# Safety Evaluation Report for

# Amendment 4 of USA/9315/B(U)F-96(DOE): Authorization of Bulk HEU Oxide Air Transport and Uranium Silicide Ground Transport

Docket No. 12-17-9315

Prepared by: ________________ Date: 1/24/13

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## SUMMARY

The National Nuclear Security Administration (NNSA), Office of Fissile Materials Disposition, submitted a letter dated June 12, 2012, requesting an amendment of the Certificate of Compliance (CoC) USA/9315/B(U)F-96(DOE) for the Model ES-3100 Type B packaging.[1] Along with the request for amendment, the ES-3100 Safety Analysis Report for Packaging (SARP), identified as SP-PKG-801940-A001, Revision 0, Page Change 3, dated June 21, 2012, was submitted with the intent to provide the necessary documentation.

The request for Amendment 4 of the CoC USA/9315/B(U)F-96(DOE) included three topics:

1) Change the $^{233}U$ concentration limit in oxide contents;
2) Add bulk highly enriched uranium (HEU) oxide as an authorized content for air transport and add uranium silicide as an authorized content for ground transport; and
3) (a) Add Viton GLT-S as an optional O-ring for extended maintenance of two years
   (b) Revise the spacer can drawing M2E801580A043 to make the vibrating absorbing silicone can pad optional
   (c) Increase the amount of $^{235}U$ in U-Al reactor fuel, make allowance for convenience cans with diameters larger than 4.25 inches along with the potential off-gassing materials in the ES-3100 Containment Vessel (CV)
   (d) Remove the requirements to place empty convenience cans on top of the loaded cans
   (e) Revise the wording on use of convenience cans to allow for contents that can not fit into a convenience can to be bagged only (no convenience can)
   (f) Add the option of applying ARG-US radiofrequency identification (RFID) systems, etc.[1]

The first topic has been approved and Revision 4 of CoC USA/9315/B(U)F-96(DOE) was issued in August 2012. The second topic of the request for Amendment 4 includes two sub-topics: a) add bulk HEU oxide as an authorized content for air transport into Table 1.3b of the SARP, and b) add uranium silicide as an authorized content for ground transport. Uranium silicide ($U_3Si_2$) is requested to be added under the category of "Uranium Compounds," and $U_3Si_2$ fuel clad in aluminum ($U_3Si_2$-Al) is requested to be added under the category of "Research reactor fuel elements and components." Since research reactor fuel elements and components have been authorized for air transport in Revision 4 to the CoC, U3Si2-Al content under this category is also requested for air transport. Additional calculations are provided in the SARP to support the authorization of $U_3Si_2$ and $U_3Si_2$-Al contents.

DOE Packaging Certification Program (PCP) staff reviewed the ES-3100 SARP Rev. 0, Page Change 3 for the second topic of the request for Amendment 4, and provided eight Q1 questions on the 9 SARP chapters. The applicant responded to all the questions and provided revisions to the SARP Rev. 0, Page Change 3, which were accepted and incorporated into the SARP Rev. 0, Page Change 4.[2]

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation as summarized in this Safety Evaluation Report (SER), DOE PCP finds that the information presented in the SARP is acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

DOE PCP has concluded that in addition to the conditions of approval in Revision 4 to the 4 CoC, the following conditions are needed pursuant to the approval of the second topic in the request for Amendment 4, as follows:

1. *For air transport, the total amount of free water in Kaolite is limited to 12 lb (5,443 g).*

2. *The following issues in the SARP are still under review and are not authorized in this certificate:*
   a) *use of the Viton GLT-S O-ring,*
   b) *extension of the periodic leak test interval to 2 years,*
   c) *use of convenience can with a diameter greater than 4.25 inches along with off-gassing packing material,*
   d) *use of empty convenience cans as spacers beneath loaded convenience cans, and*
   e) *use of a bag instead of convenience can as an option in situations that currently require convenience cans.*

3. *Only the drawings listed in Condition 5(a)(3) are authorized for use*

References


1. Request for Amendment 4 of USA/9315/B(U)F-96(DOE), submitted to James M. Shuler, Manager of Packaging Certification Program, Office of Packaging and Transportation of Department of Energy, by the National Nuclear Security Administration (NNSA), Office of Fissile Materials Disposition, June 12, 2012.

2. Safety Analysis Report for Packaging for Model ES-3100 Package with Bulk HEU Contents, SP-PKG-801940-A001 Rev. 0, Page Change 4, Babcock & Wilcox Technical Services Y-12. LLC, Y-12 National Security Complex, January 10, 2013.


## 1. GENERAL INFORMATION AND DRAWINGS

Detailed packaging descriptions, drawings and contents can be found in the ES-3100 SARP Page Change 4. The components of the ES-3100 packaging include an outer drum, impact-limiting and thermal-insulating material Kaolite 1600, neutron-absorbing material Cat 277-4, a CV, and content containers.

The second topic of the request for Amendment 4 includes the following: a) add bulk HEU oxide as an authorized content for air transport, and b) add uranium silicide as an authorized content for ground transport. The maximum concentrations of uranium isotopes that are permitted in the ES-3100 package contents are listed in Table 1.1 of the SARP. The bounding uranium isotopic concentration in HEU oxides is listed in Table 1.2 of the SARP. The maximum impurities in uranium silicide are shown in Table 1.2a. Tables 1.3, 1.3a and 1.3b with the two new contents of the SARP are shown in red below.

