content may be multiple solid pieces or oxide.

6.3.2 Material Properties

Criticality calculation models include the definition of material compositions in the geometry model for both NCT and HAC. The materials which affect nuclear criticality safety and may be present in the ES-3100 package during these conditions are fissile material content (HEU metal, aluminum and molybdenum alloys of uranium, HEU product or skull oxide, UNX crystals, or $UZrH_x$), stainless steel, 277-4 neutron poison, Kaolite, silicon rubber, Teflon or polyethylene, and various amounts of water. Other materials are present in the package (e.g., tin-coated steel convenience cans, nylon bagging, rubber O-rings, and trace impurities). However, these other materials are not present in amounts that will significantly affect the reactivity of the package. Detailed discussion of the package content and packaging materials is contained in Appendix 6.9.3. Specific topics are summarized in this section as required to support the discussion of the criticality calculations presented in Sects. 6.4–6.6.

Cases **ncsrtriga70_1_1_1** through **ncsrtriga70_1_15_15** (Appendix 6.9.6, Table 6.9.6-20b) represent the 70 % enriched TRIGA fuel content in a flooded ES-3100 package, reflected by 30.48 cm of water. Comparison of results for these cases with results for the 20 % enriched TRIGA fuel (Cases **ncsrtriga_1_1_1** through **ncsrtriga_1_15_15**) confirm that the 20 % enriched TRIGA fuel is the bounding content.

Cases **ncsrT70_131_1_1_15** through **ncsrT70_131_1_15_15** (Appendix 6.9.6, Table 6.9.6-20c) represent the the 1.31 in. diameter TRIGA fuel content in a flooded ES-3100 package, reflected by 30.48 cm of water. Comparison of results for these cases with results for the larger 1.44 in. diameter TRIGA fuel content (Cases **ncsrtriga70_1_1_1** through ncsrtriga70_1_15_15) confirm that the 1.44 in. diameter TRIGA fuel is the bounding content.

10 CFR 71.55(d)(2) requires the geometric form of a package's content not be substantially altered under the NCT. Also, 10 CFR 7155(e)(1) requires that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration. However, conclusions about damage to the fuel content can not be extrapolated from test data because a mock (test weight) content rather than actual TRIGA content is evaluated in the NCT and HAC tests of 10 CFR 71.71 and 10 CFR 71.73. Consequently, one way for addressing these requirements is to model the content in an extremely damaged condition and make a determination of subcriticality through a series of criticality calculations. Cases **ncsrt55d2_1_1_15** through **ncsrt55d2_1_15_15** (Appendix 6.9.6, Table 6.9.6-20d) represent TRIGA fuel content homogenized with variable density water over the free volume of the containment vessel, where the ES-3100 packaging is flooded and reflected by 30.48 cm of water. The variable density water ranges from the dry containment condition to the fully flooded condition. Credit for physical integrity of the content is not taken in this set of cases which model the subtantially altered content. The calculation results in Table 6.9.6-20d indicate extremely damaged content (Case **ncsrt55d2_1_15_15** with $k_{eff} + 2\sigma = 0.611$) is more reactive than the unaltered configuration (Case **ncsrtriga_1_15_15** with $k_{eff} + 2\sigma = 0.403$). Nevertheless, both cases are adequately below the USL of 0.925 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to the HAC do not result in an appreciable change in the nuetron multiplication for the single package, similar results are expected for the cases demonstrating compliance with 10 CFR 7155(e)(1).

The TRIGA content is to be transported by air; consequently, additional discussion is included in Sect. 6.7.

The 1.5-in.-diam × 2-in.-tall slugs may be packed up to ten items per press-fit lid type convenience can and up to twelve items per crimp-lid type convenience can. With nominal dimensions, each slug weighs ~1,090 g. With +1/16 in. tolerance on both the diameter and height, each slug in the calculation model weighs ~1291 g. As described in Appendix 6.9.1, different arrangements of slugs in the convenience cans are

increasing MOIFR in the water-reflected package. However, the results for Cases **ncsrunhct11_24_1_15** through **ncsrunhct11_1_1_15** demonstrate that the optimal concentration is not reached until the mass loading is reduced to ~9000 g UNH or 415 g ^{235}U/l. For Case **ncsrunhct11_9_1_15**, the $k_{eff} + 2\sigma = 0.745$.

Unlike solid HEU metal and oxide content, which are confined to the containment vessel and only water leakage into the containment vessel need be considered, the evaluation of UNH crystal content for compliance with 10 CFR 71.55(b) also requires that the leakage of liquid HEU contents out of the containment be addressed. This is because UNH crystals are soluble in water and would dissolve in the water flooding the containment vessel and the containment vessel well. For a content loading of 24,000 g UNH, the uranium concentration drops from 1106 g ^{235}U/l to 689 g ^{235}U/l. Optimum moderation at solution concentrations in the range of 415 g ^{235}U/l to 429 g ^{235}U/l occurs for fissile mass loadings of ~15,000 g UNH.

Cases **hcsrunhct12_9_1_15** (Appendix 6.9.6, Table 6.9.6-15) and **icsrunhct12_15_1_15** (Appendix 6.9.6, Table 6.9.6-16) represent the HAC model of the damaged ES-3100 package where the outer dimensions of the package are reduced accordingly. For Case **hcsrunhct12_9_1_15**, the dilution of the UNH crystals is confined to the containment vessel, and maximum reactivity occurs at ~9000 g UNH. For Case **icsrunhct12_15_1_15**, UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well, and maximum reactivity occurs at ~15,000 g UNH. 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 0.748 and 0.807 for this HAC condition. The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC do not result in a significant change in the neutron multiplication factor.

6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT

For the NCT array evaluation of ES-3100 packages, the package content is confined within the containment vessel, consistent with the result of the tests specified in §71.71 (Normal Conditions of Transport). The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, 5×5×2, ETP 27×3, ETP 16×3, and the degenerate single unit. The "N" and corresponding CSI values for arrays determined to be adequately subcritical are as follows: N = ∞, CSI = 0; N = 202, CSI = 0.4; N = 64, CSI = 0.8; N = 29, CSI = 1.7; N = 10, CSI = 5.0; and N = 16, CSI = 3.2. All arrays, except the infinite array, are reflected with 30 cm (1 ft) of water. These arrays are nearly cubic in shape for optimum array reactivity, thus eliminating the need for placing criticality controls on package arrangements in terms of stack height, width, and depth of an array. The array configurations and the range of water contents (Table 6.4) evaluated bound all possible packaging arrangements and moderation conditions for NCT.

