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DOE Packaging Certification Program

Safety Evaluation Report for Certificate of Compliance No. 9315 Amendment for the Model ES-3100 Package

Docket No. 19-11-9315

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This Safety Evaluation Report (SER) documents the independent review and confirmatory analysis by U.S. Department of Energy (DOE) Packaging Certification Program (PCP) of the Safety Analysis Report for Packaging (SARP) submitted by the National Nuclear Security Administration (NNSA) Office of Material Management and Minimization (NA-23), Material Disposition Program (NA-233), for amendment of DOE Certificate of Compliance (CoC) Number 9315 for the Model ES-3100 package, for design and content changes, to consolidate previously approved supplements, and to incorporate a previously approved letter of authorization for shipment of Highly Enriched Uranium (HEU)/molybdenum alloy right annular cylinder.

Summary

By letter [1] dated March 20, 2019, as supplemented [2 through 9] February 28, July 23, September 22, November 12, December 17, 2020 and January 21, 2021, the certificate holder, NA-233, requested renewal and amendment of DOE CoC 9315 for the Model ES-3100 package design as required by DOE Order 460.1D, *Hazardous Materials Packaging and Transportation Safety*. Due to use of the package for international shipments, Revision 17 of the CoC was issued August 5, 2020 for renewal, under Docket 20-49-9315, and for subsequent renewal of the Department of Transportation (DOT) Competent Authority Certification (CAC) USA/9315/B(U)F-96, by issuance of CAC Revision 15. Renewal of the CoC and CAC ensured continuity of international shipments.

The independent review and confirmatory analysis by DOE PCP staff of the SARP for significant for design and content changes, to consolidate previously approved supplements, and to incorporate a previously approved letter of authorization for shipment of Highly Enriched Uranium (HEU)/molybdenum alloy right annular cylinder is addressed in this SER.

The NA-233 supplement dated February 28, 2020 identified twenty-four specific changes to the packaging design, contents, or analysis, and clarifications or corrections that were implemented in SARP Revision 2, Page Change 3, as the basis to amend the CoC. The major packaging design change was to authorize “Packcrete” as an alternative to Kaolite®1600 (hereinafter referred to as Kaolite in this SER, unless otherwise specified) for use as impact-limiting and thermal-insulating material between the drum and its inner liner, and within the removable top plug. This design change is needed for fabrication of new packagings because the supplier changed the density of Kaolite. HEU Metal and Alloy, HEU Oxide, and Uranium Compounds content categories were revised to expand or clarify their definition, and HEU Oxide was included in the list of contents authorized for air transport. The thermal evaluation of the package was updated for the Packcrete configuration under normal conditions of transport (NCT) and hypothetical accident conditions (HAC), with solar insolation considered in (or included in) the initial condition for the thermal test under HAC. All chapters in the SARP, including many drawings, were revised to evaluate and implement the twenty-four changes identified by NA-233. Additional supplements submitted on July 23, September 22, and November 12 in responses to regulatory comments or questions from DOE PCP staff were implemented, along with SARP Revision 2, Page Change 3, into a final SARP Revision 3 submitted January 21, 2021.

Based on the statements and representations in the final SARP, Revision 3 and conditions listed in the following SER chapters, DOE PCP staff independently confirmed that the package design has been adequately described and evaluated in the final SARP. Therefore, staff has reasonable assurance that the regulatory requirements of Part 71 have been met and recommends amendment of the CoC by the DOE Headquarters Certifying Official (HCO).

Evaluation

The current safety basis for the ES-3100 package design is DOE CoC 9315, Revision 17, and *Safety Analysis Report for Packaging (SARP) Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, SP-PKG-801940-A001, Revision 2, dated September 8, 2016, as supplemented by:

1. *Safety Analysis Report for Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, SP-PKG-801940-A001, Revision 2, Page Change 1, dated June 26, 2017.
2. *Request for Shipment of a variation of HEU oxide in the ES-3100 Package, CoC USA/9315/B(U)F-96 (DOE), Revision 10*, Letter Kilmartin to Shuler, May 24, 2017.
3. *Revised Request for Amendment to ES-3100, Certificate of Compliance (CoC) USA/9315/B(U)F96 (DOE), Revision 10*, Docket 16-45-9315, Letter Kilmartin to Shuler, May 25, 2017.
4. *Request for Certificate Revision or Letter Amendment to Ship Low Density Oxide by Air Transport in the ES-3100 Package, CoC USA/9315/B(U)F-96 (DOE)*, Letter Kilmartin to Shuler, June 28, 2018.
5. *Criticality Evaluation of Low Density Product Oxides for Air Transport for the ES-3100 Package*, RP 801940-0020 000 00, June 2018.
6. *Safety Analysis Report for Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, SP-PKG-801940-A001, Revision 2, Page Change 2, July 11, 2019.
7. *ES–3100 Containment Vessel (CV) O-rings Life Extension Testing*, RP-801580-0022 000 01, July 11, 2019.
8. *Amendment Items for the ES-3100 Package with Bulk HEU Content, US DOE Certificate of Compliance USA/9315/B(U)F-96 (DOE)*, Letter Kilmartin to Shuler, February 28, 2020.

CoC Supplement 8 was submitted for amendment and renewal of the CoC; however, due to current use of the package for international shipments, Revision 17 of the CoC was issued for renewal only, on August 5, 2020 under Docket 20-49-9315, in order to extend the expiration date of DOT CAC USA/9315/B(U)F-96, Revision 14. DOT issued CAC Revision 15, was issued on August 20, 2020 based on their endorsement of DOE CoC 9315 Revision 17. Renewal of the DOE CoC and DOT CAC ensured continuity of international shipments, while DOE PCP staff reviewed the numerous amendment items identified in CoC Supplement 8, as implemented in SARP Rev. 2, Page Change 3.

SARP Revision 2, Page Change 3 was prepared for NA-233 by the current management and operation contractor of the Y-12 National Security Complex, Consolidated Nuclear Security, LLC (CNS Y-12 is herein referred to as "the applicant") and submitted for DOE PCP staff's independent review and confirmatory analysis on February 28, 2020. The applicant consolidated the twenty-four amendment items requested by NA-233 into a list of twenty-one items in the SARP Revision Log table, and the items are repeated below:

1. Incorporated minor editorial changes.
2. Added provisions in the SARP to permit Packcrete (in addition to Kaolite) as the thermal insulating and an impact limiting material.
3. Updated SARP and supporting analyses to authorize transport of two right annular cylinders with machined features designated as Cylinders C and D under the solid HEU metal or alloy (specified geometric shapes) category.
4. Updated references to the current Quality Assurance Program Plan (QAP-Y-91-273860-1, Revision 16).
5. Updated references to reflect current regulatory and DOE directive requirements.
6. Updated SARP and supporting analyses to include insolation prior to HAC thermal testing.
7. Added HEU oxide mixed with ThO_2 pellets under the research reactor fuel elements and components category for ground and air transport.
8. Clarified that bagging may be polyethylene, nylon, or Teflon throughout the SARP.
9. Revised SPC JS-YMN3-801580-A005 to solely control casting of the 277-4 material in the ES-3100 packaging and added SPC M801580-0004 to control casting 277-4 material in the can spacers.
10. Added uranium thorium metal alloy material to the HEU metal and alloy category.
11. Evaluated HEU metal and alloy and HEU metal or alloy turnings, fines, or powders categories with 500 g of polyethylene bagging.
12. Clinkers and screenings from metal casting operations were added with a loading restriction (Sect. 1.2.2.8, Item 15).
13. Revised Sect. 1.2.2.8, Item 6 to clarify the one-third mass loading requirement and use of can spacers consistent with the CoC.
14. Revised Sect. 1.2.2.8, Item 4 to clarify that the transportation of plutonium by air (due to transuranic concentration allowance) shall be in accordance with 10 CFR 71.88.
15. Added low density HEU oxide mass loading limits for air transport to Table 1.3b.
16. Revised Tables 1.3 and 1.3b to indicate that carbon coating for research reactor fuel elements and components is not controlled.
17. Revised Table 6.8.8.2 for the BR-2 MTR Type 2 fuel enrichment to match the analyses presented in Chap. 6.
18. Added analyses in Chap. 6 for research reactor fuel elements and components with 500 g of polyethylene.
19. Added product oxides (UO_2, UO_3, U_3O_8) mixed with ThO_2, ZrO_2, or Th metal to Tables 1.3 and 1.3b with supporting analyses.
20. Added uranium compounds (UF_4, UO_2F_2, UC, UN, U_3Si_2, and U_3Si) to Table 1.3b with supporting analyses.
21. Added uranium compounds (U_3Si_2-Al, U_3Si, and U_3Si-Al) to Table 1.3 with supporting analyses.

DOE PCP staff reviewed SARP Revision 2, Page Change 3 and issued six initial regulatory comments/questions (Qs) to NA-233 on June 09, 2020. The applicant submitted responses and proposed implementations to the Qs, for NA-233, on July 23, 2020, and proposed two additional SARP changes (new scope) that are summarized below as items 22 and 23:

22. Remove the "rough handling test requirements" of MIL-D-6054F, *Military Specification – Drum, Metal-Shipping and Storage* from SARP Chapters 2 and 8 and Drawing M2E801580A004, *Double Open Head Reinforced Drum*.
23. Delete the uranium silicide impurity allowances from the SARP Chapter 1, Table 1.2a and its references, to support uranium silicide production from other fuel fabricators (both domestic and international) and uranium silicide scrap shipments.

DOE PCP staff reviewed and accepted the applicant's responses and proposed implementation to the initial six Qs. Staff also concurred with the Item 22 change to remove the rough handling test requirement of MIL-D-6054F, Para 4.6.2, from the SARP, since this test is not required to demonstrate compliance with 10 CFR Part 71 at that stage of drum fabrication. Item 23 lacked sufficient technical justification to support this change, so staff requested additional information and clarification from the applicant on August 7, 2020.

On August 10, 2020, staff requested clarification and basis for changes in Drawings M2E801580A011 Rev. G, *Containment Vessel Assembly* and M2E801580A012 Rev. C, *Containment Vessel Body Assembly*. These changes were not included in the SARP Revision Log table. The change proposed to M2E801580A011 to allow "Company Approved Equal" for the CV body was rejected by staff because it could allow modifications to the authorized containment vessel design without prior DOE PCP review and approval. The change proposed to M2E801580A012 to allow a "Machined Body" was likewise rejected because it introduces machining as a new CV fabrication option that has not been evaluated in the SARP.

The applicant compiled staff's additional requests for information and clarification from August 7 and 10, 2020 as five additional Qs (#s 1.2, 1.3, 1.4, 6.2, and 6.3), and responded to the new Qs with proposed implementations on September 22, 2020. The applicant also proposed to two additional administrative changes to SARP Appendix 1.3.9, Equipment Specification SPC M801580-0002, *ES-3100 Ethylene Propylene Diene Monomer (EPDM) Containment Vessel O-rings* and Drawing M2E801580A002, as Items 24 and 25 below:

24. Section 4.6 of SPC M801580-0002, was revised to read "latest revision" for each vendor document, to avoid revision discrepancies. The vendor procedures were also added to the submittal checklist for the Subcontract Technical Representative.
25. Find No. 9 of the Parts List for M2E801580A002 was changed to "Shieldwerx, LLC 4529 Arrowhead Ridge Dr. SE, Rio Rancho, NM 87124, Phone: (505) 892-5144, Fax: 505-890-8319", to match SARP Appendix 1.3.5, SPC JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package*.

DOE PCP staff reviewed and accepted all responses and proposed implementations from the September 22, 2020 submittal, except for Q6.2. However, on November 6, 2020 staff concurred with Option 3 proposed by the applicant to resolve Q6.2, that is, to revise their H/X values presented in Tables 6.9.6-10a and 6.9.6-10b consistent with their previous analyses in Table 6.9.6-10 of "water inside of the CV that was not mixed with the enriched uranium content." In addition, staff requested the applicant to clarify which input files were used to calculate the U-235 mass limit for the ground transport of U_3Si for 40% and 60% enrichment as shown in Table 1.3 of the SARP.

On November 12, 2020, the applicant's criticality analyst provided sufficient clarification to staff regarding the input files supporting Table 1.3. This clarification allowed staff's criticality review and confirmatory analysis review to conclude.