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

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

| | |
|---|---|
| Oxygen | 7000 |
| Zinc | 1000 |

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

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

**Table 1.3. Authorized Content and Fissile Mass Loading Limits for Ground Transport for the ES-3100 HEU Package [a, b, c]**

| Content description | | Enrichment | CSI | No Spacers, $^{235}$U (kg) | Basis for limit | 277-4 can Spacers, [d] $^{235}$U (kg) | Basis for limit |
|---|---|---|---|---|---|---|---|
| Solid HEU metal or alloy (specified geometric shape) [e] | Cylinder A | ≤ 100% | 0.0 | 15.000 | Crit. | 25.000 | Crit. |
| | Cylinder B | ≤ 100% | 0.0 | 18.000 | Crit. | 30.000 | Crit. |
| | Square bars | ≤ 100% | 0.0 | 30.000 | Crit. | 35.200 [f] | Struct. |
| | Slugs | ≤ 95% | 0.0 | 17.374 | Crit. | - | - |
| | Slugs | ≤ 80% | 0.0 | - | - | 29.318 | Crit. |
| | Slugs | > 80%, ≤ 95% | 0.0 | - | - | 24.324 | Crit. |
| | Slugs | >80%, ≤ 95% | 0.4 | - | - | 34.749 | Crit. |
| Broken HEU metal or alloy [g] | | >95%, ≤ 100% | 0.0 | Spacers req'd [d] | | 2.774 | Crit. |
| | | | 0.4 | Spacers req'd | | 5.549 | Crit. |
| | | | 0.8 | Spacers req'd | | 9.248 | Crit. |
| | | | 2.0 | Spacers req'd | | 13.872 | Crit. |
| | | | 3.2 | Spacers req'd | | 24.969 | Crit. |
| | | >90%, ≤ 95% | 0.0 | Spacers req'd | | 3.516 | Crit. |
| | | | 0.4 | Spacers req'd | | 6.154 | Crit. |
| | | | 0.8 | Spacers req'd | | 10.549 | Crit. |
| | | | 2.0 | Spacers req'd | | 18.461 | Crit. |
| | | | 3.2 | Spacers req'd | | 26.373 | Crit. |
| | | >80%, ≤ 90% | 0.0 | Spacers req'd | | 3.333 | Crit. |
| | | | 0.4 | Spacers req'd | | 7.500 | Crit. |
| | | | 0.8 | Spacers req'd | | 12.500 | Crit. |
| | | | 2.0 | Spacers req'd | | 20.000 | Crit. |
| | | | 3.2 | Spacers req'd | | 28.334 | Crit. |
| | | >70%, ≤ 80% | 0.0 | 2.967 | Crit. | 4.450 | Crit. |
| | | | 0.4 | 5.192 | Crit. | 8.900 | Crit. |
| | | | 0.8 | 8.900 | Crit. | 16.317 | Crit. |
| | | | 2.0 | 17.059 | Crit. | 25.218 | Crit. |
| | | | 3.2 | 27.692 | Crit. | 28.184 | Crit. |
| | | >60%, ≤ 70% | 0.0 | 3.249 | Crit. | 5.198 | Crit. |
| | | | 0.4 | 5.848 | Crit. | 12.996 | Crit. |
| | | | 0.8 | 13.646 | Crit. | 20.793 | Crit. |
| | | | 2.0 | 21.444 | Crit. | 24.692 | Crit. |
| | | | 3.2 | 24.692 | Crit. | 24.692 | Crit. |
| | | ≤ 60% | 0.0 | 5.576 kg U | Crit. | 11.154 kg U | Crit. |

| Content description | | Enrichment | CSI | No Spacers, $^{235}U$ (kg) | Basis for limit | 277-4 can Spacers,[d] $^{235}U$ (kg) | Basis for limit |
|---|---|---|---|---|---|---|---|
| | | | 0.4 | 14.872 kg U | Crit. | 28.813 kg U | Crit. |
| | | | 0.8 | 28.814 kg U | Crit. | 35.20 kg U[f] | Struct. |
| | | | 2.0 | 35.20 kg U[f] | Struct. | 35.20 kg U[f] | Struct. |
| | | | 3.2 | 35.20 kg U[f] | Struct. | 35.20 kg U[f] | Struct. |
| HEU oxide[h, j] ($UO_2$, $UO_3$, $U_3O_8$, $U_3O_8$-Al, $UO_2$-Mg,[n] $UO_2$-$ZrO_2$) | | ≤ 100% | 0.0 | 15.13 kg oxide<br>9.682 kg $^{235}U$<br>921 g carbon | Crit.<br>$H_2$ gen. | Spacers not req'd | |
| Research reactor fuel elements and components[k] | $UZrH_x$ (TRIGA) | ≤ 20% | 0.0 | 0.921[i] | Crit. | Spacers not req'd | |
| | | > 20%, ≤ 70% | 0.0 | 0.408[i] | Crit. | Spacers not req'd | |
| | $UZrH_x$ (SNAP) | ≥ 93% | 0.0 | 0.857[i] | Crit. | Spacers not req'd | |
| | U-Zr | ≤ 100% | Varies | See limit for broken metal or alloy[g] | Crit. | Spacers as req'd | |
| | U-Al | ≤ 100% | 0.0 | 7.333 kg U-Al<br>525 g U<br>473 g $^{235}U$ | Crit. | Spacers not req'd | |
| | $U_3O_8$-Al | ≤ 100% | 0.0 | 15.13 kg oxide<br>9.682 kg $^{235}U$[l]<br>921 g carbon | Crit. | Spacers not req'd | |
| | $UO_2$ | ≤ 100% | 0.0 | 21.937 kg $UO_2$<br>19.308 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | Oxides of U-Zr[m] | ≤ 100% | 0.0 | 15.13 kg oxide<br>9.682 kg $^{235}U$[l]<br>921 g carbon | Crit. | Spacers not req'd | |
| | $UO_2$-Mg[n] | ≤ 100% | 0.0 | 15.13 kg oxide<br>9.682 kg $^{235}U$[l]<br>921 g carbon | Crit. | Spacers not req'd | |
| | $U_3Si_2$-Al[o] | ≤ 100% | 0.0 | 5.825 kg $U_3Si_2$-Al<br>2.227 kg U<br>450 g $^{235}U$ | Crit. | Spacers not req'd | |
| Uranium compounds | $UF_4$ | ≤ 100% | 0.0 | 3 kg $UF_4$<br>2.267 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | $UO_2F_2$ | ≤ 100% | 0.0 | 3 kg $UO_2F_2$<br>2.067 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | UC | ≤ 100% | 0.0 | 2 kg UC<br>1.815 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | UN | ≤ 100% | 0.0 | 2 kg UN<br>1.888 kg $^{235}U$ | Crit. | Spacers not req'd | |

| Content description | | Enrichment | CSI | No Spacers, $^{235}U$ (kg) | Basis for limit | 277-4 can Spacers,[d] $^{235}U$ (kg) | Basis for limit |
|---|---|---|---|---|---|---|---|
| | TRISO | ≤ 100% | 0.0 | 2 kg TRISO<br>1.815 kg $^{235}U$ | Crit. | Spacers not req'd | |
| | $U_3Si_2$ [o] | ⩾19.7%, <40%<br>⩾40%, ⩽60% | 0.0<br>0.0 | 13 kg $U_3Si_2$<br>7 Kg $U_3Si_2$ | Crit.<br>Crit. | Spacers not req'd<br>Spacers not req'd | |