6.5.1 Solid HEU Metal of Specified Geometric Shapes

For infinite and finite arrays of packages with HEU metal, the neutron multiplication factor increases as a function of the ^{235}U mass and decreases as a function of MOIFR. For example, consider the ES-3100 package loaded with three convenience cans for a total of 36,000 g ^{235}U where each can contains a 3.24-in.-diam cylinder. For package content without 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 1.027 to 0.963 with increasing MOIFR in the package [Cases **nciacyt11_36_1_1** through **nciacyt11_36_1_15** (Appendix 6.9.6, Table 6.9.6-3)]. For package content with 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.957 to 0.880 with increasing MOIFR in the package [Cases **nciacyt11_36_2_1** through **nciacyt11_36_2_15** (Appendix 6.9.6, Table 6.9.6-3)].

The effect of increasing the water content of the array is straightforward. As interspersed water is added to the packages of an array, two reactivity effects occur in series. The first effect is the tendency for reactivity to remain constant due to controlled neutron interaction between the packages of the array. For an infinite array where neutrons cannot escape from the system, neutrons are scattered about the array. In the MOIFR range of 1e-20 to 1e-02, both the interspersed moderator inside the packages of the dry array and the interstitial moderator between the package drums of the array are not sufficient for neutron thermalization and absorption to occur in the adjacent packaging materials. However, hydrogen in the 277-4 provides moderation, and neutrons are absorbed in the interspersed boron of this neutron poison. This results in a subcritical system with near constant neutron multiplication factors over the range of MOIFR. The second effect is the tendency for reactivity to decrease due to internal moderation in packages of the array. The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. The neutron multiplication factor approaches k_{eff} for the single, water-reflected unit at a full-content water fraction (MOIFR = 1.0).

The array case with a water fraction of MOIFR = 1e-04 pertains specifically to packages under NCT where the Kaolite and recesses of the package external to the containment vessel do not contain any residual moisture. This NCT case is more reactive than all other NCT cases where more moisture is present in the Kaolite and recesses of the package. Interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents because neutrons are absorbed in the hydrogen of the water. As more water is added, the packages of the array become isolated, and array reactivity ($k_{eff} + 2\sigma = 0.880$, Case **nciacyt11_36_2_15**) approaches the reactivity of the single unit ($k_{eff} + 2\sigma = 0.873$, Case **ncsrcyt11_36_2_15**).

Repeated for 4.25-in.-diam cylinders (Appendix 6.9.6, Table 6.9.6-7); 2.29-in. -square bars (Table 6.9.6-5); and 1.5-in.-diam × 2-in.-tall slugs (Table 6.9.6-9), this type of analysis for the 3.24-in.-diam cylinders demonstrates that arrays of packages with restricted fissile material (^{235}U) loading remain subcritical over the entire range of water content or MOIFR. HEU bulk metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited.

Cases **nciatriga_1_1_3** through **nciatriga_1_15_3** (Appendix 6.9.6, Table 6.9.6-20a) represent infinite arrays of packages containing the bounding TRIGA fuel content (20 % enrichment with 45 wt % U containing 307 g ^{235}U), without 277-4 canned spacers. The MOIFR is set at 1.0e-04 such that neutronic interaction between packages is maximized. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.218 to 0.525 as MOIFR increases. The $k_{eff} + 2\sigma = 0.525$ for Case **nciatriga_1_15_3** is substantially below the below the USL value of 0.925, indicating that canned spacers are not required for criticality control.

As stated in Sect. 6.4.1, 10 CFR 71.55(d)(2) requires the geometric form of a package's content not be substantially altered under the NCT. Similarly, 10 CFR 7155(e)(1) requires that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration. Even though visible signs of damage to the metal convenience can have not been observed resulting from the regulatory tests, conclusions about damage to the TRIGA fuel content are not extrapolated from test data. The regulatory requirements are addressed by modeling the TRIGA fuel content in an extremely damaged condition. A series of criticality calculations is performed for making a determination of subcriticality. Cases **nciat55d2_1_1_3** through **ncia55d2_1_15_3** (Appendix 6.9.6, Table 6.9.6-20d) represent TRIGA fuel content homogenized with variable density water over the free volume of the containment vessel. The packaging is flooded in each ES-3100 package of the infinite array. The variable density water ranges from the dry containment condition to the fully flooded condition. Credit for physical integrity of the content is not taken in this set of cases which model the subtantially altered content. The calculation results in Table 6.9.6-20d indicate extremely damaged content (Case **nciat55d2_1_15_3** with $k_{eff} + 2\sigma = 0.716$) is more reactive than the unaltered configuration (Case **nciatriga_1_15_3** with $k_{eff} + 2\sigma = 0.442$). Nevertheless, both cases are adequately below the USL of 0.925 and the requirement of 10 CFR 71.55(d)(2) is satisfied. Given that changes external to the containment vessel due to the HAC do not result in an appreciable change in the neutron multiplication for the an array of packages, similar results are expected for the cases demonstrating compliance with 10 CFR 7155(e)(1).

The array results for three slug configurations presented in Table 6.9.6-9 (Appendix 6.9.6) are for 5 or 10 slugs spaced apart in a pentagonal ring **(ncia5est11)** and for 7 slugs formed by a hexagonal ring of slugs with one slug in the center of the ring **(ncia70st11)**. These cases are used to establish the mass loading limitations, which in turn limit the number of slugs in the package to less than the number required to assemble a critical configuration.

Cases **ncia5est11_1_1_8_3** through **ncia5est11_1_1_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 18,287 g U without 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.550 to 0.923 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. The $k_{eff} + 2\sigma = 0.923$ for Case **ncia5est11_1_1_8_3** is below the USL of 0.925.

Cases **ncia5est11_2_1_8_3** through **ncia5est11_2_1_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 36,573 g ^{235}U without 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.452 to 0.806 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. The $k_{eff} + 2\sigma = 0.806$ value for Case **ncia5est11_1_2_8_3** does not exceed the USL of 0.925.

At 60 wt % ^{235}U, the $k_{eff} + 2\sigma = 0.905$ value for Case **ncia5est11_1_2_3_3** is below the USL. However, a restriction placed upon mass that requires that values must be $\leq$18,287 g ^{235}U still applies to satisfy the subcriticality requirement for the reflected containment vessel.

Cases **ncia70st11_1_8_3** through **ncia70st11_1_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 25,601 g U without 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.530 to 1.025 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. The $k_{eff} + 2\sigma = 1.025$ for Case **ncia70st11_1_8_3** exceeds the USL of 0.925.