On December 17, 2020, the applicant submitted final pages changes to implement Option 3, to update H/X values presented in Tables 6.9.6-10a and 6.9.6-10b and close out Q6.2. Staff reviewed and accepted the final page changes on December 23, 2020.

The final SARP Revision 3 was submitted by the applicant for staff's review on January 21, 2021, to verify all the agreed-upon responses and proposed implementation to all Qs were accurately implemented.

This SER documents the independent review and confirmatory analysis by DOE PCP staff of the changes in SARP Revision 3 (hereinafter referred to as "SARP" unless otherwise noted) to demonstrate the ES-3100 package design meets the requirements of 10 CFR Part 71.

1.0 General Information

The Model ES-3100 is a drum-style Type B fissile package that is approximately 110 cm (43 inches) in overall height and 49 cm (19 inches) in overall diameter and is composed of an outer drum assembly and an inner containment vessel (CV). The CV is placed inside the drum and surrounded by a cement based borated neutron absorber, Casting Catalog No. 277-4 (277-4). The purpose of the ES-3100 package design is to transport bulk high enriched uranium in various physical and chemical forms.

The outer drum assembly consists of a reinforced stainless steel, standard mil-spec 30-gal drum with an increased length. The volume formed between the drum and the attached inner liner is filled with an inorganic, castable refractory material, Kaolite, which is comprised of concrete and vermiculite, and acts as both a thermal insulating and an impact limiting material.

The CV is approximately 82 cm (32 inches) in overall height and 13 cm (5 inches) in overall diameter and is constructed of 304L stainless steel. The containment boundary consists of the 0.1-inch-thick CV body and lid assembly. The lid assembly consists of a sealing lid, a closure nut, and external retaining ring, which holds both the assembly and closure nut together. The double ethylene-propylene elastomer O-rings in the top flange of the CV permit leak testing of the containment vessel.

The maximum gross weight of the package, including contents, is 190.5 kg (420 lbs.).

1.1 Packaging

The applicant made one significant change to the packaging design, many administrative improvements and clarifications, and non-substantive or editorial items to the packaging description. Changes to important to safety (ITS) components are addressed below.

Insulation

The significant ITS change to the packaging design was the addition of Packcrete as a new thermal insulating and an impact limiting material for use in the drum and removable top plug, as an alternative to Kaolite. This change is described in SARP Section 1.2.1.2, *Insulation*, and implemented throughout SARP Chapter 1.

Kaolite was used as the insulation and impact-limiting material in the drum and removable top plug, for ES-3100 packagings fabricated through Revision 17 of the DOE CoC. However, due to a change in the supplier's specification, the new formulation of Kaolite no longer meets the density specification for the authorized package design and its supporting analysis. To fabricate new drums and removable top plugs, the applicant qualified Packcrete, as an equivalent alternative to the previous Kaolite formulation, by testing and analysis, and process controls. The Packcrete material properties were added to SARP Appendix 1.3.13, *References*. In addition, the preliminary and final method of processing Packcrete for its acceptance and use in the packaging are specified in SARP Appendices 1.3.11 and 1.3.12. Packcrete acceptance testing in SARP Chapter 8, Section 8.1.7, references Appendices 1.3.11 and 1.3.12 for the Quality Assurance (QA) and technical requirements for weighing, mixing, pouring, vibrating, curing, and baking Packcrete material.

Nuclear criticality safety

There were no changes to the specification or properties of the 277-4 neutron absorber material used and evaluated in the SARP, but the applicant made administrative changes to the procedures for mixing and casting the material, and to note a change in the supplier.

The applicant revised SARP Appendix 1.3.5, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package*, Equipment Specification SPC JS-YMN3-801580-A005, to remove the Heavy Can Spacer (Drawing M2E801580A043) from this specification and added Appendix 1.3.10, *ES-3100 Heavy Can Spacer Assemblies*, SPC M801580-0004, as the specification for casting 277-4 neutron-absorbing material in the Heavy Can Spacer.

These administrative changes do not affect the criticality safety design of the package.

1.2 Contents

The bulk HEU contents are described and defined in SARP Section 1.2.2 under the following general categories:

- HEU Metal and Alloy,
- HEU Oxide,
- Research Reactor Fuel Elements and Components,

- Uranium Compounds, and
- Uranyl Nitrate Crystals

There were no SARP changes to the maximum concentration of uranium isotopes authorized for shipment in the package (Table 1.1), the bounding uranium isotopic concentrations in oxide (Table 1.2), or the maximum content decay heat of 5 watts per package.

The applicant added information in SARP Section 1.2.2 to clarify the applicability of the §71.88(a)(3) conditions for air transport of plutonium (i.e., no more than an A_2 quantity of plutonium in any isotope or form), in addition to the authorized concentration limits of 0.0250 g/gU for Np-237 and 40.0 µg/gU for all other transuranic isotopes. This change was also implemented in SARP Section 1.2.2.8, *Loading Restrictions*, Item (4).

SARP Section 1.2.2.8, Item (6) was also expanded to clarify the use of can spacers, that is, a spacer must be positioned between each convenience can, or in the case of shipping only one convenience can, the spacer must be positioned on top of the single convenience can.

Significant changes and clarifications to the content category descriptions, definitions, and loading conditions and restrictions for ground and air transport are discussed below.

<u>HEU Metal and Alloy</u>
The content description and definition in SARP Section 1.2.2 was expanded to include:

- Thorium to the list of alloys of uranium. Since thorium is non-fissile, it does not increase the reactivity of the package.
- HEU in the form of oxide with residual metallic particles, referred to as clinkers and screenings. This content is authorized under DOE CoC 9315, Rev. 17, with Supplement 2 of the CoC as the safety basis document (Docket 17-14-9315).

The content description was also clarified to address bagging or wrapping HEU metal and alloy or convenience cans containing HEU metal and alloy, for contamination control.

SARP Table 1.3 was revised to update the loading limits for ground transport of:

- Solid HEU metal or alloy (specified geometric shapes) – added Cylinders C and D and their applicable limits,
- Broken HEU metal or alloy –updated U-235 mass limits for configurations with and without 277-4 can spacers,
- HEU metal or alloy turnings, fines, or powders – updated U-235 mass limits,
- Note "e" was expanded to define and include Cylinders C and D in the list of geometries of solid shapes,
- Note "g" was revised to clarify the requirements and applicability for less than 50 g of metal or alloy turnings, fines, or powders.

Cylinder C is a uranium-molybdenum alloy with ≤ 95 wt. % uranium and ≤ 93.5% U-235 enrichment; the cylinder length is ≤ 3.30 inches with an inner diameter of ≥ 1.50 inches, an outer diameter of ≤ 4.35 inches, and a maximum mass of 13.5 kg.

Cylinder D is a uranium-molybdenum alloy with ≤ 95 wt. % uranium and ≤ 93.5% U-235 enrichment; the cylinder length is ≤ 5.80 inches with an inner diameter of ≥ 1.35 inches, an outer diameter of ≤ 3.86 inches, and a maximum mass of 16.5 kg.

Cylinder D was authorized for shipment in the package by DOE HCO Letter of Authorization issued March 31, 2020 for Docket 19-35-9315, and extended August 31, 2020, for Docket 20-51-9315, based on the supplement *Criticality Evaluation of an Annular Cylinder in the ES-3100 Package,* RP 801940-0023 000 00, August 2019. The criticality analysis results for Cylinder C are summarized in SARP Table 6.1a, and are bounded by the existing content loadings and analysis for Cylinder D.

SARP Section 1.2.2.8, Item (13) was revised to add a limit of one cylinder per CV to the loading restrictions, for Cylinders C and D.

SARP Section 1.2.2.8, Item (15) was added for loading restrictions on clinkers and screenings, that is, clinkers and screenings will be loaded in accordance with the HEU metal or alloy turnings, fines, and powders mass loading limits in a sealed container under an inert cover gas. Clinkers and screenings shipments must be completed within 12 months after sealing the CV.

HEU Oxide

The bulk HEU content definition SARP Section 1.2.2 for the oxide UO_2-ZrO_2 was redefined as "product oxides" UO_2, UO_3, and U_3O_8 mixed with ThO_2, ZrO_2, and Th metal. Th-232 was a new radioisotope added to the HEU Oxide and Research Reactor Fuel Elements and Components contents. This change did not affect the bounding uranium isotopic concentrations in oxide of SARP Table 1.2 and will not affect the safety performance of the package. Thorium is non-fissile and does not increase the reactivity of the package and zirconium (i.e., UO_2-ZrO_2) was previously authorized.

SARP Table 1.3 was revised to update HEU Oxide loading limits for ground transport of:

- UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg –updated U-235 mass limits to three decimal places for bulk densities less than 2.0 grams/cubic centimeters (g/cc) with criticality safety index (CSI) of 0.0,
- Product oxides (UO_2, UO_3, U_3O_8) mixed with ThO_2 or mixed with Th metal – limits added to table, and
- Product oxides (UO_2, UO_3, U_3O_8) mixed with ZrO_2 – limits added to table.

SARP Table 1.3b was revised to update HEU Oxide loading limits, based on bulk-density range, for air transport of:

- UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg – U-235 mass limits revised,

- Product oxides (UO_2, UO_3, U_3O_8) mixed with ThO_2 – limits added to table,
- Product oxides (UO_2, UO_3, U_3O_8) mixed with ZrO_2 – limits added to table, and
- Product oxides (UO_2, UO_3, U_3O_8) mixed with Th metal – limits added to table.

Research Reactor Fuel Elements and Components
There were no changes in SARP Section 1.2.2 to this content description.

SARP Table 1.3 was revised to add loading limits for ground transport of UO_2-ThO_2. SARP Table 1.3b was revised to add UO_2-ThO_2 to the content description and loading limits for research reactor fuel elements and components for air transport and Note "k" was added to clarify that there is no controls of carbon coating on reactor fuel, for criticality, based on SARP Section. 6.9.8.3.1.

Uranium Compounds
The content definition in SARP Section 1.2.2 for Uranium silicide, with U_3Si_2 as the primary constituent, was redefined as Uranium-silicon compounds (U_3Si_2 and U_3Si). A weight percent of approximately 3.9 (wt.%) was added to the definition for U_3Si. The weight percent of U-235 in Uranium silicide (U_3Si_2) was expanded from 19.75 ± 0.2 wt. % to a range of 19.7 to 60 wt. %.

SARP Table 1.2a was deleted to remove the maximum impurity limit requirements for uranium silicide. These impurity limits were not established as a result of or used in the applicant's containment, shielding, or criticality evaluations of the package, but were based on quality control measures to avoid deleterious fuel effects during reactor operations.

The Uranium-silicon compound definition includes uranium silicide particles dispersed in aluminum (U_3Si_2-Al and U_3Si-Al).

SARP Table 1.3 was revised to account for the new definition of Uranium-silicon compounds and the applicable loading limits for ground transport of:

- UF_4, UO_2F_2, UC, UN, TRISO, and U_3Si_2 – updated compound mass limits to one decimal place for consistency with U-235 mass limits,
- U_3Si_2-Al, U_3Si, and U_3Si-Al – limits added to table, and
- Note "o" added to clarify that there is no limit on the amount of aluminum for U_3Si_2-Al and U_3Si-Al compounds.

SARP Table 1.3b was revised to include uranium compounds and applicable loading limits for air transport of:

- UF_4, UO_2F_2, UC, UN, U_3Si_2, and U_3Si – limits added to table,
- Note "l" was added to clarify the range of bulk densities for uranium compounds are 2.0–6.54 g/cc.
- Note "m" was added to clarify that the maximum impurities in shown in Table 1.2a are applicable for U_3Si_2 and U3Si.

Uranyl Nitrate Crystals (UNX)
There were no changes in SARP Section 1.2.2 to this content description or loading limits in SARP Table 1.3a for ground transport.

SARP Section 1.2.2.2, *Chemical and physical form*, was revised to address CV temperature changes under normal condition of transport (NCT) and hypothetical accident conditions (HAC), with insolation, and demonstrated that the decreased CV gas temperature under NCT, from 91.92°C to 90°C, and increased CV gas temperature under HAC, from 140.36°C to 167.78°C, did not change the SARP evaluation of the chemical and physical forms of UNX.