a All limits are expressed in kg $^{235}U$ unless otherwise indicated.
b With the exception of the UNX crystals (Section 1.2.2.2 of the SARP), which are loaded in crystalline solid Mass loadings cannot be rounded up.
d 277-4 can spacers as described on Drawing No. M2E801580A043 (Appendix 1.3.7 of the SARP)
e Geometries of solid shapes are as follows:
- Cylinder A is larger than 3.24 in. diameter but no larger than 4.25 in. diameter: maximum of 1 cylinder per can.
- Cylinder B is no larger than 3.24 in. diameter: maximum of 1 cylinder per can.
- Square bars are no larger than 2.29 in. × 2.29 in. (cross section): maximum of 1 bar per can.
- Slugs are a maximum of 1.5-in. diameter × 2.0 in. tall: a maximum of 10 per convenience can where the actual number permitted is restricted by the stated loading limit.

f Maximum planned content weight is 35.20 kg. Maximum analyzed for criticality safety is 35.32 kg.
g Mass limits for alloys (uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) must assume that non-uranium portion is $^{235}U$.
h Seal time must be 12 months or less. Seal time is the length of time after the ES-3100 HEU package containment vessel is sealed that the shipment must be complete.
i Evaluation limit based on specific fuel type as opposed to a maximum calculated limit for $UZrH_x$.
j Allowable HEU bulk oxide densities are 2.0-6.54 g/cm$^3$. Non-uranium metallic constituents must be counted as $^{235}U$. Moisture content in oxide is limited to 3 weight percent water.
k For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
l Non-uranium metallic constituents must be counted as $^{235}U$.
m Oxides of U-Zr are $UO_2$-Zr and $UO_2$-$ZrO_2$.
n $UO_2$-Mg shall be shipped in a glass bottle inside a metal convenience can under an inert cover gas.
o The maximum impurities in uranium silicide are shown in Table 1.2a of the SARP.

**Table 1.3a – Loading Limits for Uranyl Nitrate Crystals for Ground Transport**

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

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

**Table 1.3b. Authorized content and Fissile Mass Loading Limits for air transport of the ES-3100 HEU Package.** [a, b, c]

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

a All limits are expressed in kg $^{235}U$ unless otherwise indicated.
b Mass loadings cannot be rounded up.
c The loading limit for mixed-mode transportation is taken as the most restrictive limit for either ground or air mode of transportation (Table 1.3 or 1.3b of the SARP).
d Mass limits for alloys (uranium with aluminum, molybdenum, zirconium, stainless steel, titanium, tungsten, niobium, silicon, or vanadium) must assume that non-uranium portion is $^{235}U$.
e For SNAP $UZrH_x$, $x \leq 2$. For TRIGA $UZrH_x$, $x \leq 1.6$.
f Oxides of U-Zr are $UO_2$-Zr and $UO_2$-$ZrO_2$.
g CSI is governed by ground transport mode.
h Seal time must be 12 months or less. Seal time is the length of time after the ES-3100 HEU package containment vessel is sealed that the shipment must be complete.
i Allowable HEU bulk oxide densities are 2.0-6.54 g/cm$^3$. Non-uranium metallic constituents must be counted as $^{235}U$. Moisture content in oxide is limited to 3 weight percent water.
j $UO_2$-Mg shall be shipped in a glass bottle inside a metal convenience can under an inert cover gas.

Criticality Safety Index

On the basis of the results of the criticality safety analysis presented in Chapter 6 of the SARP Page Change 4, DOE PCP has confirmed, using the procedure in 10 CFR 71.59(b), that the Criticality Safety Index (CSI) is zero (0) for the newly added contents, the bulk HEU oxide for air transport, and the uranium silicide for ground transport.

Radiation Level and Transport Index

DOE PCP has confirmed that the radiation transport indices (TIs) for the new contents are less than 4.9, the TI calculated for 24 kg HEU oxide, which is less than 10, the TI limit in 10 CFR 71.47(a) for ***non exclusive use shipment***. The actual TI of the ES-3100 package will be determined by measurement prior to shipment.

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the general information and drawings presented in Chapter 1 of the SARP are acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

Evaluations of design and performance of the package for safety and regulatory compliance in structural, thermal, containment, shielding, criticality safety, operating procedures, acceptance tests and maintenance, and quality assurance are given in the remaining sections of this SER.

DOE PCP has concluded that in addition to the conditions of approval in Revision 4 to the CoC, the following condition is needed pursuant to the approval of the second topic in the request for Amendment 4, as follows: *Only the drawings listed in Condition 5(a)(3) are authorized for use*

## 2. STRUCTURAL

DOE PCP staff reviewed the structural design and performance of the ES-3100 package for air transport of bulk HEU oxide and ground transport of uranium silicide, as described in Chapter 2 of the SARP Page Change 4. DOE PCP staff also reviewed the material compatibility between HEU oxide and uranium silicide contents and other packaging components.

The amount of HEU oxide for air transport is 5.281 kg, which is bounded by the radioactive content weight limit of 35.2 kg of the ES-3100 HEU package. Therefore, the structural evaluation in the original SARP remains valid. The enhanced structural tests described in 10 CFR 71.55(f)(1) and (2) for air transport of fissile material packages were not conducted, which means the condition of the package following the tests cannot be demonstrated. Therefore, in Chapter 6 of the SARP, worst-case assumptions regarding the geometric arrangement of the package and contents were made for the criticality analysis, with all moderating and structural components of the packaging taken into account. These assumptions are consistent with the expected worst-case results of the mechanical and thermal tests specified in 10 CFR 71.55(f)(1) and (2).

For air transport, IAEA TS-R-1, Paragraph 618, requires that packages maintain integrity of containment when exposed to ambient temperatures ranging from -40$^{o}$C to +55$^{o}$C, and Paragraph 619 requires that packages be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than maximum normal operating pressure (MNOP) plus 95 kPa (13.78 psi). The condition for calculating MNOP for air transport is an ambient temperature of 55$^{o}$C in still air without solar insolation (IAEA TS-G-1.1, Paragraph 619.3). The calculated MNOP for air transport is 28.778 psi at a CV temperature of 63.4$^{o}$C (146.11$^{o}$F). The CV was then evaluated at a pressure differential of 293.43 kPa (42.558 psi = 28.778 psi + 13.78 psi), and the results show that the structural integrity of the CV can be maintained.