At 70 wt % ^{235}U, the $k_{eff} + 2\sigma = 0.884$ value for Case **ncia70st11_1_4_3** is below the USL. The 17,989 g ^{235}U falls within the restriction placed upon mass that requires that values must be $\leq$18,287 g ^{235}U to satisfy the subcriticality requirement for the reflected containment vessel.

Cases **ncia5est11_2_2_8_3** through **ncia5est11_2_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 36,573 g ^{235}U with 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.582 to 0.983 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. At 80 wt % ^{235}U, the $k_{eff} + 2\sigma = 0.909$ value for Case **ncia5est11_2_2_5_3** is just below the USL. Therefore, a restriction on mass and enrichment for slug content is that for $\leq$80 wt % ^{235}U, the mass of ^{235}U in the package must not exceed 29,333 g as a prerequisite for the shipment of the package slug content and with 277-4 canned spacers under a CSI = 0.0.

Cases **ncia70st11_2_8_3** through **ncia70st11_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent infinite arrays of packages containing 25,601 g ^{235}U with 277-4 canned spacers. The $k_{eff} + 2\sigma$ values increase from 0.473 to 0.914 as the enrichment is increased from 19.0 wt % to 100.0 wt % ^{235}U. Therefore, the restriction placed on mass and enrichment for slug content is that for between 80 and 100 wt % ^{235}U, the mass of ^{235}U in the package must not exceed 25,601 g as a prerequisite for the shipment of the package with slug content and 277-4 canned spacers under a CSI = 0.0.

Cases **ncf15est11_2_2_8_3** through **ncf15est11_2_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent a 13 × 13 × 6 array of packages for which the corresponding rounded CSI = 0.4. The $k_{eff} + 2\sigma = 0.941$ for Case **ncf15est11_2_2_8_3** at 100 wt % ^{235}U exceeds the USL of 0.925. Case **ncf15est11_2_2_7_3** at 95 wt % ^{235}U with $k_{eff} + 2\sigma = 0.921$ is below the USL of 0.925 to permit increasing the limit on enrichment for mass loadings of ≤34.7 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 35,142 g ^{235}U and no canned spacers between content locations. The $k_{eff} + 2\sigma$ values range from 1.138 to 0.913 with increasing MOIFR [Cases **nciabmt11_36_1_8_1** through **nciabmt11_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-11)]. The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. Array reactivity ($k_{eff} + 2\sigma = 0.913$) approaches the reactivity of the water-saturated, water-reflected single package Case **ncsrbmt11_36_1_15** ($k_{eff} + 2\sigma = 0.891$).

In the series of calculations using the ES-3100 package model with NCT geometry (Cases **nciabmt11_1_*n*_*m*_3** through **nciabmt11_*36*_*n*_*m*_3**), the enrichment of the content is varied from 19 wt % to 100 wt % ^{235}U. These array cases with a water fraction of MOIFR = 1e-04 pertain specifically to NCT packages where both the neutron poison of the body weldment liner inner cavity and the Kaolite are dry (in the as-manufactured condition) and both the recesses of the package external to the containment vessel and the interstitial space between the drums of the array do not contain any residual moisture. As stated before, this NCT case is more reactive than all other NCT cases where more moisture is present in the Kaolite and recesses of the package. Increased interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents to a point where the packages of the array become isolated.

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_36_1_8_15** versus Case **cvr3lha_36_2_8_15**) indicate that 277-4 canned spacers are required in this enrichment range, where the maximum evaluated fissile mass loading of 35,142 g ^{235}U is possible. However, the fissile mass loading must be limited to 2,774 g ^{235}U (Case **nciabmt11_3_2_8_3**) in order for the $k_{eff} + 2\sigma$ value (= 0.904) to be below the USL of 0.925. 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 **nciabmt11_4_2_7_3** and **nciabmt11_4_2_6_3**) 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 ~2774 g, while the fissile mass loading limit decreases with the reduction in enrichment as illustrated in Table 6.1b. As stated previously, these fissile mass loading limits for a CSI = 0 are contingent upon the infinite array of damaged packages also being adequately subcritical for 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 <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 product oxide decreases as a function of decreasing ^{235}U mass [Cases **nciaoxt11_1_24_1_3** through **nciaoxt11_1_16_1_3** (Appendix 6.9.6, Table 6.9.6-13)]. The $k_{eff} + 2\sigma$ values are below the USL of 0.925.

Cases **nciask_1_15** through **nciask_10_15** (Appendix 6.9.6, Table 6.9.6-18) evaluate infinite arrays of packages having the 10 skull oxide compositions described in Sect. 6.4.3. The MOIFR is set at 1.0e-04 such that neutronic interaction between packages is maximized. The $k_{eff} + 2\sigma$ values, ranging from 0.656 to 0.764, are substantially below the below the USL value of 0.925, indicating that canned spacers are not required for criticality control.

The CSI = 0.0 for an infinite array of packages having product oxide content with a maximum of 21,125 g ^{235}U or having skull oxide content with a maximum of 16,399 g ^{235}U and 921 g graphite. The suitability of this determination is contingent upon satisfactory results under the HAC evaluation (Sect. 6.6.3.)

6.5.4 UNH Crystals

Unlike HEU metal, broken metal or oxide content, UNH crystal is soluble in water (Sect. 6.4.4). Near optimum solution concentration occurs at content mass loadings of ~9000 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 increasing MOIFR. Cases **nciaunhct11_8_24_1_1** through **nciaunhct11_8_24_1_15** (Appendix 6.9.6, Table 6.9.6-15) reveal the effect of isolating the individual array units from each other with the introduction of water above ~0.01 MOIFR. Array reactivity ($k_{eff} + 2\sigma = 0.721$) approaches the reactivity of the water-saturated, water-reflected unit single package ($k_{eff} + 2\sigma = 0.702$).

The difference between Cases **nciaunhct11_8_*nn*_1_3** and **nciaunhct11_8_*nn*_2_3** is the absence of 277-4 canned spacers in the former case and the presence of 277-4 canned spacers in the latter case. The 277-4 canned spacers are not actually modeled in the NCT package calculation models for UNH crystals content. 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 canned spacers.

In a series of NCT calculations (Cases **nciaunhct11_8_*nn*_1_3**), the $k_{eff} + 2\sigma$ values are above the USL of 0.925 for mass loadings between 9,000 and 21,000 g UNH crystals. Although mass loadings above 21,000–24,000 are adequately subcritical, credit is not taken for water tightness that is demonstrated by the NCT (and HAC) tests. Therefore, mass loading are restricted to <8 kg UNH crystals. The CSI = 0.0 [10 CFR 71.59(a)(1) and 10 CFR 71.59(b)] for ES-3100 packages having a maximum of 3789g ^{235}U. The suitability of this determination depends upon satisfactory results under the HAC evaluation of Sect. 6.6.4. [10 CFR 71.59(a)(2) and 10 CFR 71.59(b)]

The $k_{eff} + 2\sigma$ values are expected to range from subcritical to critical for array configurations where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. 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 in each package of an array. This condition is an accident condition, not credible for NCT.