Shipping and Loading Configurations
SARP Section 1.2.2.4 was expanded to include nylon or Teflon as wrapping or bagging material for contamination control and references SARP Section, 6.2.4, Item 7, as the basis for limiting the amount of hydrogenous packing material inside the CV to an equivalent mass of 500 g of polyethylene. The applicant also revised the minimum free volume or void volume in the CV from 55 to 43 in^3 to allow for gas expansion and off-gassing of material at temperatures associated with NCT or HAC, if closed convenience cans with an outer diameter greater than 4.25 in. are used. These changes were implemented in SARP Section 1.2.2.8, *Loading Restrictions*, Items (8) and (9).

Maximum Normal Operating Pressure (MNOP)
SARP Section 1.2.2.5 was revised to change the CV MNOP and design pressure (and pressure units from absolute to gauge), from 215.24 kPa (31.218 psia) and 801.17 kPa (116.2 psia), respectively, to 107.39 kPa (15.576 psig) and 1378.95 kPa (200 psig), respectively.

1.3 Drawings

The following SARP/CoC drawings were updated for changes that are not important to safety (NITS) with respect to package performance under NCT and HAC. Data plate changes were made to comply with the current DOT marking requirement in §172.301 for "UN" packagings fabricated on or after January 1, 2017, and to address the marking exception for "UN" packagings fabricated before that date. The identification number marking preceded by "UN" must be marked in characters at least 12 mm (0.47 inch) high, which the drawings now reflect (i.e., .50 inch high) for newly fabricated packagings.

- M2E801580A037, Revision J: Corrected the points of application of Notes 9 and 10 with respect to the Parts List Find Nos. 15 and 17 and changed the font size of the second and the fourth row lettering on the ES-3100 data plate from ".38 high characters" to ".50 high characters" to comply with §172.301(a).
- M2E801580A001, Revision D: Notes 1 and 2 deleted (references for drawing interpretations); Note 5 was revised for painting the drawing number, revision, and serial number on the side of the drum; and Note 9 was added for painting or etching the serial number on the drum lid.
- M2E801580A004, Revision C: Notes 1 and 2 deleted (references for drawing interpretations); Note 7 was revised to remove rough handling test requirement for the drum seam weld per MIL-D-6054F, Para. 4.6.2.

- M2E801580A008: Revision D: Added new Find No. 9 "Paint, Black Enamel" to the Parts List, and a new Note 9 for painting M2E801580A001, revision, and serial number on the top plug.
- M2E801580A010, Revision G: Note 5 was revised to change the marking depth from ".003-.005 DEEP…" to ".003-.02 DEEP…"; Note 7 was added to address the DOT exception of §172.301(a)(1)(ii) for permanently marked for packagings fabricated prior January 1, 2017; changed font size of second and the fourth-row lettering on the ES-3100 data plate from ".38 high characters" to ".50 high characters" to comply with §172.301(a).
- M2E801580A014, Revision C: Notes 1 and 2 deleted (references for drawing interpretations); Note 6 added for operational check and gap measurements related to CV sealing;
- M2E801580A024, Revision D: Notes 1, 2, and 3 deleted (references for drawing interpretations, dimension units); Note 7 revised to change the reference weight from 26.7 g to 24.3 g.
- M2E801580A043, Revision C: Note 4 and Parts List Find No. 5 (277-4 Filler) specification revised to change equipment specification to SPC M801580-0004.

The following SARP/CoC drawings were updated for some changes that are NITS with respect to package performance under NCT and HAC, and some changes that are ITS. The ITS changes include the introduction of Packcrete as a thermal impact limiter in M2E801580A002 and M2E801580A008, allowance of "Company Approved Equal" for CV body assembly and modified VCO threaded plug in M2E801580A011, and allowance for machining the CV body from a solid billet of steel as a method of fabrication in M2E801580A012. The change in M2E801580A011 for "Company Approved Equal" is not appropriate for the CV body assembly, which is a Quality Category A component (SARP Table 9.2). The change in M2E801580A012 to allow machining the CV body from a solid billet of steel is not evaluated in the SARP and therefore not acceptable to DOE PCP staff. The CoC must include a condition to restrict these changes related to the CV.

- M2E801580A002, Revision C: Notes 1, 2, 3, and 7 deleted (references for drawing interpretations, dimension units, and dimension and features flagged for inspection symbol); Notes 8 and 10 revised to include Packcrete and its specification; Parts List Find No. 4 description, material, and specification were revised to include Packcrete; and Find No. 9 (277-4) was updated for the supplier change to "ThermoElectron Corp information to Shieldwerx, LLC 4529 Arrowhead Ridge Dr SE, Rio Rancho, NM 87124, Phone: (505) 892-5144, Fax: 505-890-8319", to match SPC JS-YMN3-801580-A005.
- M2E801580A008, Revision C: Notes 1, 2, 3, and 7 deleted (references for drawing interpretations, dimension units, and dimension and features flagged for inspection symbol); Notes 4 and 8 revised to include Packcrete; Note 6 was revised to include Equipment Specification SPC-M801580-0003 for casting Packcrete and to modify the specification for casting Kaolite to use only Equipment Spec JS-YMN3-801580-A003 in the top plug (i.e., option to use JS-YMN3-801580-A002 deleted); Parts List Find No. 6 description, material, and specification were revised to include Packcrete as thermal impact limiter, and add Kaolite specifications to the parts list.

- M2E801580A011, Revision H: Note 13 added for load testing the CV Assembly to 172±8 lb. (the maximum weight of a loaded CV is approximately 123 lb.; a "Load Test Diagram" diagram added; and Parts List Find Nos. 2 (CV body assembly) and 6 (modified VCO threaded plug) were revised to allow "Company Approved Equal" for these parts.
- M2E801580A012, Revision D: Notes 1, 2, 3, and 6 deleted (references for drawing interpretations, dimension units, and dimension and features flagged for inspection symbol); Note 8 deleted (preference to fabricate a formed CV body, Find No. 2, to a welded CV body, Find No. 4); Part List Find No. 2 description was revised to allow it to be fabricated from a "Machined Body".

1.4 Conclusion

Based on a review of the statements and representations in the SARP, DOE PCP staff concludes that the packaging and content changes in support of the CoC amendment request have been described in sufficient detail to provide an adequate basis for the package evaluation under 10 CFR Part 71.

2.0 Structural Evaluation

The objective of this structural review is to determine that the information presented in the SARP, including the description of the packaging, design and fabrication criteria, structural material properties, and structural performance of the package design for the tests under NCT and HAC, is complete and meets the requirements of 10 CFR Part 71.

There were no changes to the mass limits or total weights for each shipping arrangement. The 40.82-kg (90-lb) maximum CV content weight and 35.2-kg (77.60-lb) HEU content weight limits remain the bounding cases for the structural, thermal, and containment evaluation of the package.

The SARP content changes introduced a new radioisotope, Th-232, in product oxides UO_2, UO_3, U_3O_8 mixed with ThO_2, or Th-metal, with no change to the content weight limit for product oxides of 24 kg (52.91 lb.). This content change does not affect the structural design of the package because the contribution of Th-232 activity and its decay heat in the thermal and containment analysis, relative to the uranium isotopes it is compounded with, is negligible.

The applicant expanded the list of authorized bagging materials within the CV from polyethylene bags to polyethylene, nylon, or Teflon bags, but retained the same limit for equivalent mass of 500 g polyethylene for hydrogenous packing material inside the CV; therefore, this change did not affect the pressure or flammable gas generation calculations under NCT or HAC.

The applicant updated the minimum free or void volume in the CV from 55 to 43 in^3 for loading arrangements that utilize closed metal cans with diameters greater than 10.8 cm (4.25 inches) for gas expansion and off-gassing of material at temperatures associated with NCT or HAC. This change was based on the results of the new thermal analysis for the Packcrete configuration, and a correction to the empty CV volume calculations in SARP Appendices 3.5.1, *Containment*

Vessel Pressure due to Normal Conditions of Transport for the Proposed Contents and 3.5.2 *Containment Vessel Pressure due to Hypothetical Accident Conditions for the Proposed Contents*. The empty CV volume was determined from ALGOR finite element software and was corrected from 637.18 in^3 (10,441.51 cm^3) to 623.38 in^3 (10,215.36 cm^3). This change required the applicant to update CV pressure calculations in SARP Chapter 3, and the results of the updated calculations implemented in SARP Chapters 2, 3, and 4.

DOE PCP staff review of the SARP Chapter 2 changes focused on the effect of using Packcrete as an essentially equivalent alternative impact-limiting and thermal-insulating material with respect to the structural performance of the package. The applicant updated the thermal analysis of the package under NCT and HAC [Design and Analysis Calculation (DAC) DAC M801940-0002 000 00] for the Packcrete configuration at 0 and 5 watts, and several cases of the Kaolite configuration for comparison. This updated thermal analysis includes solar insolation as the initial condition for the HAC thermal test and a steady state analysis of both configurations to demonstrate compliance with IAEA air transport requirements. The results of the DAC M801940-0002 000 00 were used as input to a new thermal stress analyses of the drum assembly under NCT (DAC M801940-0003 000 00) for the Packcrete configuration at 0 and 5 watts and includes cases of the Kaolite configuration for comparison. The applicant also implemented the results of a stress analysis (DAC M900000-0002 000 00), that was previously review by DOE PCP staff, of the CV at higher temperature and internal pressure conditions than evaluated in SARP Revision 2. The results of these three updated analyses of the package design were implemented throughout the SARP Chapter 2 text and tables.

The applicant used an analysis by comparison of Packcrete to Kaolite properties and calculations, to demonstrate compliance with 10 CFR Part 71 for the structural performance of the package under NCT and HAC. DOE PCP staff verified compliance by document review.

The following references were added to SARP, Appendix 2.12.1 and implemented throughout SARP Chapter 2, as the technical basis for changes to the structural evaluation of the package design:

- DAC M900000-0002 000 00, C. R. Hammond, *ASME Code Subsections NB and WB Stress Analysis of ES-3100 Containment Vessel*, B&W Y-12, Y-12 National Security Complex, April 19, 2011 (**NOTE** – this DAC supplements DAC M900000-0003 in SARP Chapter 2 and 3, because of the increased upper temperature range, from 350°F to 400°F),
- DAC M801940-0002 000 00, A. D. McLaurine, *Thermal Analysis of the ES-3100 Package for NCT and HAC*, Consolidated Nuclear Security, LLC, Y-12 National Security Complex, December 2019 (**NOTE** – this DAC is now the primary thermal analysis for the package design, since DAC-PKG-801940-A001 only references Kaolite),
- DAC M801940-0003 000 00, A. D. McLaurine, *Thermal Stress Analysis of the ES-3100 Package for NCT*, Consolidated Nuclear Security, LLC, Y-12 National Security Complex, December 2019 (**NOTE** – This DAC supersedes DAC-PKG-801940-A002 in the SARP Chapters 2 and 3 with input from DAC M801940-0002 000 00),

- RP 802282-0002 000 02, *Packcrete Material Properties*, Consolidated Nuclear Security, LLC, Y-12 National Security Complex, June 2016,
- SSG-26, Specific Safety Guide No., Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition), International Atomic Energy Agency, Vienna, 2014, and
- SSR–6, Specific Safety Requirements No., Regulations for the Safe Transport of Radioactive Material, International Atomic Energy Agency, Vienna, 2012 (**NOTE** – SSR-6 supersedes TS-R-1, *Regulations for the Safe Transport of Radioactive Material*).

DAC M900000-0002 000 00 was previously reviewed by DOE PCP staff for Docket 10-57-9867, to certify the package design for shipment of plutonium oxide. This DAC was added to the SARP as the technical basis to support changes in the maximum CV design temperature from 350°F to 400°F, internal pressure differential from 101.5 psig to 200 psig, at the same external pressure of 21.7 psig, and demonstrates that the CV design meets American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (ASME BPVC, 2010), Section III requirements for structural design in both Section III, Division I, Subsection NB and Section III, Division 3, Subsection WB. The maximum calculated internal pressure of the CV under HAC was updated to be 1206.58 kPa (175.00 psia) in accordance with DAC M801940-0002 000 00, based on a calculated maximum average CV gas temperature of 167.39°C (333.31°F). The calculated stresses caused by the internal pressure of the CV under HAC were determined by multiplying the stress at the design conditions, from DAC M900000-0003 and SARP Table 2.6, by a factor equal to the ratio of operating pressures to the design pressure and adding any contribution from the closure nut preload. All the calculated stresses in the CV components are below the ASME BPVC allowable stress limits. The results of DAC M900000-0002 000 00 are implemented in SARP Chapter 2:

- Sections:
    - 2.1.2 *Design Criteria*
    - 2.2.1 *Material Properties and Specifications*,
    - 2.4.3 *Positive Closure—10 CFR 71.43(c)*, and
    - 2.7.4.3, *Stress calculations*, and
- Tables:
    - 2.5. *Allowable stress intensity (S_m) for the containment vessel materials of construction*,
    - 2.16. *Mechanical properties of the metallic components of the containment vessel*, and
    - 2.51. *HAC ES-3100 containment vessel stress compared to the allowable stress*.