The weight of the $U_3Si_2$ contents is limited to 13 kg, which is bounded by the radioactive content weight limit of 35.2 kg. Therefore, the structural evaluation of the ES-3100 package remains valid for the shipment of uranium silicide contents.

HEU oxide has previously been authorized for ground transport in the ES-3100 package; therefore, there is no material incompatibility issue for HEU oxide. The uranium silicide content is either $U_3Si_2$ in tin-plated carbon-steel, stainless-steel, or nickel-alloy convenience cans, or $U_3Si_2$-Al in a modified convenience can or protected on each end with an open-ended can constructed of stainless steel, tin-plated carbon steel, or nickel alloy. Therefore, there is no material incompatibility between the contents and the packaging components.

On the basis of the statements and representations in the SARP Page Change 4 and the DOE PCP staff's confirmatory evaluation, DOE PCP finds that the structural design and performance presented in Chapter 2 of the SARP are acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 3. THERMAL

DOE PCP staff reviewed the thermal design and performance of the ES-3100 package for air transport of bulk HEU oxide and ground transport of uranium silicide, as described in Chapter 3 of the SARP Page Change 4. The review and evaluation were focused on the decay heat of the new contents.

The material requested to be shipped via air transportation is only 5.281 kg HEU oxide in $^{235}U$, with enrichment nearly 100%, as detailed in Table 1.3b in Chapter 1 of the SARP Page Change 4. This content mass is less than the 7.00 kg metal or alloy of HEU in $^{235}U$ that has been previously evaluated and approved for air transport. The decay heat of 5.281kg HEU oxide in $^{235}U$ is bounded by 5 W, the decay heat calculated for 35.2 kg HEU.

IAEA regulations in TS-R-1 require that an air transport package be evaluated 1) at a maximum differential pressure of MNOP plus 95 kPa, and 2) at an ambient temperature ranging from -40$^{o}$ C to 55$^{o}$ C. DOE PCP staff reviewed the calculation results in the SARP Page Change 4, and found the peak temperatures of all packaging components within the allowable limits.

The $U_3Si_2$ limit for ground transport is either 13 kg (for enrichment of 19.7~40%) or 7 kg (for enrichment of 40~60%). The $U_3Si_2$-Al limit for ground transport is 5.825 kg (or 0.45 kg in 235U). Both cases are bounded by the above-mentioned 32.5 kg HEU, producing a maximum decay heat of 5 W.

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the thermal design and performance presented in Chapter 3 of the SARP are acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 4. CONTAINMENT

DOE PCP staff reviewed the design analysis, full-scale testing, and similarity of the ES-3100 prototypes in Chapter 4 of the SARP Page Change 4. DOE PCP staff also reviewed the analysis described in Appendices 4.5.1 and 4.5.2, which provide the reference air leakage rates and the allowable leakage rate for the CV using He for leak testing under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

Containment Boundary

The containment boundary consists of the CV body, lid assembly, and inner O-ring (Fig. 1.3 of the SARP). A summary of the containment boundary design and acceptance basis is given in Table 4.2 of the SARP. The O-rings (Drawing M2E801580A013, Appendix 1.3.7) are manufactured from ethylene propylene diene monomer (EPDM) in accordance with Equipment Specification SPC-M801580-0002 (Appendix 1.3.10). The SARP describes a test in which a full-scale prototype was chilled to ≤ -40$^{o}$ C and subjected to an NCT drop test and the entire HAC test battery. The CV was leak tested and found to be leaktight. The SARP states that the continuous-service temperature rating of the EPDM O-ring has been verified by testing. DOE PCP staff concurs with this statement.

Containment under NCT

The ANSI N14.5-1997 requirements are used for all stages of containment verification. The design, fabrication, maintenance, and periodic leakage rate limit is $1 \times 10^{-7}$ ref-cm$^3$/s air (or equivalent). According to the SARP (Section 4.2, page 4–8), the acceptance criterion for preshipment leakage rate testing shall be either (1) a leakage rate of not more than the reference air leakage rate, LR (as obtained in

Appendix 4.5.2), or (2) no detected leakage rate when tested to a sensitivity of at least $10^{-3}$ ref-$cm^3$/s. The SARP states that the containment system meets the leaktight criterion defined in ANSI N14.5-1997 after the conclusion of the NCT and HAC test series documented in ORNL/NTRC-013. DOE PCP staff reviewed the test procedures and the results and found them acceptable.

The International Civil Aviation Organization (ICAO) issues *Technical Instructions for the Safe Transport of Dangerous Goods by Air*. The ICAO Technical Instructions (ICAO TI) directly apply to the international civil transport of dangerous goods. Part 6, Chapter 7, Section 7.2.3 of the ICAO TI states that "Packages containing radioactive material must be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than maximum normal operating pressure plus 95 kPa." The International Air Transport Association (IATA) Dangerous Goods Regulations (DGRs) are applicable to all IATA member airlines. The IATA DGRs essentially replicate the requirement set forth in the ICAO TI, and therefore air transport of the bulk HEU package needs to satisfy the requirement specified in Section 7.2.3 of the IATA DGRs. In order to comply with 49 CFR 173.410(i)(2), the range of temperatures evaluated shall be from -40$^{o}$ C to +55$^{o}$ C (ambient temperature). According to TS-G-1.1, Paragraph 619.3, the evaluation at an ambient temperature of 55$^{o}$ C does not consider insolation; however, self-heating of the package is taken into account. DOE PCP staff reviewed Appendix 4.5.2, which incorporates these pressure and temperature requirements for air transport, and found the calculations acceptable.

Containment under HAC

The maximum allowable release of radioactive material in 10 CFR 71.51(a)(2) under HAC is $A_2$ in one week. Calculations have been conducted in Appendix 4.5.2 of the SARP to determine the regulatory leakage criteria to satisfy the above requirements. Table 4.7 of the SARP shows the regulatory leakage criteria for HAC. Table 4.8 of the SARP shows the containment vessel design verification tests for HAC. DOE PCP staff reviewed the test results in ORNL/NTR-013 and found them acceptable.