For Cases **ncf1unhct12_8_*nn*_1_3**, the $k_{eff} + 2\sigma$ values are below the USL of 0.925. Given that the results for NCT (Sect. 6.5.4) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.4

for packages with a maximum of UNH crystals. The CSI = 0.4 [10 CFR 71.59(a)(1) and 10 CFR 71.59(b)] for ES-3100 packages having a maximum of 24,000 g UNH crystal. Likewise, the suitability of this determination depends upon satisfactory results under the HAC evaluation of Sect. 6.6.4.

6.6 EVALUATION OF PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

Except for UNH crystals, the package content is confined within the containment vessel for the HAC array evaluation of ES-3100 packages, consistent with the result of the tests specified in 10 CFR 71.73 (Hypothetical Accident Conditions). The array sizes examined in this evaluation are infinite, 13×13×6, 9×9×4, 7×7×3, 5×5×2, 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 = 0.4; N = 73, CSI = 0.7; N = 25, CSI = 2.0; and N = 19, CSI = 2.7. All arrays, except the infinite array, are reflected with 30 cm (1 ft) of water. These array are nearly cubic in shape for optimum reactivity of the array, thus eliminating the need for placing criticality controls on package arrangements in terms of stack height, width, and depth of an array. The array configurations and the range of water contents (Table 6.4) evaluated bound all possible packaging arrangements and moderation conditions for HAC.

For the single damaged package, and for infinite and finite arrays of damaged packages with HEU metal, HEU oxide, or UNH crystal content, the neutron multiplication factor changes as a function of the ^{235}U mass, MOIFR, or applicable solution concentration in the same manner as in an array of undamaged packages.

6.6.1 Solid HEU Metal of Specified Geometric Shapes

For infinite and finite arrays of damaged packages with HEU metal, the neutron multiplication factor increases as a function of the ^{235}U mass and decreases as a function of MOIFR. For example, consider the ES-3100 package loaded with three convenience cans that contain a 3.24-in.-diam cylinder with 12,000 g ^{235}U for a total of 36,000 g ^{235}U. For package content without 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 1.027 to 0.967 with increasing MOIFR in the damaged packages [Cases **hciacyct12_36_1_1** through **hciacyt12_36_1_15** (Appendix 6.9.6, Table 6.9.6-3)]. For package content with 277-4 canned spacers, the $k_{eff} + 2\sigma$ values range from 0.956 to 0.884 with increasing MOIFR in the damaged package [Cases **hciacyt12_36_2_1** through **hciacyt12_36_2_15** (Appendix 6.9.6, Table 6.9.6-3)].

The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. The neutron multiplication factor approaches k_{eff} for the single, water-reflected unit at a full content-water fraction (MOIFR = 1.0). Comparison of these results with the corresponding NCT cases (Sect. 6.5.1.) indicates no significant differences. This result is as expected given that the neutron multiplication in an infinite array is independent of pitch between fissile contents but is dependent on changes in mass and moderation in the array. The changes in both the outer dimensions and the compositions of the Kaolite and 277-4 of the ES-3100 package due to HAC result in changes to the neutron multiplication factor on the order of ~0.001 to 0.002.

Repeated for 4.25-in.-diam cylinders (Appendix 6.9.6, Table 6.9.6-7); 2.29-in.-square bars (Table 6.9.6-5); and 1.5-in.-diam × 2-in.-tall slugs (Table 6.9.6-9), this type of analysis for the 3.24-in.-diam cylinders demonstrates that arrays of damaged packages with restricted fissile material (^{235}U) loading remain subcritical over the entire range of water content or MOIFR. HEU bulk metal or alloy content not covered by the specified geometric shapes (cylinder, square bar, or slug contents) will be in the HEU broken metal category, and so limited.

Cases **hciatriga_1_1_3** through **hciatriga_1_15_3** (Appendix 6.9.6, Table 6.9.6-20) represent infinite arrays of damaged packages containing the bounding TRIGA fuel content (20 % enrichment with 45 wt % U containing 307 g ^{235}U), without 277-4 canned spacers. For these cases, the $k_{eff} + 2\sigma$ values increase from 0.218 to 0.526 as MOIFR increases. The $k_{eff} + 2\sigma = 0.526$ for Case **hciatriga_1_15_3** is substantially below the USL of 0.925, indicating that canned spacers are not required for criticality control. Given that the results for NCT (Sect. 6.5.2) and HAC are adequately subcritical, packages with TRIGA fuel content $\leq$921 g ^{235}U may be shipped under a CSI = 0.

As stated in Sect. 6.5.1, calculation results presented in Table 6.9.6-20d for an infinite array of ES-3100 packages (NCT packaging with extremely damaged TRIGA fuel content) is substantially below the USL of 0.925. Similar results are expected for an infinite array of ES-3100 packages (HAC packaging with extremely damaged TRIGA fuel content) given that changes external to the containment vessel due to the HAC do not result in an appreciable change in the neutron multiplication for the an array of packages. Therefore, the 10 CFR 7155(e)(1) requirement that the package be adequately subcritical under HAC with the package contents in the most reactive credible configuration is satisfied.

Consider the ~1090 g, 1.5-in.-diam x 2-in.-tall slugs that may be packed ten per convenience can. Cases **hcf25est11_2_2_8_3** through **hcf25est11_2_2_1_3** (Appendix 6.9.6, Table 6.9.6-9) represent a 9×9×4 array of packages for which the corresponding rounded CSI = 0.4. Case **hcia5est12_2_2_8_3** at 100 wt % with $k_{eff} + 2\sigma = 0.923$ is below the USL. Therefore, the restriction upon enrichment under the NCT evaluation, which requires values be $\leq$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 18,287 g ^{235}U for eliminating the restriction on enrichment.

Case **hcf25est12_2_2_8_3** at 100 wt % ^{235}U (Appendix 6.9.6, Table 6.9.6-9) represents a 9 × 9 × 4 array of packages for which the corresponding rounded CSI = 0.4. Although Case **ncf25est12_2_2_7_3** at 95 wt % ^{235}U with $k_{eff} + 2\sigma = 0.905$ is below the USL of 0.925, the fissile mass loading limit is conservatively set by the NCT result, which requires that the enrichment not exceed 80 wt % ^{235}U for 36 kg uranium mass loadings. The $k_{eff} + 2\sigma$ decreases sufficiently when the array size is reduced to permit increasing the limit on enrichment to $\leq$95 wt % ^{235}U for mass loadings of 34.7 kg uranium metal. These CSI determinations are contingent upon satisfactory results under the HAC evaluation (Sect. 6.6.1).