DAC M801940-0002 000 00 was added to determine the temperature distribution within the package with Packcrete as the insulation material, under steady-state conditions, NCT, and HAC, with insolation as the initial condition for HAC, for cases with 0 and 5 watts of internal decay heat. The DAC also includes cases of the Kaolite configuration for comparison with Packcrete, and a steady state analysis of both configurations with ambient conditions at 55°C (131°F) in still air and in the shade, in accordance with IAEA SSR-6, Para. 620, and SSG-26, Para. 621.3, for air transport. This DAC demonstrates that the package design with Packcrete and Kaolite configurations under steady-state conditions are 38.30°C (100.94°F) of 38.31°C (100.1°F), respectively, and therefore meet the §71.43(g) requirement that the maximum surface temperature of the package is less than 50°C (122°F). The CV O-ring is the ITS packaging component with the lowest service temperature [i.e., 1000 hours of continuous service at 150°C (302°F)]. The maximum temperatures in the O-ring location under NCT, for both configurations with 5 watts, were 89.53°C (193.16°F) for Packcrete and 89.49°C (193.1°F) for Kaolite, and under HAC 153.18°C (307.7°F) for Packcrete and 149.05°C (300.3°F) for Kaolite. The technical justification for exceeding the O-ring service temperature under HAC is addressed in SARP Section 2.7.8 *Summary of Damage*, based on the evaluation in SARP Section 3.4.3 *Maximum Temperatures and Pressure* and Table 3.29, *Predicted temperatures of the containment vessel due to HAC*. The results of this DAC are implemented in SARP Chapter 2:

- Sections:
    - 2.6 *NORMAL CONDITIONS OF TRANSPORT* and
    - 2.7.8 *Summary of Damage* (under HAC)
- Table:
    - 2.20. *Summary of temperatures and pressures for NCT*.

DAC M801940-0003 was added to evaluate the structural response of the drum assembly with Packcrete when subjected to temperature distributions calculated from DAC M801940-0002 for NCT, for cases with 0 and 5 watts of internal decay heat, and includes cases of the Kaolite configuration for comparison. DAC M801940-0003 demonstrates that the maximum drum stresses from all regulatory NCT simulations are below the applicable stress limits established by ASME BPVC Section VIII, Div. 1, Subsection A, Part UG-23. The results of this DAC are implemented in SARP Chapter 2:

- Sections:
    - 2.6.1.2 *Differential thermal expansion* and
    - 2.6.2 *Cold* (under NCT).
- Tables:
    - Table 2.20a. *Maximum calculated stress in the drum assembly components during NCT hot conditions (100°F, decay heat, solar insolation)*,
    - Table 2.22a. *Maximum calculated stress in the drum assembly components during NCT cold conditions (-40°F, no decay heat, no solar insolation)*

RP 802282-0002 000 02 was added to present the material properties of Packcrete. In-process controls and testing requirements from this report are incorporated in the Packcrete equipment specification, SPC M801794-0003, to ensure consistency of Packcrete material properties in the drum body and lid assemblies. The results of this report are implemented in SARP Chapter 2:

- Sections:
    - 2.1.1.1 *Drum assembly*,
    - 2.2.1 *Material Properties and Specifications*,
    - 2.6 *NORMAL CONDITIONS OF TRANSPORT*, and

   - 2.7 *HYPOTHETICAL ACCIDENT CONDITIONS*.
- Tables:
   - Table 2.14. *Mechanical properties of the cast refractory insulation*

SSG-26 and SSR–6 were added to update the SARP to reference the current IAEA regulations for air transport of SSR-6, Paragraph 620. The requirements of SSR-6 are implemented and evaluated in SARP Chapter 2, in accordance with guidance from SSG-26, paragraph 621.3:

- Sections:
   - 2.1.1.1 *Drum assembly*,
   - 2.2.1 *Material Properties and Specifications*,
   - 2.6 *NORMAL CONDITIONS OF TRANSPORT.*
- Tables:
   - Table 2.21a. *ES-3100 containment vessel evaluation for internal pressure developed during air transport in accordance with IAEA SSR-6, Paragraph 620*.

2.1 Structural Design, Materials, and Fabrication and Examination

There were no ITS changes to the package structural design, except for use of Packcrete as an equivalent alternative to Kaolite in the Drum Assembly Weldment (Dwg. M2E801580A002) and Top Plug Weldment (Dwg. M2E801580A008). The applicant used an analysis by comparison of the material properties and qualification testing to show equivalency of Packcrete with Kaolite, and thus credit the existing structural evaluation in the SARP to authorize use of Packcrete in the package design. Both the Kaolite and Packcrete are mixtures of cement and vermiculite and have the same nominal cured density of 358.8 ± 48.1 kg/m^3 (22.4 ± 3 lb./ft^3) and a maximum continuous service temperature limit of 871°C (1600°F).

The structural design of the Drum Assembly in SARP Section 2.1.1.1 was revised and implemented throughout SARP Chapter 2 to include Packcrete, in addition to Kaolite, in the description for impact-limiting and thermal insulating material used in the package. The applicant also added references in the Drum Assembly description to Packcrete material properties (RP 802282-0002 000 02), procedures for manufacturing and qualifying Packcrete for use in the packaging (Equipment Specifications SPC M801794-0003 and SPC M801580-0003), and SARP Drawings M2E801580A002 and M2E801580A008.

In-process controls and testing requirements confirm the Packcrete materials properties are implemented in the equipment specifications, to ensure its consistent thermal and mechanical material properties in the Drum Assembly and validity with the analysis performed on the package design.

DOE PCP staff confirmed by document review that the material properties of Packcrete, such as chemical composition, density, dynamic impact crush strength, thermal conductivity, specific heat, coefficient of linear expansion, elastic modulus, and Poisson's ratio, are essentially equivalent to Kaolite. Therefore, the physical testing results and the conditions analyzed for the package using Kaolite are also applicable to the package using Packcrete. Since Packcrete is fabricated from the same base materials as Kaolite, it is not expected react chemically or galvanically with the packaging metals in contact with it.

The description in SARP Section 2.1.1.3 *Packaging materials* was expanded to include nylon, or Teflon bags for use inside or outside any convenience can or bottle within the CV boundary. This change was implemented throughout SARP Chapter 2. Nylon or Teflon are not expected react chemically or galvanically with the packaging metals or contents in contact with it. The current off-gassing material mass limits for polyethylene bagging material apply to nylon and Teflon.

The design criteria in SARP Section 2.1.2 *Design Criteria* was revised to include DAC M900000-0002 as the basis for the CV internal design pressure by ASME Code stress analysis performed with bounding operating conditions of 200 psig internal pressure, 21.7 psig external pressure, and at 400°F. The stress intensities of the CV materials at 400°F are implemented in SARP Table 2.5 *Allowable stress intensity (S_m) for the containment vessel materials of construction* and used in subsequent tables and sections in SARP Chapter 2. In addition, the bounding load case used in SARP Chapters 2 and 4 for the maximum normal operating pressure under NCT was revised from 215.46 kPa (31.25 psia) at 93.33°C (200.0°F), to 210.29 kPa (30.50 psia) at 90°C (194°F).

SARP Table 2.6, *ES-3100 containment vessel design evaluation allowable stress comparisons,* was revised to correct an error to the allowable pressure of the Closure nut ring from 20,900 psi to 15,675 psi. SARP Table 2.12, *Mechanical properties of the metallic components of the drum assembly,* was revised to correct errors to the allowable stress intensity values at 200 °F and 300°F for ASME SA-240 Type 304 stainless steel, from 20 ksi (at both temperatures) to 16.7 ksi at 200 °F and 15 ksi at 300°F.

The materials analysis of the Teflon™ FEP (fluorinated ethylene propylene) bottles used for transport uranyl nitrate crystals and analysis of uranyl nitrate hexahydrate (UNH) in SARP 2.2.1, *Material Properties and Specifications,* were revised to update the maximum temperature predicted inside the CV under HAC (with solar insolation), at the location near the Teflon™ FEP bottles, from 140.56°C (285.00°F) to 198.04°C (388.48°F). This CV temperature increase is still below the lower limit of the FEP decomposition temperature of 260°C (500°F). In addition, the maximum CV temperature under NCT, with insolation, was revised 91.92°C (197.46°F) to 89.60°C (193.28°F). These NCT and HAC temperature changes did not effect the conclusion that uranyl nitrate dihydrate and lower hydrates will remain in a solid phase during transportation.

SARP Section 2.3, *FABRICATION AND EXAMINATION,* was revised to add fabrication, examination, and acceptance requirements for Packcrete used in the Drum Assembly. These requirements reference SARP Appendices 1.3.11 (SPC M801794-0003) and Appendix 1.3.12 (SPC M801580-0003).

2.2 General Requirements, NCT, and HAC

The evaluation in SARP Section 2.4.3, *Positive Closure—10 CFR 71.43(c)* was revised to replace the value used as the maximum differential pressure under NCT from 190.46 kPa (27.63 psi) [215.46 − 25] to 185.29 kPa (26.87 psi) [210.29 − 25], based on changes in SARP Section 2.6.3, *Reduced External Pressure* from the revised NCT and HAC thermal analysis (DAC M801940-0002), and to replace the value used as the maximum differential pressure under HAC from 674.31 kPa (97.80 psi) to 1105.23 kPa [160.3 psi (175 psia -14.7 psia)], based on the analysis of the CV in DAC M900000-0002. These changes do not affect the applicant's conclusion that the CV cannot be opened unintentionally by pressure that may arise within the package under NCT.

The applicant used an analysis by comparison of Packcrete to Kaolite, and calculations, to demonstrate compliance with 10 CFR Part 71 for the structural performance of the package under NCT and HAC. The results of the NCT and HAC thermal analysis and calculations (DAC M801940-0002) and thermal stress analysis and calculations under NCT (DAC M801940-0003) of the package with the Packcrete configuration were used to update SARP Sections 2.6, NCT and 2.7 HAC. The results show that the thermal stresses induced by either insulation materials are minimal and do not reduce the effectiveness of structural design of the package.

SARP Section 2.6, NCT, was revised to update the reference air leakage rate of the CV under NCT from $\leq 1.3792 \times 10^{-4}$ ref-cm^3/s to $\leq 1.4025 \times 10^{-4}$ ref-cm^3/s, based on an update to the leakage rate calculations in SARP Appendix 4.5.2, using a pressure of 30.50 psia at a temperature of 194°F for the NCT evaluation and a pressure of 175.0 psia at a temperature of 334°F for the HAC evaluation.

The ES-3100 packages with Table 1.3b contents in the SARP are transported by air; therefore, the IAEA SSR-6, para. 621 criteria were incorporated into the SARP. In addition, for compliance with 49 CFR 173.410(i)(2), the range of ambient temperature evaluated is from −40 to 55°C for air transport. Thermal analysis has been conducted in the SARP to calculate the temperatures and the pressures for air transport conditions, in Reference 6 and appendix 3.5.1 of the SARP. Table 2.21a of the SARP shows the calculated stresses of the CV components under IAEA SSR-6, Paragraph 620 air transport conditions, which are below the allowable stresses. Containment performance of the ES-3100 under air transport conditions is evaluated in Section 4 of this TRR.

DOE PCP staff reviewed these changes and find they are acceptable.

2.3 Conclusion

Based on review of the statements and representations in the SARP, DOE PCP staff has reasonable assurance that the structural design of the package continues to meet the requirements of 10 CFR Part 71.