Conclusion

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the containment design and performance presented in Chapter 4 of the SARP are acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 5. SHIELDING

DOE PCP staff reviewed Chapter 5 of the SARP Page Change 4 for air transport of bulk HEU oxide and ground transport of uranium silicide. The DOE PCP staff also evaluated the adequacy of the shielding evaluation of the package in Chapter 5 of the SARP during NCT and HAC.

The ES-3100 packaging does not contain material specifically intended for radiation shielding, although the stainless steel of the drum and the CV, the Kaolite material, and the 277-4 material provide some radiation attenuation. Restricting the amount of source material keeps the radiation dose rates below the regulatory limits.

DOE PCP staff used ORIGEN-S to calculate the source terms in the confirmatory evaluation of the uranium silicide contents, including impurities specified in Table 1.2a of the SARP. The gamma and the neutron source spectra of the uranium silicide are compared with the reference HEU uranium oxide content in Table 5.1 and Table 5.2, respectively.

Table 5.1 shows a higher (by ~7%) total photon source for the reference $UO_2$ than for the $U_3Si_2$, on the basis of per gram HEU. The gamma dose rates for the $U_3Si_2$ content can be estimated from the ratio of the gamma source terms without explicit MCNP calculations.

**Table 5.1 Comparison of 18-group Gamma Spectra for 1.0 gram HEU in $UO_2$ and $U_3Si_2$**

| Gamma Group | Gamma Energy (MeV) | | $UO_2$ | $U_3Si_2$ |
|---|---|---|---|---|
| | Lower | Upper | 10.5 years decay | |
| 18 | 8.00E+00 | 1.00E+01 | 4.39E-05 | 5.11E-05 |
| 17 | 6.50E+00 | 8.00E+00 | 2.13E-04 | 2.45E-04 |
| 16 | 5.00E+00 | 6.50E+00 | 1.13E-03 | 1.28E-03 |
| 15 | 4.00E+00 | 5.00E+00 | 2.96E-03 | 3.28E-03 |
| 14 | 3.00E+00 | 4.00E+00 | 9.56E-03 | 1.01E-02 |
| 13 | 2.50E+00 | 3.00E+00 | 1.01E+04 | 1.01E+04 |
| 12 | 2.00E+00 | 2.50E+00 | 1.16E-01 | 6.56E-02 |
| 11 | 1.66E+00 | 2.00E+00 | 5.23E+01 | 5.83E+01 |
| 10 | 1.33E+00 | 1.66E+00 | 6.26E+02 | 6.32E+02 |
| 9 | 1.00E+00 | 1.33E+00 | 2.22E+02 | 2.60E+02 |
| 8 | 8.00E-01 | 1.00E+00 | 1.51E+03 | 1.58E+03 |
| 7 | 6.00E-01 | 8.00E-01 | 2.76E+03 | 2.85E+03 |
| 6 | 4.00E-01 | 6.00E-01 | 2.70E+04 | 2.71E+04 |
| 5 | 3.00E-01 | 4.00E-01 | 2.83E+05 | 2.83E+05 |
| 4 | 2.00E-01 | 3.00E-01 | 5.11E+04 | 4.83E+04 |
| 3 | 1.00E-01 | 2.00E-01 | 1.29E+05 | 7.53E+04 |
| 2 | 5.00E-02 | 1.00E-01 | 5.55E+05 | 5.40E+05 |
| 1 | 1.00E-02 | 5.00E-02 | 1.13E+06 | 9.09E+05 |
| **Total for Groups 1 to 18** | | | **2.19E+06** | **1.90E+06** |

Table 5.2 shows a higher (by ~12%) total neutron source for the reference $UO_2$ than for the $U_3Si_2$, on the basis of per gram HEU. The neutron dose rates for the $U_3Si_2$ content can be estimated from the reference $UO_2$ content results from the ratio of the neutron source terms without explicit MCNP calculations.

**Table 5.2 Comparison of 27-group Neutron Spectra for 1.0 gram HEU in $UO_2$ and $U_3Si_2$**

| Neutron Group | Neutron Energy (MeV) | | $UO_2$ | $U_3Si_2$ |
|---|---|---|---|---|
| | Lower | Upper | 15 years decay | |
| 27 | 6.38E+00 | 2.00E+01 | 7.30E-04 | 8.59E-04 |
| 26 | 3.01E+00 | 6.38E+00 | 3.36E-02 | 2.02E-02 |
| 25 | 1.83E+00 | 3.01E+00 | 1.03E-01 | 5.69E-02 |
| 24 | 1.42E+00 | 1.83E+00 | 2.48E-02 | 1.97E-02 |
| 23 | 9.07E-01 | 1.42E+00 | 2.19E-02 | 2.23E-02 |
| 22 | 4.08E-01 | 9.07E-01 | 1.56E-02 | 4.40E-02 |
| 21 | 1.11E-01 | 4.08E-01 | 8.92E-03 | 1.88E-02 |
| 20 | 1.50E-02 | 1.11E-01 | 1.78E-03 | 2.94E-03 |
| 19 | 3.04E-03 | 1.50E-02 | 8.21E-05 | 7.92E-05 |
| 18 | 5.83E-04 | 3.04E-03 | 6.98E-06 | 7.17E-06 |
| 17 | 1.01E-04 | 5.83E-04 | 5.83E-07 | 5.65E-07 |
| 16 | 2.90E-05 | 1.01E-04 | 3.64E-08 | 3.74E-08 |
| 15 | 1.07E-05 | 2.90E-05 | 4.87E-09 | 5.07E-09 |
| 14 | 3.06E-06 | 1.07E-05 | 1.53E-09 | 1.03E-09 |
| 13 | 1.86E-06 | 3.06E-06 | 1.98E-10 | 1.06E-10 |
| 12 | 1.30E-06 | 1.86E-06 | 8.53E-11 | 4.12E-11 |
| 11 | 1.13E-06 | 1.30E-06 | 2.59E-11 | 1.16E-11 |
| 10 | 1.00E-06 | 1.13E-06 | 1.83E-11 | 7.44E-12 |
| 9 | 8.00E-07 | 1.00E-06 | 2.86E-11 | 1.09E-11 |
| 8 | 4.14E-07 | 8.00E-07 | 5.28E-11 | 1.54E-11 |
| 7 | 3.25E-07 | 4.14E-07 | 1.16E-11 | 2.87E-12 |
| 6 | 2.25E-07 | 3.25E-07 | 1.27E-11 | 2.85E-12 |
| 5 | 1.00E-07 | 2.25E-07 | 1.11E-11 | 2.63E-12 |
| 4 | 5.00E-08 | 1.00E-07 | 1.13E-12 | 5.75E-13 |
| 3 | 3.00E-08 | 5.00E-08 | 3.95E-13 | 1.64E-13 |
| 2 | 1.00E-08 | 3.00E-08 | 2.81E-13 | 1.09E-13 |
| 1 | 1.00E-11 | 1.00E-08 | 2.87E-15 | 1.70E-14 |
| **Total for Groups 1 to 27** | | | **2.10E-01** | **1.86E-01** |