The changes in both the outer dimensions of the package and the compositions of the Kaolite and 277-4 due to HAC result in an ~0.001 change in the neutron multiplication factor.

6.6.2 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 35,142 g ^{235}U with no canned spacers between content locations. The $k_{eff} + 2\sigma$ values range from 1.14 to 0.939 with increasing MOIFR, Cases **hciabmt12_36_1_8_1** through **hciabmt12_36_1_8_15** (Appendix 6.9.6, Table 6.9.6-11). The introduction of water above ~0.01 MOIFR shows the effect of isolating the individual array units from each other. Array reactivity ($k_{eff} + 2\sigma = 0.939$) approaches the reactivity of the water-saturated, water-reflected single package ($k_{eff} + 2\sigma = 0.891$, Case **hcsrbmt12_36_1_15**, Table 6.9.6-11).

Cases **hciabmt12_1_*nn_mm*_3** through **hciabmt12_36_*nn_mm*_3** model the ES-3100 with the reduced-diameter HAC package model where the enrichment of the content is varied from 60 wt % to 100 wt % ^{235}U. These array cases with MOIFR = 1e-04 pertain specifically to HAC packages where the neutron poison of the body weldment liner inner cavity is at 90% moisture content, but the Kaolite is dry (in the as-manufactured condition), and neither recess of the package external to the containment vessel and the interstitial space between the drums of the array contains any residual moisture. As stated before, this HAC case is more reactive than all other HAC cases where more moisture is present in the Kaolite and recesses of the package. Increasing the interspersed water between the containment vessels in the array will reduce neutronic interaction between the flooded contents to a point where the packages of the array become isolated.

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_36_1_8_15** versus Case **cvr3lha_36_2_8_15**, Appendix 6.9.6, Table 6.9.6-10) indicate that 277-4 canned spacers are required in this enrichment range, where the maximum evaluated mass loading of 35,142 g ^{235}U is possible. However, the fissile mass loading must be limited to 2774 g ^{235}U (Case **hciabmt12_3_2_8_3**) in order for the $k_{eff} + 2\sigma$ value (= 0.905) to be below the USL of 0.925. 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 ≤2774 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 <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 decreasing ^{235}U mass [Cases **hciaoxt12_1_24_1_3** through **hciaoxt12_1_16_1_3** (Appendix 6.9.6, Table 6.9.6-13)]. The $k_{eff} + 2\sigma$ 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 product oxide with a maximum of 21,125 g ^{235}U.

Cases **hciask_1_15** through **hciask_10_15** (Appendix 6.9.6, Table 6.9.6-18b) evaluate infinite arrays of damaged packages having the 10 skull oxide compositions described in Sect. 6.4.3. The differences between the HAC case results and the NCT case results are not statistically significant. The $k_{eff} + 2\sigma$ values, ranging from 0.658 to 0.767, are substantially below the USL value of 0.925. Given that the results for NCT (Sect. 6.5.3) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.0 for an infinite array of packages having skull oxide content with a maximum of 16,399 g ^{235}U and 921 g graphite.

6.6.4 UNH Crystals

Unlike HEU metal, broken metal or oxide content, UNH crystal is soluble in water, as mentioned in Sect. 6.4.4. Near optimum solution concentration occurs at content mass loadings of 9000 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 increasing MOIFR. Cases **hciaunhct12_8_24_1_1** through **hciaunhct12_8_24_1_15** (Appendix 6.9.6, Table 6.9.6-15) reveal the effect of isolating the individual array units from each other with the introduction of water above ~0.01 MOIFR. Array reactivity ($k_{eff} + 2\sigma = 0.729$) approaches the reactivity of the water-saturated, water-reflected unit single package ($k_{eff} + 2\sigma = 0.705$).

Like the NCT evaluation, the difference in the HAC package calculation model represented by Cases **hciaunhct12_8_*nn*_1_3** and **hciaunhct12_8_*nn*_2_3** is the absence of 277-4 canned spacers in the former case and the presence of 277-4 canned spacers in the latter case. For the HAC package calculation models with of UNH crystal content, the 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 canned spacers.

In a series of HAC calculations, Cases **hciaunhct11_8_*nn*_1_3**, the calculated $k_{eff} + 2\sigma$ values are below the USL of 0.925 for loading with <9000 g UNH crystals. Given that the results for NCT (Sect. 6.5.4) and HAC are adequately subcritical, the CSI = 0.0 [10 CFR 71.59(a)(2) and 10 CFR 71.59(b)] for packages having a maximum of 3789g ^{235}U crystal.

The $k_{eff} + 2\sigma$ values are expected to range from subcritical to critical for array configurations where UNH crystals are dissolved in the water flooding the containment vessel and the containment vessel well. 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 in each package of an array. The leakage out of the containment vessel of content moderated "to such an extent as to cause maximum reactivity consistent with the physical and chemical form of material" is not considered credible HAC based on results for tests specified in 10 CFR 71.73.

In a series of HAC calculations, Cases **hcf2unhct121_8_*nn*_1_3**, the calculated $k_{eff} + 2\sigma$ values are below the USL of 0.925 for loading with <9000 g UNH crystals. Given that the results for NCT (Sect. 6.5.4) and HAC are adequately subcritical, packages may be shipped under a CSI = 0.4 for packages with a maximum of 24,000 g UNH crystals.

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

A series of calculations are performed for determining the most reactive configuration of the content and surrounding packaging material in an ES-3100 package that undergoes catastrophic destruction. Fissile content mass loadings that remain under the USL for these catastrophic events are identified. Subcriticality is demonstrated after due consideration of such aspects as the efficiency of moderator, loss of neutron absorbers, rearrangement of packaging components and contents, geometry changes and temperature effects. The seven calculation models used in this evaluation are described in Sect 6.3.1.4. Key model dimensions and parameters are tabulated in Tables 6.9.6-21 through 6.9.6-23, Appendix 6.9.6.

6.7.1 Results for Solid HEU, One Piece per Convenience Can

Cases **atdmr_10_8** through **atdmr_7_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 1 (Fig. 6.11, Section 6.3.1.4). HEU solid or broken metal of three convenience cans is homogenized with 513 g of polyethylene, representing the potential use of hydrogenous packing materials in the ES-3100. The fissile core is configured into a spherical shape with an exterior 20 cm water reflector. As shown in Fig. 6.17 and Table 6.9.6-21, the $k_{eff} + 2\sigma$ values decrease as a function of both enrichment and ^{235}U mass. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925. The $k_{eff} + 2\sigma$ value for 7 kg of HEU at 100 % enrichment is 0.792.