3.0 Thermal Evaluation

The objective of this thermal review is to verify that the thermal performance of the package has been adequately evaluated for the tests specified under NCT and HAC and that the package design satisfies the thermal requirements of 10 CFR Part 71

There was no change to the maximum heat load of 5 Watts for the package design. This limit remains the bounding case for the structural, thermal, and containment evaluations in the SARP.

The SARP content changes introduced a new radioisotope, Th-232, in product oxides UO_2, UO_3, U_3O_8 mixed with ThO_2, or Th-metal, with no change to the content weight limit for product oxides of 24 kg (52.91 lb.). This content change does not affect the thermal design of the package because the contribution of Th-232 activity and its decay heat in the thermal and containment analysis, relative to the uranium isotopes it is compounded with, is negligible.

The applicant expanded the list of authorized bagging materials within the CV from polyethylene bags to polyethylene, nylon, or Teflon bags, but retained the same limit for equivalent mass of 500 g polyethylene for hydrogenous packing material inside the CV; therefore, this change did not affect the pressure or flammable gas generation calculations under NCT or HAC.

The applicant updated the minimum free or void volume in the CV from 55 to 43 in^3 for loading arrangements that utilize closed metal cans with diameters greater than 10.8 cm (4.25 inches) for gas expansion and off-gassing of material at temperatures associated with NCT or HAC. This change was based on the results of the new thermal analysis for the Packcrete configuration, and a correction to the empty CV volume calculations in SARP Appendices 3.5.1, and 3.5.2. The empty CV volume was determined from ALGOR finite element software, and was corrected from 637.18 in^3 (10,441.51 cm^3) to be 623.38 in^3 (10,215.36 cm^3). This change required the applicant to update CV pressure calculations in SARP Chapter 3, and the results of the updated calculations implemented in SARP Chapters 2, 3, and 4.

DOE PCP staff review of the SARP Chapter 3 changes focused on the effect of using Packcrete as an essentially equivalent alternative impact-limiting and thermal-insulating material with respect to the structural performance of the package. The applicant updated the thermal analysis of the package under NCT and HAC (Design and Analysis Calculation (DAC) DAC M801940-0002 000 00) for the Packcrete configuration at 0 and 5 watts, and several cases of the Kaolite configuration for comparison. This updated thermal analysis includes solar insolation as the initial condition for the HAC thermal test and a steady state analysis of both configurations to demonstrate compliance with IAEA air transport requirements. The results of the DAC M801940-0002 000 00 were used as input to a new thermal stress analyses of the drum assembly under NCT (DAC M801940-0003 000 00) for the Packcrete configuration at 0 and 5 watts, and includes cases of the Kaolite configuration for comparison. The applicant also implemented the results of an existing, previously reviewed stress analysis (DAC M900000-0002 000 00) of the CV at higher temperature and internal pressure conditions than evaluated in SARP Revision 2. The results of these three updated analyses of the package design were implemented throughout the SARP Chapter 3 text, tables, and appendices.

The applicant used an analysis by comparison of Packcrete to Kaolite, and calculations, to demonstrate compliance with 10 CFR Part 71 for the thermal performance of the package under NCT and HAC. DOE PCP staff verified compliance by document review and a confirmatory thermal analysis for the most conservative cases to independently verify the results of the new thermal calculations in DAC M801940-0002 000 00.

The following references were added to SARP, Appendix 3.5.5, and implemented throughout SARP Chapter 3, as the technical basis for changes to the thermal evaluation of the package design:

- DAC M801940-0002 000 00, A. D. McLaurine, *Thermal Analysis of the ES-3100 Package for NCT and HAC*, Consolidated Nuclear Security, LLC, Y-12 National Security Complex, December 2019 (**NOTE** – this DAC is now the primary thermal analysis for the package design, since DAC-PKG-801940-A001 only references Kaolite),
- DAC M801940-0003 000 00, A. D. McLaurine, *Thermal Stress Analysis of the ES-3100 Package for NCT*, Consolidated Nuclear Security, LLC, Y-12 National Security Complex, December 2019 (**NOTE** – This DAC supersedes DAC-PKG-801940-A002 in the SARP Chapters 2 and 3 with input from DAC M801940-0002 000 00),
- DAC M900000-0002 000 00, C. R. Hammond, *ASME Code Subsections NB and WB Stress Analysis of ES-3100 Containment Vessel*, B&W Y-12, Y-12 National Security Complex, April 19, 2011 (**NOTE** – this DAC supplements DAC M900000-0003 in SARP Chapters 2 and 3, because of the increased upper temperature range, from 350°F to 400°F),
- RP 802282-0002 000 02, *Packcrete Material Properties*, Consolidated Nuclear Security, LLC, Y-12 National Security Complex, June 2016, and
- SSR–6, Specific Safety Requirements No., Regulations for the Safe Transport of Radioactive Material, International Atomic Energy Agency, Vienna, 2012.

These references were summarized in Section 2 of this SER.

DOE PCP staff verified the results of DAC M801940-0002 000 00 were implemented in SARP Chapter 3:

- Sections:
    - 3.1 *DESCRIPTION OF THERMAL DESIGN,*
    - 3.1.3.1 *NCT summary tables,*
    - 3.3 *THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT,*
    - 3.4 *THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS,* 3.4.1 *Initial Conditions,*
    - 3.4.3 *Maximum Temperatures and Pressure*,
    - 3.4.4 *Maximum Thermal Stre*sses,
    -
- Tables:
    - 3.3 *Summary of results of evaluation for the ES-3100 under NCT,*

- 3.8. *Thermal properties of the materials used in the thermal analysis,*
- 3.9 *Mechanical properties of the materials used in the static stress analyses*,
- 3.19 *HAC maximum temperatures using Packcrete (ASH, HTC, HD, 277HD)*,
- 3.20 *HAC maximum temperatures using Packcrete (ASH, HTC, HD, 277LD)*,
- 3.21 *HAC maximum temperatures using Packcrete (ASH, LTC, LD, 277HD)*,
- 3.22 *HAC maximum temperatures using Packcrete (ASH, LTC, LD, 277LD)*,
- 3.23 *HAC maximum temperatures using Packcrete (HSH, LTC, LD, 277HD)*,
- 3.24 *HAC maximum temperatures using Packcrete (HSH, LTC, LD, 277LD)*,
- 3.25 *HAC maximum temperatures using Packcrete (LSH, HTC, HD, 277HD)*,
- 3.26 *HAC maximum temperatures using Packcrete (LSH, HTC, HD, 277LD)*,
- 3.27 *HAC maximum temperatures using Kaolite (Kaolite LD, 277LD)*,
- 3.28 *Predicted temperature adjustments (°F) for containment vessel due to HAC*, and
- 3.29 *Predicted temperatures of the containment vessel due to HAC*

▪ Figures:
- 3.5 *ANSYS axisymmetric FEA model of the ES-3100 upper portion*,
- 3.6 *ANSYS axisymmetric FEA model of the ES-3100 lower portion*, and
- 3.7 *ES-3100 nodal temperature locations of interest.*

▪ Appendix:
- 3.5.1 *Containment Vessel Pressure due to Normal Conditions of Transport for the Proposed Contents, VII. Maximum containment vessel pressure differential in accordance with air transport guidance*

Staff verified the results of DAC M801940-0003 000 00 and DAC M900000-0002 000 00 were implemented in SARP Chapter 3, Section 3.3.3 *Maximum Thermal Stresses*.

Staff verified the results of RP 802282-0002 000 02 were implemented in SARP Chapter 3:

▪ Sections:
- 3.3 *THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT*,
- 3.4.3 *Maximum Temperatures and Pressure*,

Staff verified the requirements of SSR-6 are implemented and evaluated in SARP Chapter 3, in accordance with guidance from SSG-26, paragraph 621.3:

▪ Sections:
- 3.3.1 *Heat and Cold*,
- 3.3.2 *Maximum Normal Operating Pressure*,

▪ Appendix:
- 3.5.1 *Containment Vessel Pressure due to Normal Conditions of Transport for the Proposed Contents, VII. Maximum containment vessel pressure differential in accordance with air transport guidance*

3.1 Thermal Design

There were no ITS changes to the package thermal design, except for use of Packcrete as an equivalent alternative to Kaolite in the Drum Assembly Weldment (Dwg. M2E801580A002) and Top Plug Weldment (Dwg. M2E801580A008). Packcrete has some different thermophysical properties than Kaolite (e.g., heat capacity and thermal conductivity), so the applicant performed extensive physical testing and qualification of Packcrete material and updated the NCT and HAC thermal analysis with Packcrete and Kaolite package configurations for comparison. The applicant varied the density, thermal conductivity, and specific heat capacity of the Packcrete configuration in the thermal analysis to ensure the performance of Packcrete is sufficiently similar to Kaolite. Both the Kaolite and Packcrete are mixtures of cement and vermiculite and have the same nominal cured density of 358.8 ± 48.1 kg/m^3 (22.4 ± 3 lb./ft^3) and a maximum continuous service temperature limit of 871°C (1600°F).

3.2 NCT and HAC

The NCT and HAC thermal calculations in the SARP are based on a detailed axisymmetric model of the package (DAC M801940-0002 000 00). The material properties of either Kaolite or Packcrete were applied in the model, while the material properties of all other packaging components were kept unchanged for comparison. The applicant used ANSYS Mechanical computer code for conducting thermal analysis of package with a heat flux ranging from 0 to 5 W applied to the inner surfaces of the CV.

3.2.1 NCT

The calculated temperature distribution of the package at 38°C in the shade is reported in SARP Table 3.14, which shows that the peak temperature of the accessible surfaces of the package, with the Packcrete configuration is 39.42°C (102.96°F) and 39.27°C (102.676°F) for Kaolite configuration. These surface temperatures are below the §71.43(g) limit of 50°C (122°F) for non-exclusive use shipments. DOE PCP staff performed a confirmatory analysis and staff's results are in good agreement with the SARP.

The calculated temperature distribution of the package at 38°C with solar insolation is reported in SARP Table 3.16, which shows that the maximum temperatures of the packaging components are within their individual service temperature limits. The most temperature-sensitive ITS packaging components in the ES3100 design are the Cat 277-4 and ethylene propylene diene monomer (EPDM) O-ring (SARP Table 3.11): both have an allowable service temperature range from −40 to 150°C (−40 to 302°F). Table 3.16 reports a maximum temperature of 89.54°C (193.17°F) for the Packcrete and 89.49°C (193.08°F) for the Kaolite configurations in the area of the EPDM O-ring and 88.72°C (191.70°F) for Packcrete and for 89.09°C (192.36) Kaolite configurations at the Node L interface between the CV and Cat 277-4. DOE PCP staff verified the thermal analysis methods, models and results, including boundary conditions, assumption, expressions of the heat tranfer modes among package components, heat loading, and thermal properties for the package materials in the SARP. Staff also performed confirmatory thermal analysis, and finds staff's thermal analysis results are in good agreement with the SARP. The difference between the maximum temperatures of the individual packaging components with the Packcrete configuration as compared with the Kaolite configuration are marginal.

3.2.2 HAC

The thermal performance of package under HAC was initially evaluated by a combination of physical testing and thermal analysis. The HAC thermal tests were conducted in an industrial furnace on six test units with the Kaolite insulation configuration and BoroBond-4™ in place of Cat 277-4. The applicant applied temperature indicating labels to packaging components to document the peak packaging component temperatures during the thermal test (SARP Table 3.4). The test units did not include an internal heat load or solar insolation, so the applicant made adjustments to increase the maximum recorded temperatures from the label data (i.e., blackout dots) to account for (1) the temperature interval between blackout dots; (2) the temperature increase due to the effects of applying solar insolation prior to the HAC thermal test; (3) the temperature increase due to the decay heat load of the actual contents being shipped; (4) the temperature increase due to effects of applying solar insolation during cool-down; (5) the effects of the HAC crush test at different locations along the body of the package; (6) thermal capacitance difference in the proposed contents and hardware used during testing; and (7) temperature difference occurring when using Packcrete vs Kaolite. SARP Table 3.29 summarizes the results after adding these temperature adjustments to the recorded label temperatures for the Test Unit 5 (TU-5), which shows the stainless-steel components of the CV will not be adversely affected by the HAC conditions; however, the final predicted CV temperature of 368.23°F exceeds the normal recommended service limit for EPDM O-rings (Table 3.11 in SARP). This service limit is based on 302°F for 1,000 hours, but this temperature may be exceeded for short durations as defined in Figure 2-28 *Seal Life at Temperature* of the Parker O-Ring Handbook (ORD 5700). Based on Figure 2-28, the applicant determined that the O-ring would perform at 368.23°F for approximately five hours and above 302°F for approximately 11 hours. The applicant then used the graph shown in DAC M801940-0002 000 00, Fig. 7-24 *Transient temperatures for HAC Cooldown with insolation before and after the fire [(LSH, HTC, HD, 277LD)-case and 5 W],* to demonstrate the EPDM O-ring material would fall below 302°F within 5 hours, so the ORD 5700 criteria is met. DOE PCP staff reviewed ORD 5700 and DAC M801940-0002 000 to verify that the EPDM O-ring should be able to survive HAC conditions.