In order to evaluate the adequacy of the shielding design for the two contents, DOE PCP staff compared the shipping content weights and the ORIGEN-S-calculated source terms. Table 5.3 shows the content weights and the gamma and neutron source multiplication factors that are used to estimate the MCNP dose rates in Table 5.4.

**Table 5.3 Source Multiplication Factors Used to Estimate the MCNP-calculated Dose Rates**

| | **Reference** | **Air Transport** | **Uranium Silicides** | |
|---|---|---|---|---|
| Content Type | $UO_2$ | $UO_2$ | $U_3Si_2$ | $U_3Si_2$-Al |
| Content (kg) | 24 | 7.19 | 13 | 5.825 |
| U fraction | 0.88 | 0.88 | 0.93 | 0.39 |
| HEU (kg) | 21.12 | 6.33 | 12.05 | 2.277 |
| $^{235}U$ (kg) | 19.43 | 5.281 | 4.82 | 0.91 |
| Ratio of HEU (kg) to $UO_2$ reference | 1.00 | 0.30 | 0.57 | 0.45 |
| Ratio of gamma source to $UO_2$ reference | 1.00 | 1.00 | 0.93 | 0.93 |
| Ratio of neutron source to $UO_2$ reference | 1.00 | 1.00 | 0.88 | 0.88 |
| Gamma dose rate multiplication factor | 1.00 | 0.30 | 0.53 | 0.42 |
| Neutron dose rate multiplication factor | 1.00 | 0.30 | 0.50 | 0.39 |

**Table 5.4 Calculated Maximum Dose Rates for the New Contents**

| **Maximum Dose Location** | | **Reference (mSv/h)** | **Staff-calculated (mSv/h)** | | | **10 CFR 71 Limits (mSv/h)** |
|---|---|---|---|---|---|---|
| | | **$UO_2$** | **Air Transport $UO_2$** | **Ground Transport $U_3Si_2$** | **Ground Transport $U_3Si_2$-Al** | |
| NCT, on package surface | Bottom surface of the package | **0.81** | 0.243 | 0.430 | 0.338 | **2** |
| NCT, 1 m from package surface | 1 m from the side surface of the package | **0.049** | 0.0147 | 0.0260 | 0.0204 | **0.1** |
| HAC | 1 m from the side surface of the CV | **0.11** | 0.033 | 0.058 | 0.046 | **10** |

Table 5.4 shows that the maximum dose rates for air transport of bulk HEU oxide are ~1/3 of those for the reference $UO_2$. The maximum dose rates for ground transport of the $U_3Si_2$ are ~1/2 of those for the reference $UO_2$, and the maximum dose rates for ground transport of the $U_3Si_2$-Al are ~2/5 of those for the reference $UO_2$. All are well below the 10 CFR 71 regulatory limits, with substantially large safety margins.

The TI is calculated to be 4.9 for the 24-kg HEU oxide content. During actual operations with the ES-3100 packaging, the TI will be determined by measurement prior to shipment.

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the shielding design and performance presented in Chapter 5 of the SARP are acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 6. CRITICALITY

DOE PCP staff reviewed the criticality safety design of the ES-3100 package described in Chapter 6 of the SARP Page Change 4, and the criticality evaluations for uranium silicide (Appendix 6.9.8 of the SARP), MIT fuel (Appendix 6.9.8 of the SARP), and air transport of bulk HEU oxide (Appendix 6.9.9 of the SARP). DOE PCP staff also performed Monte Carlo analyses to independently confirm the criticality safety for a single package, as well as for an array of packages under the most reactive conditions during NCT and HAC for the requested content additions and changes.

Package Description

The ES-3100 package design includes a stainless steel CV inside a 30-gallon outer drum (see Figures 1.1 and 1.2 of the SARP). The payload is placed in convenience cans or bottles or otherwise protected to prevent contamination of the interior surface of the containment vessel. The package includes two features intended for criticality control: neutron absorber that surrounds the CV and can spacers placed between convenience cans, both filled with alumina borated cement. The drawings included in the SARP provide the dimensions of the relevant packaging components. Chapter 2 of the SARP provides material specifications for the packaging components.

Contents

The contents of the ES-3100 package include various forms of uranium metal, uranium alloys, uranium oxides, uranyl nitrate hydrate, uranium compounds, and unirradiated TRIGA fuel elements (see Tables 1.3, 1.3a, and 1.3b of the SARP for loading limits). Some of these contents were previously approved. The new contents addressed by this SER are addition of bulk HEU oxide as an authorized content for air transport, addition of uranium silicide ($U_3Si_2$) either in powder form or as fuel clad in aluminum ($U_3Si_2$-Al) for ground transport, and an increase in the $^{235}$U limit for U-Al fuel to allow shipment of MIT fuel.

The $^{235}$U content of $U_3Si_2$-Al research reactor fuel is significantly smaller than the $^{235}$U content of MIT fuel. Page 6-601 of the SARP states that $U_3Si_2$ fuel having similar dimensions and less fissile content is bounded by MIT U/Al fuel. Consequently, no specific calculations were performed for $U_3Si_2$-Al research reactor fuel in the SARP. DOE PCP staff concurs with this approach. Calculations were performed in the SARP and in the confirmatory analysis for $U_3Si_2$ powder.

The $^{235}$U enrichment limit varies with uranium form and payload mass and can range up to 100% for some payload configurations. Neutron absorber can spacers are required to meet criticality safety requirements for some payload configurations. These can spacers are not required for air transport of bulk HEU oxide, ground transport of uranium silicide, or ground transport of MIT fuel.