Cases **atdmsr_7_8_11** through **atdmsr_7_1_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 2 (Fig. 6.12, Section 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness stainless steel shell and an exterior 20 cm water reflector. As shown in Fig 6.18 and Table 6.9.6-21, the maximum $k_{eff} + 2\sigma$ values occur at zero stainless steel thickness. The $k_{eff} + 2\sigma$ value for 7 kg of HEU at 100% enrichment and zero stainless steel thickness is 0.793. The $k_{eff} + 2\sigma$ values decrease to minimum values for steel thicknesses of 0.99 cm at 100 % enrichment and thicknesses of 1.47 cm at 19 % enrichment while the NLF decreases from ~ 0.07 to 0.06. The NLF continues to decrease to a value of 0.03 as stainless steel is added up to the 66,133 g amount of the containment vessel and the liner and drum assembly. At maximum stainless steel thickness, the $k_{eff} + 2\sigma$ values increase to within 0.02 of the values for zero stainless steel thickness. The stainless steel of the ES-3100 packaging is not as effective a reflector as the 20 cm water surrounding the core. The overall effect of adding the stainless steel of the ES-3100 packaging to the configuration is the reduction in the neutron multiplication factor for the system. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925.

Cases **atdmkr_7_8_11** through **atdmkr_7_1_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 3 (Fig. 6.13, Section 6.3.1.4). The fissile core of Model 1 is blanketed with a variable thickness Kaolite shell and an exterior 20 cm water reflector. As shown in Fig. 6.19 and Table 6.9.6-21, the maximum $k_{eff} + 2\sigma$ values occur at a Kaolite shell thickness of zero. For 7 kg of HEU at 100 % enrichment, the $k_{eff} + 2\sigma$ value is 0.793. $K_{eff} + 2\sigma$ values decrease to asymptotic values at shell radii of ~14.74 cm (Kaolite thicknesses of ~ 8.66 cm) while the NLF decreases from ~ 0.07 to 0.03. The NLF continues to decrease to a value of 0.006 as water-saturated Kaolite is added up to the 128,034 g pre-bake amount inside the body weldment outer liner and the drum top plug. The asymptotic values for $k_{eff} + 2\sigma$ are ~ 0.043 below maximum $k_{eff} + 2\sigma$ values which occur at zero Kaolite thickness.

Cases **atdmdkr_7_8_11** through **atdmdkr_7_8_1** (Table 6.9.6-21, Appendix 6.9.6) pertain to Model 3 (Fig. 6.13, Section 6.3.1.4), where dry Kaolite is being evaluated consistent with test results of 10 CFR 71.55(d). Only 7 kg of HEU at 100 % enrichment is evaluated in these cases. As shown in Fig. 6.20 and Table 6.9.6-21, the $k_{eff} + 2\sigma$ value decreases to a minimum value at a shell radius of 31.08 cm (dry Kaolite thickness of 25.03 cm). The NLF decreases gradually from ~ 0.07 to 0.05 as NCT Kaolite is added up to the amount contained inside the body weldment outer liner and the drum top plug. Neutron leakage from a configuration with the NCT Kaolite of the ES-3100 packaging is much greater than leakage from one with water-saturated Kaolite. Over the range of moisture content, the Kaolite of the ES-3100 packaging is not as effective a reflector as the 20 cm water surrounding the core. The overall effect of adding Kaolite to the system is the reduction in neutron multiplication in the system. The $k_{eff} + 2\sigma$ values are substantially below the USL of 0.925.

Table 6.9.6-20c. Results for 1.31 in. smaller diameter $UZrH_x$ content at 70.1 wt % ^{235}U in packaging calculation model

case name	np (in)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	k_{eff}+2σ	case name	k_{eff}	σ	k_{eff}+2σ
nciaT70_131_1_14_3	0.0	5,667	338	8,284	640.38	1.0e-04	0.43010	0.00115	0.43241				
nciaT70_131_1_15_3	0.0	5,667	338	9,205	711.53	1.0e-04	0.45804	0.00122	0.46047				

Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	k_{eff}+2σ	case name	k_{eff}	σ	k_{eff}+2σ
homogenized content in flooded containment vessel, single package reflected [10 CFR 71.55(d)(2)]													
NCT													
no can spacers (np thickness = 0.0 in.)													
mocfr													
ncsrt55d2_1_1_15	0.0	10,400	921	0	0.00	1.0e+00	0.11370	0.00054	0.11477				
ncsrt55d2_1_6_15	0.0	10,400	921	900	25.50	1.0e+00	0.15074	0.00061	0.15196				
ncsrt55d2_1_7_15	0.0	10,400	921	1,800	51.00	1.0e+00	0.19298	0.00070	0.19439				
ncsrt55d2_1_8_15	0.0	10,400	921	2,700	76.50	1.0e+00	0.24182	0.00082	0.24346				
ncsrt55d2_1_9_15	0.0	10,400	921	3,599	102.00	1.0e+00	0.29424	0.00084	0.29591				
ncsrt55d2_1_10_15	0.0	10,400	921	4,499	127.50	1.0e+00	0.34858	0.00100	0.35059				
ncsrt55d2_1_11_15	0.0	10,400	921	5,399	153.00	1.0e+00	0.40341	0.00119	0.40579				
ncsrt55d2_1_12_15	0.0	10,400	921	6,299	178.50	1.0e+00	0.45802	0.00109	0.46020				
ncsrt55d2_1_13_15	0.0	10,400	921	7,199	204.00	1.0e+00	0.51163	0.00121	0.51404				
ncsrt55d2_1_14_15	0.0	10,400	921	8,098	229.51	1.0e+00	0.56264	0.00129	0.56521				
ncsrt55d2_1_15_15	0.0	10,400	921	8,998	255.01	1.0e+00	0.60824	0.00136	0.61095				
moifr													
ncsrt55d2_1_15_15	0.0	10,400	921	8,998	255.01	1.0e+00	0.60824	0.00136	0.61095				
ncsrt55d2_1_15_8	0.0	10,400	921	8,998	255.01	3.0e-01	0.55284	0.00122	0.55528				
ncsrt55d2_1_15_6	0.0	10,400	921	8,998	255.01	1.0e-01	0.53397	0.00114	0.53626				

Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	k_{eff}+2σ	case name	k_{eff}	σ	k_{eff}+2σ
ncsrt55d2_1_15_5	0.0	10,400	921	8,998	255.01	1.0e-02	0.52373	0.00115	0.52604				
ncsrt55d2_1_15_4	0.0	10,400	921	8,998	255.01	1.0e-03	0.52361	0.00124	0.52609				
ncsrt55d2_1_15_3	0.0	10,400	921	8,998	255.01	1.0e-04	0.52050	0.00116	0.52283				
ncsrt55d2_1_15_2	0.0	10,400	921	8,998	255.01	1.0e-05	0.52366	0.00123	0.52611				
ncsrt55d2_1_15_1	0.0	10,400	921	8,998	255.01	1.0e-20	0.52390	0.00120	0.52631				
with can spacers (np thickness = 1.4 in.)													
mocfr													
ncsrt55d2_2_1_15	1.4	10,400	921	0	0.00	1.0e+00	0.10877	0.00048	0.10972				
ncsrt55d2_2_6_15	1.4	10,400	921	839	23.76	1.0e+00	0.14519	0.00062	0.14643				
ncsrt55d2_2_7_15	1.4	10,400	921	1,677	47.52	1.0e+00	0.18564	0.00082	0.18729				
ncsrt55d2_2_8_15	1.4	10,400	921	2,515	71.29	1.0e+00	0.23269	0.00095	0.23459				
ncsrt55d2_2_9_15	1.4	10,400	921	3,354	95.05	1.0e+00	0.28305	0.00082	0.28469				
ncsrt55d2_2_10_15	1.4	10,400	921	4,192	118.81	1.0e+00	0.33734	0.00105	0.33944				
ncsrt55d2_2_11_15	1.4	10,400	921	5,031	142.57	1.0e+00	0.39111	0.00128	0.39367				
ncsrt55d2_2_12_15	1.4	10,400	921	5,869	166.33	1.0e+00	0.44324	0.00114	0.44553				
ncsrt55d2_2_13_15	1.4	10,400	921	6,708	190.09	1.0e+00	0.49696	0.00128	0.49951				
ncsrt55d2_2_14_15	1.4	10,400	921	7,546	213.86	1.0e+00	0.54756	0.00093	0.54942				
ncsrt55d2_2_15_15	1.4	10,400	921	8,385	237.62	1.0e+00	0.59538	0.00144	0.59825				
moifr													
ncsrt55d2_2_15_15	1.4	10,400	921	8,385	237.62	1.0e+00	0.59538	0.00144	0.59825				
ncsrt55d2_2_15_8	1.4	10,400	921	8,385	237.62	3.0e-01	0.53671	0.00112	0.53895				
ncsrt55d2_2_15_6	1.4	10,400	921	8,385	237.62	1.0e-01	0.52002	0.00107	0.52217				
ncsrt55d2_2_15_5	1.4	10,400	921	8,385	237.62	1.0e-02	0.50958	0.00123	0.51204				
ncsrt55d2_2_15_4	1.4	10,400	921	8,385	237.62	1.0e-03	0.50803	0.00111	0.51024				
ncsrt55d2_2_15_3	1.4	10,400	921	8,385	237.62	1.0e-04	0.50785	0.00116	0.51018				
ncsrt55d2_2_15_2	1.4	10,400	921	8,385	237.62	1.0e-05	0.50851	0.00117	0.51086				

Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	k_{eff}+2σ	case name	k_{eff}	σ	k_{eff}+2σ
ncsrt55d2_2_15_1	1.4	10,400	921	8,385	237.62	1.0e-20	0.50763	0.00113	0.50989				
homogenized content in flooded containment vessel, array packaging model for CSI=0.0 [10 CFR 71.55(d)(2)]													
NCT													
no can spacers (np thickness = 0.0 in.)													
moifr													
nciat55d2_1_1_3	0.0	10400	921	0	0.00	1.0e-04	0.13090	0.00039	0.13168				
nciat55d2_1_6_3	0.0	10400	921	900	25.50	1.0e-04	0.18600	0.00056	0.18713				
nciat55d2_1_7_3	0.0	10400	921	1,800	51.00	1.0e-04	0.24841	0.00078	0.24997				
nciat55d2_1_8_3	0.0	10400	921	2,700	76.50	1.0e-04	0.31679	0.00074	0.31826				
nciat55d2_1_9_3	0.0	10400	921	3,599	102.00	1.0e-04	0.38338	0.00097	0.38531				
nciat55d2_1_10_3	0.0	10400	921	4,499	127.50	1.0e-04	0.44808	0.00093	0.44993				
nciat55d2_1_11_3	0.0	10400	921	5,399	153.00	1.0e-04	0.51062	0.00096	0.51254				
nciat55d2_1_12_3	0.0	10400	921	6,299	178.50	1.0e-04	0.56869	0.00104	0.57076				
nciat55d2_1_13_3	0.0	10400	921	7,198	204.00	1.0e-04	0.62259	0.00112	0.62484				
nciat55d2_1_14_3	0.0	10400	921	8,098	229.51	1.0e-04	0.67077	0.00100	0.67276				
nciat55d2_1_15_3	0.0	10400	921	8,998	255.01	1.0e-04	0.71379	0.00131	0.71641				
with can spacers (np thickness = 1.4 in.)													
nciat55d2_02_1_3	1.4	10400	921	0	0.00	1.0e-04	0.12620	0.00039	0.12697				
nciat55d2_02_6_3	1.4	10400	921	838	23.76	1.0e-04	0.17224	0.00043	0.17310				
nciat55d2_02_7_3	1.4	10400	921	1,677	47.52	1.0e-04	0.22779	0.00057	0.22894				
nciat55d2_02_8_3	1.4	10400	921	2,515	71.29	1.0e-04	0.28723	0.00081	0.28884				
nciat55d2_02_9_3	1.4	10400	921	3,354	95.05	1.0e-04	0.34934	0.00079	0.35091				
nciat55d2_02_10_3	1.4	10400	921	4,192	118.81	1.0e-04	0.40899	0.00097	0.41094				
nciat55d2_02_11_3	1.4	10400	921	5,031	142.57	1.0e-04	0.46775	0.00101	0.46977				
nciat55d2_02_12_3	1.4	10400	921	5,869	166.33	1.0e-04	0.52454	0.00105	0.52664				
nciat55d2_02_13_3	1.4	10400	921	6,708	190.09	1.0e-04	0.57561	0.00105	0.57771				