DOE PCP staff performed an independent confirmatory HAC thermal analysis of package design with the Packcrete configuration. For conservatism, staff used the lowest specific heat (thus fast thermal diffusion) and highest thermal conductivity (high flow-in heat flux from fire) of the Packcrete material since it leads to fast heat diffusion [$D = k/(\text{density} \times Cp)$]. Staff's analysis results show that O-ring area reached a peak temperature of 306°F at about 3 hours after the HAC fire, and a 298°F peak O-ring temperature with Kaolite. The results demonstrate that the applicant's maximum final predicted CV temperature of 368.23°F is very conservative. Based on staff' confirmatory analysis the substitution of Packcrete for Kaolite should not affect the thermal performance of package design, and the EPDM O-ring remains within the supplier's performance criteria under HAC.

3.2.3 MNOP, Air Transport, and Maximum HAC pressure

The MNOP in the CV, as defined in §71.4, is 107.39 kPa (15.576 psig, SARP Section 3.3.2), or in absolute pressure terms 208.75 kPa (30.276 psia). This MNOP is based on the calculated temperature in the CV under NCT of 89.60°C (193.28°F, SARP Table 3.6), which is assumed to be constant throughout the CV and its contents. The applicant rounded the maximum gas temperature and MNOP in the CV to 90°C (194°F) and 210.29 kPa (30.50 psia) for NCT analyses in SARP Chapters 2 and 4.

For air transport, in accordance with IAEA SSR-6, Para. 621, the CV must be capable of withstanding, without loss or dispersal of the radioactive contents, an internal pressure that produces a pressure differential of not less than the MNOP plus 95 kPa. The applicant performed an analysis of the package with a steady state condition at 55°C in the shade. The results are shown in SARP Table 3.15. The MNOP of the CV is calculated in SARP Appendix 3.5.1 using the highest temperature predicted for the CV [64.44°C (147.99°F) at Node V in Table SARP Table 3.15] as the average gas temperature throughout the CV void volume. The maximum pressure differential across the CV boundary is the resultant pressure plus 95 kPa or 117.69 kPa (17.07 psig). These values for temperature and pressure are subsequently used in Chapter 4 to determine the leakage criteria that satisfies the requirements of ANSI N14.5.

The average adjusted gas temperature and maximum pressure in the CV under HAC are calculated to be 167.39°C (333.31°F) and 1206.24 kPa (174.95 psia), respectively (SARP Table 3.7).

These MNOP, pressure differential, and maximum CV pressure under HAC are below the CV operating conditions of 200 psig internal pressure and 21.7 psig external pressure, at 400°F, based on the evaluation performed in DAC M900000-0002 000 00 and summarized in SARP Table 2.51.

3.3 Conclusion

Based on review of the statements and representations in the SARP, and DOE PCP staff's confirmatory analysis, staff has reasonable assurance that the thermal design of the package continues to meet the requirements of 10 CFR Part 71.

4.0 Containment Evaluation

The objective of this containment review is to verify that the package design satisfies the containment requirements of 10 CFR Part 71 under NCT and HAC.

There were no changes to the containment system design and was no changes to the maximum A_2 value of 4,752.8 (at 70 years), or maximum activity of 0.72554 TBq (at 10 years). These limits remains the bounding case for the containment evaluation in the SARP.

The SARP content changes introduced a new radioisotope, Th-232, in product oxides UO_2, UO_3, U_3O_8 mixed with ThO_2, or Th-metal, with no change to the content weight limit for product oxides of 24 kg (52.91 lb.). This content change does not affect the containment design of the package because the A_2 value of Th-232 is unlimited, so it does not contribute to A_2 value of the mixture. Therefore, the containment analyses documented in SARP Appendix 4.5.2 is still valid and bounding for mixtures of Th-232 oxide or metal with uranium.

The applicant expanded the list of authorized bagging materials within the CV from polyethylene bags to polyethylene, nylon, or Teflon bags, but retained the same limit for equivalent mass of 500 g polyethylene for hydrogenous packing material inside the CV; therefore, this change did not affect the containment calculations under NCT or HAC.

The applicant updated the minimum free or void volume in the CV from 55 to 43 in^3 for loading arrangements that utilize closed metal cans with diameters greater than 10.8 cm (4.25 inches) for gas expansion and off-gassing of material at temperatures associated with NCT or HAC. This change was based on the results of the new thermal analysis for the Packcrete configuration, and a correction to the empty CV volume calculations in SARP Appendices 3.5.1, and 3.5.2. The empty CV volume was determined from ALGOR finite element software, and was corrected from 637.18 in^3 (10,441.51 cm^3) to be 623.38 in^3 (10,215.36 cm^3). This change required the applicant to update CV pressure calculations in SARP Chapter 3, and the results of the updated calculations implemented in SARP Chapters 2, 3, and 4.

The CV temperature and pressure changes under NCT and HAC (DAC M801940-0002 000 00 and DAC M900000-0002 000 00) required the applicant to update the leakage rate calculations in SARP Appendix 4.5.2 *Calculation of the ES-3100 CV Regulatory Reference Air Leakage Rates*, for NCT, HAC, and air transport. The updated calculations are based on CV pressure of 30.50 psia at 194°F for the NCT evaluation, a pressure of 175.0 psia at 334°F for the HAC evaluation, and maximum differential pressure of 117.69 kPa (17.07 psi) at 64.44°C (147.99°F), for the SSR-6 air transport evaluation. SARP Appendix 4.5.2 relies on the input from SARP Appendix 3.5.1, Table 7 (for NCT), Table 9 (for air transport), and Appendix 3.5.2, Table 7 (for HAC).

The following references were added to SARP, Appendix 4.5.3, and implemented throughout SARP Chapter 4, as the technical basis for changes to the containment evaluation of the package design:

- DAC M900000-0002 000 00, C. R. Hammond, *ASME Code Subsections NB and WB Stress Analysis of ES-3100 Containment Vessel*, B&W Y-12, Y-12 National Security Complex, April 19, 2011 (**NOTE** – this DAC supersedes DAC M900000-0003 in SARP Chapter 4, because of the increased upper temperature range, from 350°F to 400°F),
- SSG-26, Specific Safety Guide No., Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition), International Atomic Energy Agency, Vienna, 2014, and
- SSR–6, Specific Safety Requirements No., Regulations for the Safe Transport of Radioactive Material, International Atomic Energy Agency, Vienna, 2012 (**NOTE** – SSR-6 supersedes TS-R-1, *Regulations for the Safe Transport of Radioactive Material*).

These references were summarized in Section 2 of this SER.

DOE PCP staff verified the results of M900000-0002 000 00 were implemented in SARP Chapter 4 as the basis for the CV internal pressure differential of 1378.95 kPa (200 psig), in SARP Section 4.1.1 *Containment Boundary*.

Staff verified the requirements of SSR-6 are implemented and evaluated in SARP Chapter 4, in accordance with guidance from SSG-26, paragraph 621.3:

- Section:
  - 4 *CONTAINMENT*
- Table
  - 4.6 *10 CFR 71.51(a)(1) leakage criteria for air transport in accordance with IAEA environmental conditions*
- Appendix:
  - 4.5.2 *Calculation of the ES-3100 CV Regulatory Reference Air Leakage Rates*

The CV temperature and pressure changes under NCT and HAC (DAC M801940-0002 000 00 and DAC M900000-0002 000 00) required the applicant to update the leakage rate calculations in SARP Appendix 4.5.2 *Calculation of the ES-3100 CV Regulatory Reference Air Leakage Rates*, for NCT, HAC, and air transport, and implement the results in SARP Tables 4.5 *Regulatory leakage criteria for NCT*; 4.6. *10 CFR 71.51(a)(1) leakage criteria for air transport in accordance with IAEA environmental conditions*, and 4.8 *Regulatory leakage criteria for HAC*. The updated calculations are based on CV pressure of 30.50 psia at 194°F for the NCT evaluation, a pressure of 175.0 psia at 334°F for the HAC evaluation, and maximum differential pressure of 117.69 kPa (17.07 psi) at 64.44°C (147.99°F), for the SSR-6 air transport evaluation. SARP Appendix 4.5.2 relies on the input from SARP Appendix 3.5.1, Table 7 (for NCT), Table 9 (for air transport), and Appendix 3.5.2, Table 7 (for HAC). DOE PCP staff reviewed and conducted a confirmatory containment analysis, and the results are in good agreement with the SARP.

IAEA SSR-6, para. 621, states: "Packages containing radioactive material, to be transported by air, shall be capable of withstanding, without loss or dispersal of radioactive contents from the containment system, an internal pressure that produces a pressure differential of not less than the maximum normal operating pressure plus 95 kPa." The allowable leakage rates at the calculated lower (-40°F) and upper (147.99°F) temperature limits for air transport were evaluated in SARP Appendix 4.5.2 and summarized in SARP Table 4.6. The CV has been tested to meet the ANSI N14.5 leaktight criterion, which is substantially below the allowable leakage rates in SARP Table 4.6 for air transport. Therefore, the IAEA SSR-6 requirement of no loss or dispersal of radioactive contents from the containment system has been satisfied.

Based on review of the statements and representations in the SARP, and DOE PCP staff's confirmatory analysis, staff has reasonable assurance that the containment design of the package continues to meet the requirements of 10 CFR Part 71.

5.0 Shielding Evaluation

The purpose of the shielding review is to confirm that the package (the packaging together with its contents) meet the external radiation requirements in 10 CFR Part 71.

There were no changes to the package shielding design, source term, or the model used in the analysis, except for the change from Kaolite to Packcrete. The applicant clarified, throughout SARP Chapter 5 that the NCT surface dose rates are 1 mm from the drum surface. The dose rates calculated for 36 kg of HEU metal bound those for all shipping configurations as described in SARP Tables 1.3, 1.3a, and 1.3b.

The applicant added SARP Appendix 5.5.3, *Comparative NCT Dose Rates for Kaolite and Packcrete*, to demonstrate that there are only minor statistical differences among the calculated dose rates for different source configurations using either the Kaolite or Packcrete impact-absorbing and thermal-insulating materials; therefore, the Kaolite shielding calculations in SARP Chapter are bounding for Packcrete. NCT doses rates in SARP Table 5.7, *Side dose rates for different HEU metal source configurations*, were updated with the maximum dose rates from Table 5.5.3.2 *Dose rates 1 mm from package side surface using Kaolite and Packcrete for NCT*, of Appendix 5.5.3.

The following references were added to SARP Appendix 5.5.4, and implemented in SARP Chapter 5:

- ORNL/TM-2005/39, Version 6.1, Scale: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design, UT-Battelle, Oak Ridge National Laboratory, June 2011,
- Paul, P. K., "Dose Rate Evaluation for the ES-3100 Package with HEU Content Using MCNP, ADVANTG, Monaco, and MAVRIC," Nuclear Technology, 205:6, 847–866, 2019. (https://doi.org/10.1080/00295450.2018.1533319), and
- RP 802282-0002 000 02, Packcrete Material Properties, Consolidated Nuclear Security, LLC, Y-12 National Security Complex, June 2016.

ORNL/TM-2005/39 and Paul 2019 were implemented in SARP Section 5.4.4 *External Radiation Levels*, as a reference that compared the Monte Carlo N-Particle Transport Code (MCNP) calculated dose rates for the HEU metal contents with the Monaco (ORNL/TM-2005/39) calculated dose rates in a journal paper (Paul 2019), and found them to be in general agreement.