Each of the new content categories is evaluated with respect to criticality safety in Chapter 6 of the SARP (Appendixes 6.9.8 and 6.9.9). Descriptions of the ES-3100 packaging design features include identification of packaging materials, densities and compositions of packaging materials, and the fissile/fissionable material forms, masses, and isotopic compositions of the payloads. DOE PCP staff confirmed that criticality-related information in the SARP is complete and representative of the actual materials specified for the ES-3100 package. DOE PCP staff also confirmed that the models used in the criticality calculations are consistent with the drawings and the detailed package description given in the SARP.

Criticality Models

The KENO V.a code was used in the SARP for criticality analyses. Section 6.1.2 of the SARP notes that the expanded tests specified in 10 CFR 71.55(f)(1), (2), and (3) for air transport were not performed. Instead, analytical methods were used to demonstrate compliance of the ES-3100 package with the requirements of 10 CFR 71.55(f) by following the IAEA guidance for situations in which the condition of the package after testing cannot be shown (TS-G-1.1, Para. 680.2).

No credit was taken for package geometry in the air transport analysis. Conservative spherical models were used in Appendix 6.9.9 of the SARP for analysis of air transport. The payload was modeled as a spherical mixture of HEU oxide, water, and 500 g of polyethylene. The polyethylene represents the maximum amount of hydrogenous packing material in the package. The allowable density range of the HEU oxide in the SARP is 2.0–6.54 g/cm$^3$. The theoretical density of $UO_2$ is 10.96 g/cm$^3$, and the SARP assumed that the difference between the specific volume of the oxide at theoretical density and the specific volume of the oxide within the allowed oxide density range was occupied by water. For modeling purposes, this assumption means that the water content of the oxide in the models was much greater than the actual allowed moisture content of the oxide.

Six spherical models were analyzed for air transport in the SARP. Model 1 consisted of the payload sphere surrounded by a 20-cm water shell. In model 2, the payload sphere was surrounded by a stainless steel shell of varying thickness (stainless steel in the package) and a 20-cm water shell. In Model 3, the stainless steel shell was replaced by a wet Kaolite shell. In model 4, a homogeneous spherical mixture of oxide, water in the oxide, polyethylene, and wet Kaolite was surrounded by 20 cm of water. In Model 5, a homogeneous sphere consisting of oxide, water in the oxide, polyethylene, and excess water in the Kaolite was surrounded by a Kaolite shell and by 20 cm of water. Finally, in Model 6, a homogeneous mixture of part of the oxide, water in the oxide, polyethylene, and wet Kaolite was surrounded by a shell consisting of the remainder of the oxide and by a 20-cm water shell. These models conservatively envelop all credible configurations that could arise during the air transport. Furthermore, the layer of 277-4 neutron absorber between the CV and the Kaolite is neglected in these models.

The payload and the neutronically significant components of the ES-3100 package were included in the KENO V.a models for ground transport of uranium silicide and MIT fuel. Separate models were developed for single-package, NCT and HAC analyses. Two single-package models, one consisting of a full ES-3100 package and the other of just the containment vessel, were used to calculate the neutron multiplication factors for the uranium silicide and MIT fuel under fully flooded and reflected conditions. The NCT and HAC array calculations for uranium silicide and MIT fuel were based on detailed models of the ES-3100 package and on infinite arrays.

The SARP criticality analyses for uranium silicide and MIT fuel did not take credit for watertight containment either in the single-package analyses or in the array analyses. Water was modeled as the moderator and reflector for the single-package and array calculations. The SARP determined the configurations of maximum reactivity with respect to moisture content within the containment vessel and moisture contents of the neutron absorber and impact-absorbing insulation.

The Standard Composition Library and the 238GROUPNDF5 nuclear data library in the SCALE code package were used for all KENO V.a calculations in the SARP and in the confirmatory analyses. Section 6.8 of the SARP and Section 6.9.8.7 of Appendix 6.9.8 of the SARP summarize the determination of the minimum $k_{safe}$ value. The lowest $k_{safe}$ value determined from the validation for the proposed new contents is 0.924. Therefore, any configurations of ES-3100 packages with $k_{eff} + 2\sigma$ < ksafe are deemed subcritical. All calculations incorporated sufficient neutron histories to ensure statistical uncertainty ($\sigma$) less than 0.002 and adequate convergence. DOE PCP staff concurs that the benchmark experiments and corresponding bias value are applicable and conservative as applied to the ES-3100 package.

Air Transport of Bulk HEU Oxide

Six models were developed and analyzed in the SARP for air transport of bulk HEU oxide. All of these models are summarized in this SER and are described in more detail in Section 6.3.1.4 and Appendix 6.9.9 of the SARP. These models conservatively envelop all credible configurations that could arise during air transport.

Table 6.1 below shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Appendix 6.9.9 of the SARP and DOE PCP staff's confirmatory analyses for air transport of bulk HEU oxide. All six configurations resulted in acceptable $k_{eff} + 2\sigma$ values that are below the $k_{safe}$ limit of 0.924. Therefore, the ES-3100 package with bulk HEU oxide content and loading limits listed in Table 1.3b of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(f) related to air transport.

Ground Transport of Uranium Silicide and MIT Fuel-Evaluation of a single package under NCT and HAC

The analyses in Section 6.4 of the SARP show that maximum reactivity occurs for a fully flooded, reflected package, so the single package analysis is based on a fully flooded, reflected package. Appendix 6.9.8 of the SARP analyzed both a fully flooded, reflected containment vessel and a fully flooded, reflected package.

Table 6.1 below shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Appendix 6.9.8 of the SARP and DOE PCP staff's confirmatory analyses for the uranium silicide content and MIT fuel content in the single-package configuration. All single-package configurations resulted in acceptable $k_{eff} + 2\sigma$ values that are below the $k_{safe}$ limit of 0.924. Therefore, the ES-3100 single package with the proposed uranium silicide content, the increased $^{235}U$ limit in U-Al for MIT fuel, and the loading limits listed in Table 1.3 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(b) related to a flooded single package.