Table 6.9.6-20d. Results for $UZrH_x$ content at 19.7 wt % ^{235}U in packaging calculation model

case name	np (in)	$UZrH_x$ (g)	^{235}U (g)	H_2O (g)	h/x	mocfr/ moifr	k_{eff}	σ	k_{eff}+2σ	case name	k_{eff}	σ	k_{eff}+2σ
nciat55d2_02_14_3	1.4	10400	921	7,546	213.86	1.0e-04	0.62437	0.00100	0.62637				
nciat55d2_02_15_3	1.4	10400	921	8,385	237.62	1.0e-04	0.66968	0.00118	0.67203				

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	htox	Rc (cm)	H_2O (g)	Kao (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2σ$
compromised package, HEU in spherical configuration, 20.0 cm water reflector														
10,000g HEU														
atdmr_10_8	10,000	513	na	na	1.72	6.3828	na	na	na	na	0.0699	0.84749	0.00166	0.85080
atdmr_10_7	9,500	513	na	na	1.81	6.3821	na	na	na	na	0.0700	0.83119	0.00116	0.83352
atdmr_10_6	9,000	513	na	na	1.91	6.3814	na	na	na	na	0.0704	0.81788	0.00124	0.82037
atdmr_10_5	8,000	513	na	na	2.15	6.3801	na	na	na	na	0.0703	0.79457	0.00108	0.79673
atdmr_10_4	7,000	513	na	na	2.46	6.3788	na	na	na	na	0.0708	0.76800	0.00105	0.77010
atdmr_10_3	6,000	513	na	na	2.87	6.3775	na	na	na	na	0.0708	0.73829	0.00119	0.74067
atdmr_10_2	4,000	513	na	na	4.30	6.3749	na	na	na	na	0.0707	0.67494	0.00115	0.67723
atdmr_10_1	1,900	513	na	na	9.06	6.3721	na	na	na	na	0.0714	0.58800	0.00115	0.59030
9,000g HEU														
atdmr_9_8	9,000	513	na	na	1.91	6.2772	na	na	na	na	0.0709	0.82760	0.00126	0.83012
atdmr_9_7	8,550	513	na	na	2.01	6.2766	na	na	na	na	0.0706	0.81397	0.00109	0.81615
atdmr_9_6	8,100	513	na	na	2.12	6.2760	na	na	na	na	0.0709	0.80283	0.00125	0.80533
atdmr_9_5	7,200	513	na	na	2.39	6.2747	na	na	na	na	0.0713	0.77712	0.00131	0.77973
atdmr_9_4	6,300	513	na	na	2.73	6.2735	na	na	na	na	0.0713	0.75186	0.00109	0.75403
atdmr_9_3	5,400	513	na	na	3.19	6.2723	na	na	na	na	0.0717	0.72734	0.00146	0.73025
atdmr_9_2	3,600	513	na	na	4.78	6.2698	na	na	na	na	0.0716	0.66431	0.00106	0.66642
atdmr_9_1	1,710	513	na	na	10.06	6.2673	na	na	na	na	0.0722	0.58032	0.00113	0.58259
8,000g HEU														

Table 6.9.6-21. Results for solid HEU metal content for air transportation

case name	^{235}U (g)	CH_2 (g)	H_2O (g)	Kaolite (g)	htox	Rc (cm)	H_2O (g)	Kao (g)	Shell (g)	Rs (cm)	nlf	k_{eff}	σ	$k_{eff} + 2σ$
atdmr_8_7	7,600	513	na	na	2.26	6.1674	na	na	na	na	0.0715	0.79619	0.00117	0.79853
atdmr_8_6	7,200	513	na	na	2.39	6.1668	na	na	na	na	0.0727	0.78301	0.00116	0.78533
atdmr_8_5	6,400	513	na	na	2.69	6.1657	na	na	na	na	0.0719	0.75965	0.00114	0.76193
atdmr_8_4	5,600	513	na	na	3.07	6.1646	na	na	na	na	0.0716	0.73554	0.00108	0.73771
atdmr_8_3	4,800	513	na	na	3.58	6.1634	na	na	na	na	0.0726	0.70989	0.00097	0.71182
atdmr_8_2	3,200	513	na	na	5.38	6.1612	na	na	na	na	0.0728	0.65175	0.00102	0.65379
atdmr_8_1	1,520	513	na	na	11.32	6.1588	na	na	na	na	0.0733	0.57379	0.00106	0.57592
7,000g HEU														
atdmr_7_8	7,000	513	na	na	2.46	6.0547	na	na	na	na	0.0727	0.78948	0.00115	0.79178
atdmr_7_7	6,650	513	na	na	2.59	6.0541	na	na	na	na	0.0729	0.77766	0.00132	0.78030
atdmr_7_6	6,300	513	na	na	2.73	6.0536	na	na	na	na	0.0730	0.76315	0.00123	0.76560
atdmr_7_5	5,600	513	na	na	3.07	6.0526	na	na	na	na	0.0732	0.74249	0.00125	0.74499
atdmr_7_4	4,900	513	na	na	3.51	6.0516	na	na	na	na	0.0727	0.72132	0.00116	0.72365
atdmr_7_3	4,200	513	na	na	4.10	6.0506	na	na	na	na	0.0741	0.69486	0.00105	0.69696
atdmr_7_2	2,800	513	na	na	6.15	6.0485	na	na	na	na	0.0735	0.64123	0.00116	0.64355
atdmr_7_1	1,330	513	na	na	12.94	6.0464	na	na	na	na	0.0737	0.56794	0.00130	0.57053
compromised package, HEU in spherical configuration, Kaolite shell, 20.0 cm water reflector														
7,000g HEU 100% enrichment														
atdmsr_7_8_11	7,000	513	na	na	2.46	6.0547	na	na	66,133.1	13.0264	0.0300	0.76978	0.00129	0.77236
atdmsr_7_8_10	7,000	513	na	na	2.46	6.0547	na	na	59,519.8	12.6235	0.0314	0.76732	0.00118	0.76967
atdmsr_7_8_9	7,000	513	na	na	2.46	6.0547	na	na	52,906.5	12.1930	0.0330	0.76002	0.00125	0.76252
atdmsr_7_8_8	7,000	513	na	na	2.46	6.0547	na	na	46,293.2	11.7298	0.0345	0.75671	0.00121	0.75913
atdmsr_7_8_7	7,000	513	na	na	2.46	6.0547	na	na	39,679.9	11.2268	0.0374	0.75221	0.00109	0.75438
atdmsr_7_8_6	7,000	513	na	na	2.46	6.0547	na	na	33,066.6	10.6742	0.0395	0.75004	0.00120	0.75245
atdmsr_7_8_5	7,000	513	na	na	2.46	6.0547	na	na	26,453.3	10.0575	0.0423	0.74240	0.00101	0.74442