RP 802282-0002 000 02 was summarized in Section 2 of this SER and implemented in SARP Appendix 5.5.3 in the NCT shielding analysis to compare Packcrete and Kaolite based on their slightly different material densities and chemical specifications. SARP Section 5.3.2 *Material Properties*, was revised to add Packcrete in the description of impact-absorbing and thermal-insulating materials. Note b was added to SARP Table 5.8, *Shielding model material specifications for the ES-3100 package with HEU content*, to reference the new NCT analysis in SARP Appendix 5.5.3.

The applicant revised SARP Table 5.8 to add properties of the Silicone rubber pads used as packing material. These pads are used in the Shielding Model and analysis, but its properties were previously omitted from Table 5.8.

5.1 NCT Confirmatory Analysis

DOE PCP staff performed a confirmatory analysis of SARP Appendix 5.5.3. The applicant and staff used the same shielding model configuration described in SARP Section 5.3. The NCT shielding calculations performed in the SARP were based on detailed MCNP5 code models of the package using the ENDF/B-VII.0 nuclear data library. The material composition of the impact-limiting and thermal-insulating material and the respective density were changed from Kaolite to Packcrete based on Appendix Table 5.5.3.1 *Shielding model Kaolite and Packcrete, material specifications*.

The MCNP code and the ENDF/B-VII.0 nuclear data library was used by the applicant and DOE PCP staff's shielding calculations. The applicant's calculations were performed using MCNP5 and staff used MCNP6.2.

Table 5-1 of this SER (below) shows the applicant's (Appendix 5.5.3, Table 5.5.3.2) and staff's maximum calculated photon and neutron (including the secondary photons produced by the neutron interactions) dose rates which were at package surface side for the hemi-shell source and top dose rates for a solid source, respectively. It was concluded that replacing Kaolite with Packcrete does not affect the shielding properties of the insulation material, and consequently, the shielding performance of the package. The shielding evaluation of the package using Kaolite bounds the shielding evaluation for using Packcrete.

Table 5-1: Calculated Maximum Photon and Neutron NCT Dose Rates of the ES-3100 using Kaolite or Packcrete [(mrem/h) with ± one sigma uncertainty (%)]

Configuration	Kaolite - Photons		Packcrete - Photons	
	Applicant	Staff	Applicant	Staff
Cylindrical hemi-shell	95.8 ± 1.47%	97.8 ± 0.58%	95.136 ± 0.44%	97.5 ± 0.53%
Configuration	**Kaolite – Neutrons***		**Packcrete – Neutrons***	
	Applicant	**Staff**	**Applicant**	**Staff**
Solid cylinder at the top of CV	1.5786 ± 0.32%	1.70 ± 0.91%	1.5088 ± 0.38	1.60 ± 0.91%

* Includes the dose rate from secondary photons.

For the HAC shielding evaluation of the package shielding design, the applicant assumes the CV remains intact, but all the packaging materials external to the CV are removed. Therefore, changing the insulating material from Kaolite to Packcrete does not affect the HAC shielding evaluation of the package.

5.2 Conclusion

Based on review of the statements and representations in the SARP, and DOE PCP staff's confirmatory analysis, staff has reasonable assurance that the package shielding design meets the external radiation requirements of 10 CFR Part 71.

6.0 Criticality Evaluation

The purpose of the criticality review is to confirm that the package together with its contents meet the requirements in 10 CFR Part 71 for nuclear criticality safety (NCS).

The NCS design of the package consists of the Drum Assembly and watertight CV. The drum body weldment liner inner cavity contains a neutron poison, 277-4, which serves as a strong neutron absorber. The 277-4 material is also used in can spacers within the CV. There were three changes to the NCS design. The first change was a material change from Kaolite to Packcrete in the drum body; the second change to include nylon or Teflon as authorized bagging material inside the CV, and the third change was decrease of the minimum void volume in the CV if closed convenience cans with an outer diameter >4.25 in. are used, from to 55 to 43 in^3, to allow for gas expansion and offgassing of material at temperatures associated with NCT or HAC. The applicant demonstrated that these changes did not affect the performance of the package to meet the requirements of 10 CFR Part 71 for NCS.

The applicant revised SARP 6.1.2 *Codes and Standards*, to reference the current IAEA regulations and advisory material for air transport of fissile material: from TS-R-1, Sect. 680 to SSR-6, Para. 683, and TS-G-1.1, Sect. 680.2 to SSG-26, Para. 683.2. No additional NCS analysis was required for this administrative change.

The limit for equivalent mass of 500 g polyethylene for hydrogenous packing material (polyethylene, nylon, or Teflon bagging material) inside the CV was unchanged. Nylon ($C_{12}H_{22}N_2O_2$) and Teflon (C_2F_4) have a lower hydrogen density than water and polyethylene and are therefore bounded by polyethylene in the current NCS analysis.

The decrease in the minimum CV void volume, when closed convenience cans with an outer diameter >4.25 in. are used, from to 55 to 43 in^3, does not affect the NCS performance of the package because the correct CV internal dimensions, inner diameter of 12.852 cm (5.06 in.) and the usable height of 78.74 cm (31.0 in.) were used in the NCS analysis. The empty CV working volume of 637.18 in^3 (10,441.51 cm^3) to 623.38 in^3 (10,215.36 cm^3) was corrected for the SARP Chapter 3 CV pressure calculations.

The content changes in SARP Section 1.2.2 and fissile loading limits for ground transport and air transport in SARP Tables 1.3 and 1.3b, and described in Section 1.2 of this SER, were updated by the applicant in the SARP Chapter 6 Appendices.

DOE PCP staff's review of the SARP Chapter 6 changes focused on the effect of Packcrete material properties and the content changes in SARP Section 1.2.2 with respect to the NCS performance of the package.

The following references were added to SARP Appendix 6.9.12, and implemented in SARP Chapter 6:

- RP YAREA-F-0524 000 00, Validation of SCALE 6.1.3 for Criticality Safety Analyses of HEU Systems using the Workstations ENGHPC, CENGHPC, and ENGHPC02, Consolidated Nuclear Security, LLC, Y-12 National Security Complex, September 2016,
- SSG-26, Specific Safety Guide No., Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition), International Atomic Energy Agency, Vienna, 2014, and
- SSR–6, Specific Safety Requirements No., Regulations for the Safe Transport of Radioactive Material, International Atomic Energy Agency, Vienna, 2012 (**NOTE** – SSR-6 supersedes TS-R-1, *Regulations for the Safe Transport of Radioactive Material*).

Packcrete Material Properties (RP 802282-0002 000 02) was not included in Chapter 6 list of references, but is the basis of the new Section 6.9.3.5 *Packcrete* of SARP Appendix 6.9.3 *Package Material Compositions*. In Appendix 6.9.3, the applicant performed array calculations of package with low density Packcrete and low density water, since it has been shown in the Kaolite calculations that lower density materials are the most reactive for array calculations (due to the enhancement of interaction effects). In addition, Appendix 6.9.3 also includes several series of calculations in the analysis comparing Kaolite and Packcrete. The results are listed in the following tables:

- Table 6.9.3.5-2. *Comparative calculations Kaolite vs Packcrete for single package (maximum amount of water in Kaolite and Packcrete)*,
- Table 6.9.3.5-3. *Comparative array calculations Kaolite vs Packcrete* (i.e., minimum amount of water is used), and
- Table 6.9.3.5-4. *Comparative array calculations for Kaolite vs Packcrete with no water*.

Based on the results of these calculations, it is demonstrated that the $k_{eff} + 2\sigma$ calculations performed for Kaolite bound the Packcrete package configuration.

RP YAREA-F-0524 000 00 – SARP Section 6.3.3 *Computer Codes and Cross-Section Libraries*, was updated to clarify that KENO V.a calculations were performed using Criticality Safety Analysis Sequences, Module 5 (CSAS5) in SCALE 6.1.1 for low density uranium oxides, and Monte Carlo CSAS5 and 238-group ENDF/B-VII (V7-238 gr) cross-section library of SCALE 6.1.3 was used for the content changes in SARP 1.2.2 for calculations for annular cylinders; broken metal, turning, fines, powders, poly wrapped reactor fuel, U_3Si_2-Al and U_3Si compounds, compounds by air, thorium oxide mixed with uranium oxide in fuel pellets and bulk oxide, zircalloy oxide mixed with uranium oxide, thorium mixed with uranium oxide, were performed using the. The following new tables in SARP Appendix 6.9.6 *Abridged Summary Tables of Criticality Calculation Results*, were added for the content changes in SARP 1.2.2. These tables are the basis for the NCS calculation results in SARP Sections 6.4 *SINGLE PACKAGE EVALUATION*, 6.5 *EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT*, 6.6 *EVALUATION OF PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS*, and 6.7 *FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT*.

<u>Cylinder Content</u>

- Table 6.9.6-1a. *Results for cylinder C and D HEU content in CV calculation model*,

- Table 6.9.6-2a. *Results for cylinder C and D content in single package calculation model*, and
- Table 6.9.6-3d. *Results for cylinder C and D content in infinite array package calculation model.*

Broken Metal Content

- Table 6.9.6-10a. *Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) with 500 g polyethylene in CV calculation model*,
- Table 6.9.6-10b. *Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) with 500 g polyethylene with thorium in CV calculation model*,
- Table 6.9.6-11. *Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) in packaging calculation model*,
- Table 6.9.6-11a. *Results for HEU content (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) with 500 g polyethylene in packaging calculation model*, and
- Table 6.9.6-11aa. *Results for HEU content mixed with thorium (solid metal of unspecified geometric shape and characterized as broken metal, broken metal, turnings, fines, or powder) with 500 g polyethylene in packaging calculation model*.

HEU Product Oxide Content

- Table 6.9.6-12a. *Results for HEU oxide content with 500 g polyethylene in CV calculation model*,
- Table 6.9.6-12b. *Results for HEU oxide/thorium oxide content with 500 g polyethylene in CV calculation model*,
- Table 6.9.6-12c. *Results for HEU oxide/zirconium oxide content with 500 g polyethylene in CV calculation model*,
- Table 6.9.6-12d. *Results for HEU oxide/thorium metal content with 500 g polyethylene in CV, calculation model*,
- Table 6.9.6-13c. *Results for low density HEU oxide content in single unit packaging calculation model*,
- Table 6.9.6-13d. *Results for low density HEU oxide content in array packaging calculation model*,
- Table 6.9.6-13e. *Results for HEU oxide/thorium oxide content in single-unit packaging calculation model*,
- Table 6.9.6-13f. *Results for HEU oxide/zirconium oxide content in single-unit packaging calculation model*,
- Table 6.9.6-13g. *Results for HEU oxide/thorium metal content in single-unit packaging calculation model*,
- Table 6.9.6-13h. *Results for HEU oxide/thorium oxide content in array packaging calculation model*,
- Table 6.9.6-13i. *Results for HEU oxide/zirconium oxide content in array packaging calculation model*, and

- Table 6.9.6-13j. *Results for HEU oxide/thorium metal content in array packaging calculation model.*

Air Transport Content
- Table 6.9.6-24a. *Results for compounds content for air transportation (Models 1-5)* and
- Table 6.9.6-24b. *Results for compounds content for air transportation (Model 6)*.

The following Tables were updated in SARP Appendix 6.9.6 to run additional cases of the package model using SCALE 6.1.3:

Cylinder Content
- Table 6.9.6-1. Results for the 3.24 in.-diam cylinder HEU content in CV calculation model,
- Table 6.9.6-3. Results for the 3.24-in.-diam cylinder HEU content in package calculation model,
- Table 6.9.6-6. *Results for the 4.25 in.-diam cylinder HEU content in CV calculation model*, and
- Table 6.9.6-7. *Results for the 4.25 in.-diam cylinder HEU content in packaging calculation model.*

Square Bar Content
- Table 6.9.6-4. *Results for the 2.29 in square bar HEU content in CV calculation model* and
- Table 6.9.6-5. *Results for the 2.29 in square bar HEU content in packaging calculation model.*

Slugs Content
- Table 6.9.6-8. *Results for 1.5 in.-diam × 2.0-in.-tall slug HEU metal content in CV calculation model* and
- Table 6.9.6-9. *Results for the 1.5 in.-diam × 2.0-in.-tall slug HEU metal content in packaging calculation model.*

Unirradiated TRIGA Reactor Fuel Element Content
- Table 6.9.6-19a. *Results for UZrHx content in CV calculation model*,
- Table 6.9.6-20a. *Results for UZrHx content at 19.7 wt % 235U in packaging calculation model*, and
- Table 6.9.6-20b. *Results for UZrHx content at 70.1 wt % 235U in packaging calculation model.*

SARP Appendix 6.9.11 was revised to remove the NCS analysis of *HEU Metal Turnings, Fines or Powders (>80% enriched)* and *Low Density Oxides* and associated Tables 6.9.11: 1 through 4, 11 through 18, 23 through 32, 39 through 42, and 53 through 55, from this appendix and include them, with an updated NCS analysis of these contents, in SARP Appendix 6.9.6.