Ground Transport of Uranium Silicide and MIT Fuel-Evaluation of undamaged package arrays (NCT)

The NCT undamaged package array model for each of the proposed new or changed contents consisted of an infinite array of packages. The analyses in Chapter 6 of the SARP show that maximum reactivity occurs in an array of ES-3100 packages when the containment vessel is flooded and the packaging is dry, referring to a configuration in which (a) the neutron poison of the body weldment liner inner cavity and the impact absorbing insulation are dry, (b) recesses of the package external to the containment vessel do not contain any residual moisture, and (c) the interstitial space between packages in the array does not contain any residual moisture. All of the NCT array configurations are based on a flooded containment vessel and dry packaging to maximize the $k_{eff}$ of the array.

Table 6.1 below shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in the SARP and DOE PCP staff's confirmatory analyses for the new or changed contents under NCT. All NCT arrays resulted in acceptable $k_{eff} + 2\sigma$ values that are below the $k_{safe}$ limit of 0.924. Therefore, the ES-3100 package with the proposed uranium silicide content, the increased $^{235}U$ limit in U-Al for MIT fuel, and the loading limits listed in Table 1.3 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(d) and 10 CFR 71.59(a)(1).

Ground Transport of Uranium Silicide and MIT Fuel-Evaluation of damaged package arrays (HAC)

The analyses presented in Sections 6.4, 6.5, and 6.6 of the SARP show that the difference between calculated $k_{eff} + 2\sigma$ values for NCT arrays and corresponding HAC arrays is not significant. For that reason, separate HAC calculations were not performed for the uranium silicide powder content. DOE PCP staff concurs that the HAC results would not differ significantly from the NCT results for the uranium silicide powder. HAC calculations were performed for the MIT fuel.

The HAC damaged package array model for the MIT fuel consisted of an infinite array of packages, each with a flooded containment vessel and dry packaging to maximize the keff of the array. Table 6.1 below also shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in the SARP and DOE PCP staff's confirmatory analyses for the MIT fuel under HAC. All HAC arrays resulted in acceptable $k_{eff} + 2\sigma$ values that are below the ksafe limit of 0.924. Therefore, the ES-3100 package with the proposed uranium silicide content, the increased $^{235}$U limit in U-Al for MIT fuel, and the loading limits listed in Table 1.3 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(e) and the HAC-related requirements of 10 CFR 71.59(a)(2).

**Table 6.1 Summary of SARP and DOE PCP Staff Confirmatory Analyses for the 9315 (ES-3100) Package**

| Case | Content | SARP Case | Maximum $k_{eff} + 2\sigma$ [a] | |
|---|---|---|---|---|
| | | | SARP | Staff |
| **HEU Bulk Oxide – Air Transport** | | | | |
| A1 | HEU oxide | 5atdor_1_1_6 | 0.91679 | 0.91396 |
| A2 | HEU oxide | 5atdosr_11 | 0.89434 | 0.89249 |
| A3 | HEU oxide | 5atdo15kr_6 | 0.72859 | 0.72934 |
| A4 | HEU oxide | 5athop15kr_5 | 0.57417 | 0.57111 |
| A5 | HEU oxide | 5athopw15kr_5 | 0.83003 | 0.83217 |
| A6 | HEU oxide | 5athop15kor_5_2_4 | 0.58351 | 0.58109 |
| **Uranium Silicide and MIT Fuel – Ground Transport** | | | | |
| **Single Package – Flooded CV or Package** | | | | |
| S1 | Uranium silicide | 5cvcrpdusit11_8_2_13_15 | 0.91978 | 0.91770 |
| S2 | Uranium silicide | 5ncsrdpust11_8_2_13_15 | 0.82447 | 0.82143 |
| S3 | MIT fuel | 5cvcrmitfpt11_6_1_15 | 0.47286 | 0.47381 |
| **NCT Array** | | | | |
| N1 | Uranium silicide | 5nciadpust11_3_7_7_3 | 0.91940 | 0.92005 |
| N2 | Uranium silicide | 5nciadpust11_2_7_13_3 | 0.89041 | 0.89464 |
| N3 | MIT fuel | 5nciamitfpt11_6_1_3 | 0.47215 | 0.47360 |
| **HAC Array** | | | | |
| H1 | MIT fuel | 5hciamitfpt12_6_1_3 | 0.47453 | 0.47334 |

a Upper subcritical limit $k_{safe}$ value is 0.924.

Criticality Safety Index (CSI) for Nuclear Criticality Control

On the basis of NCT/HAC infinite array analyses of the proposed new contents, a minimum CSI of 0.0 was determined and reported in Chapter 1 of the SARP. DOE PCP concurs that this CSI value is appropriate for the ES-3100 package with the proposed uranium silicide content, the increased $^{235}$U limit in U-Al for MIT fuel, and the loading limits listed in Table 1.3 of the SARP.

Conclusion

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the criticality safety design and performance presented in Chapter 6 of the SARP are acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 7. PACKAGE OPERATIONS

DOE PCP staff reviewed the requirements for general operating procedures for loading, unloading, shipping, and receiving the ES-3100 packages; preparation of empty ES-3100 packages for transport; and other operations as described in Chapter 7 of the SARP Page Change 4. The specific operational requirements for the package are presented in Chapter 7, and shall be implemented by the package user.

The package user shall develop specific written operating procedures to ensure that the package operations are conducted in accordance with the CoC and Chapter 7 of the SARP. In addition, for air transport, the shipper shall verify and document that the total free water in the Kaolite is less than 12 lb (5,443 g).

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the package operations presented in Chapter 7 of the SARP are acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

DOE PCP staff reviewed the requirements for Acceptance Tests and Maintenance in Chapter 8 of the SARP Page Change 4. There is no change required in Chapter 8 of the SARP for air transport of bulk HEU oxide and ground transport of uranium silicide.

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the acceptance tests and maintenance program presented in Chapter 8 of the SARP are acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

DOE PCP has concluded that in addition to the conditions of approval in the Rev. 4 CoC, the following condition is needed:

*"For air transport, the total amount of free water in Kaolite is limited to 12 lb (5,443 g)."*

## 9. QUALITY ASSURANCE

DOE PCP staff reviewed the requirements for the quality assurance (QA) program in Chapter 9 of the SARP Page Change 4. There is no change required in Chapter 9 of the SARP for air transport of bulk HEU oxide and ground transport of uranium silicide.

On the basis of the statements and representations in the SARP Page Change 4 and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the QA program presented in Chapter 9 of the SARP is acceptable for air transport of bulk HEU oxide and ground transport of uranium silicide, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.