6.1 Summary of SARP and Confirmatory NCS Analysis

SER Table 6-1 below shows the SARP (Table 6.9.3.5-3) and DOE PCP staff's NCS analysis results of the finite array (13×13×6) of packages containing 15.5 kg of uranium oxide at the density of 2g/cm^3, with the minimum water density in Kaolite and Packcrete configurations. The calculations with Packcrete were performed using the minimum amount of water found in Kaolite samples because the minimum amount of water found in Packcrete samples is greater. KENO.V and MCNP6.2 were used by the applicant and staff for their respective NCS analysis. Staff confirms that the water content and density, which are of primary importance for NCS, are sufficiently similar between the Kaolite and the Packcrete configurations and that the NCS analysis of Kaolite is bounding.

Table 6-1. NCS Analysis of the 13×13×6 Array of ES-3100 Packages Containing 15.5 kg of Uranium Oxide at 2 g/cm^3 using Kaolite and Packcrete

Configuration	$k_{eff} + 2\sigma$			
	Kaolite		Packcrete	
	SARP	Staff	SARP	Staff
15.5 kg HEU oxide at 2 g/cm^3	0.93250	0.93852	0.93165	0.93855

SER Table 6-2 below shows the summary of SARP (Table 6.1c) and DOE PCP staff's NCS analysis results for ground transport of a single package with HEU broken metal, or solid HEU metal of unspecified geometric shape and characterized as broken metal, with 500 g of polyethylene in the water flooded CV. The amount of water in the flooded CV is calculated on the basis that the convenience can steel is replaced with water. Can pads and spacers are omitted from the model. The upper subcritical limit (USL) is 0.93520.

Table 6-2. NCS Analysis for Broken Metal or Solid Metal of Unspecified Geometric Shape Characterized as Broken Metal with 500 g Polyethylene in the flooded CV

Case	Enrichment	U-235 (kg)	$k_{eff} + 2\sigma$	
			SARP	Staff
cvr3lhap_9_1_6_15	100%	22.40	0.93380	0.93565
cvr3lhap_18_1_5_15	95%	23.37	0.93678	0.93522
cvr3lhap_28_1_4_15	90%	27.99	0.93258	0.93473
cvr3lhap_34_1_3_15	80%	28.80	0.90434	0.90584
cvr3lhap_34_1_2_15	70%	25.20	0.87555	0.87555
cvr3lhap_34_1_1_15	60%	36.00	0.84316	0.84360

SER Table 6-3 below shows the SARP (Table 6.9.8.8-7c) and DOE PCP staff's NCS analysis results for ground transport of U_3Si, 40% and 60% enriched, in an infinite package array (CSI=0), with 500 g of polyethylene in the water flooded CV, without spacers. The results are the basis for the loading limits in SARP Table 1.3. The USL is 0.93520.

Table 6-3. NCS Analysis for Ground Transport of 40% and 60% Enriched U_3Si in Infinite Array (CSI=0) Packaging with 500 g of Polyethylene in Flooded CV

Case	Uranium Compound	Enrichment	CSI	U_3Si (kg)	U-235 (kg)	$k_{eff} + 2\sigma$	
						SARP	Staff
nciapdus3sit11_2_6_2	U_3Si	40%	0	14.0	5.387	0.83919	0.83969
nciapdu3st11_3_4_2	U_3Si	60%	0	8.5	4.906	0.93627	0.93242

SER Table 6-4 below shows the SARP (Table 6.9.6-24a) and DOE PCP staff's NCS analysis results for air transport of 40% and 60% enriched U_3Si saturated at 2.0 g/cm^3 with 500 g of polyethylene in the water flooded CV. The results are the basis for the loading limits in SARP Table 1.3b. The USL is 0.93680.

Table 6-4. NCS Analysis for Air Transportation of 40% and 60% Enriched U_3Si Saturated at 2.0 g/cm^3 with 500 g of Polyethylene in Flooded CV

Case	Uranium Compound	Enrichment	U_3Si (kg)	U-235 (kg)	$k_{eff} + 2\sigma$	
					SARP	Staff
athu3sipw12kr40_6_5	U_3Si	40%	8.5	3.270	0.93532	0.93770
athu3sipw12kr60_5_5	U_3Si	60%	6.5	3.613	0.93552	0.93396

DOE PCP staff reviewed SARP Chapters 1 and 6 and finds the following changes are bound by the existing content loadings and NCS analyses,

- Addition of Cylinder C and Cylinder D, with description, in SARP Table 1.3, under the "Solid HEU metal or alloy (specified geometric shapes" content category;
- Addition of three types of HEU oxide contents, with loading limits for different density ranges, i.e. product oxides (UO_2, UO_3, U_3O_8) mixed with ThO_2, product oxides (UO_2, UO_3, U_3O_8) mixed with Th metal, and product oxides (UO_2, UO_3, U_3O_8) mixed with ZrO_2, in separate entries in Tables 1.3 and 1.3b; meanwhile, the UO_2-ZrO_2 content was removed from the entry "UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, UO_2-ZrO_2", in both Tables 1.3 and 1.3b;
- Addition of UO_2-ThO_2 pellets under the "Research reactor fuel elements and components content" category in Tables 1.3 and 1.3b;
- Addition of a statement in footnote "k" of Tables 1.3 and 1.3b, "Carbon coating for reactor fuel is not controlled (section 6.9.8.3.1)", which is supported by the criticality evaluation and analysis in Chapter 6; addition of footnote "o", "No control of the amount of aluminum", to Table 1.3, which is a valid statement based on NCS analysis; and addition of footnote "l" to Table 1.3b to clarify that for air transport, the allowable uranium compound bulk densities shall be in the range of 2.0 – 6.54 g/cm^3;
- Inclusion of 500 g of polyethylene, which is equivalent to 1,285.14 g of water as explained in SARP Section 6.9.3.7, in the NCS analysis of the "Research reactor fuel elements and components" content category, does not increase the reactivity of the package; and
- SARP Table 6.9.8.1-2 for the BR-2 MTR Type 2 fuel enrichment was corrected from ≤100% to ≤ 93%, consistent with the model configuration in SARP Section 6.9.8.3.1 and NCS analysis in SARP Section 6.9.8.6.1.

6.2 Conclusion

Based on a review of the information and representations provided in the SARP, and DOE PCP staff's confirmatory analysis, staff has reasonable assurance that the package NCS design for the contents, as modified, described in the SARP satisfies the NCS requirements in 10 CFR Part 71.

7.0 Operating Procedures

The SARP provides a description of package operations, including package loading and unloading operations, and the preparation of an empty package for shipment. Loading and unloading procedures show a general approach to perform operational activities because site-specific conditions may require the use of different equipment and loading or unloading steps.

DOE PCP staff reviewed the SARP Chapter 7 *Operating Procedures* to verify that the package will be operated in a manner that is consistent with its design evaluation.

The SARP changes to the *Operating Procedures* include:

- Use of nylon, or Teflon bags as bagging material in the CV,
- Corrected the drum lid nut and washer part descriptions in SARP Table 7.1. *Replacement parts for the ES-3100 packaging*,
- Recommendation that labels applied to the packaging should be vinyl type or placed on plain vinyl tape is now a requirement,
- Addition another option for applying the package identification number marking to the drum, and
- Update to the "example" leakage test procedure in SARP Appendix 7.5.2, *Example Leak-Test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-074, Shipping Container Leak Test*.

References to the Code of Federal Regulations and DOE Directives in SARP Appendix 7.5.3 were updated to their current revisions.

DOE PCP's staff review confirmed:

- The use of nylon, or Teflon bagging material was properly and adequately implemented in SARP Section 7.1.1.1, *Content preparation*, Step 2; 7.1.1.2 *Packaging preparation* Step 23; 7.1.2 *Loading of Content*, Step 3; and 7.2.2 *Removal of Contents*, Step 16.
- The corrected drum lid nut and washer descriptions in SARP Table 7.1 are proper and consistent with other sections of the SARP and Drawing M2E801580A005.
- The new requirement that labels applied to the packaging should be vinyl type or placed on plain vinyl tape was added to improve the ease of label removal and to minimize adhesive build-up on the packaging surfaces. This new requirement was added as Item 6 to the list of operation procedure requirements in SARP Section 7, and implemented in the Notes for SARP Sections 7.1.2.2, Step 19 and 7.3 *PREPARATION OF EMPTY PACKAGE FOR TRANSPORT* Step 28.

- The new option in SARP Section 7.1.2.2, Step 21c. for applying the package identification number marking to the drum, per Drawing M2E801580A010, *Data Plate Details*, is required for packaging fabricated after January 1, 2017 in accordance with 49 CFR 172.301, *General marking requirements for non-bulk packagings*.
- The example leakage test procedure in SARP Appendix 7.5.2, Y51-01-B2-R-074, Revision A.8 was superseded by Revision A.9. Revision A.9 was issued because the compressor was eliminated from the leak test station.

Based on review of the statements and representations in the SARP, DOE PCP staff concludes that the combination of the engineered safety features and the operating procedures provide adequate measures and reasonable assurance for safe operation of the package in accordance with 10 CFR Part 71.

8.0 Acceptance Tests and Maintenance Program

The objective of this review is to verify that the acceptance tests for the packaging meet the requirements of 10 CFR Part 71 and that the maintenance program is adequate to assure packaging performance during its service life.

DOE PCP staff reviewed the SARP Chapter 8 *Acceptance Tests and Maintenance Program* to ensure that appropriate acceptance tests and maintenance program are specified for the package.

The SARP changes to the *Acceptance Tests and Maintenance Program* include:

- The addition in SARP Section 8 of three new specifications:
  - Item 6 is a new stand-alone specification, M801580-0004, *Heavy Can Spacers* (SARP Appendix 1.3.10),
  - Items 7 and 8 is are specifications for Packcrete, SPC M801794-0003 *Packcrete Preliminary Lot Qualification* (SARP Appendix 1.3.11) and SPC M801580-0003 ES-3100 *Packcrete Final Lot Qualification and Production Processing* (SARP Appendix 1.3.12),
- Include Packcrete throughout the Chapter,
- Addition of nylon and Teflon bagging material in the CV,
- Removal of the extra-regulatory rough-handling test requirement for drum acceptance,
- Clarification that “Diamond S” symbol is used, in addition to “Diamond I”, on the drawings or equipment specifications to designate significant dimensions or features, which are specifically inspected and documented in the inspection reports,
- Update the MNOP from 16.518 to 15.567 psig,
- Correction to drum lid nut description to from “5/8-11 UNC” to “5/8-11 UNC-2B”,
- Option for Leakage Test personnel qualification to sign or use badge number for identification,
- Update to the “example” leakage test procedure in SARP Appendix 7.5.2, *Example Leak-test Procedure, Y-12 Product Specification Procedure Y51-01-B2-R-140, He Leak Testing in B2*, and
- SARP Appendix 8.3.2, *References*, was revised to update references to Code of Federal Regulations and DOE Directives to their current revisions.

DOE PCP's staff review confirmed:

- The specification SPC M801580-0004 (SARP Appendix 1.3.10) was added to the fabrication requirements for the packaging components listed in SARP Chapter 8. The applicant revised SARP Appendix 1.3.5, *Equipment Specification* SPC JS-YMN3-801580-A005, to remove the *Heavy Can Spacer* (Drawing M2E801580A043) from this specification and added Appendix 1.3.10, SPC M801580-0004, as a stand-alone specification for casting 277-4 neutron-absorbing material in the *Heavy Can Spacer*.
- The new specifications SPC M801794-0003 (SARP Appendix 1.3.11) and SPC M801794-0003 (SARP Appendix 1.3.12) for Packcrete were added to the fabrication requirements for the packaging components listed in SARP Chapter 8.
- Packcrete was implemented, as an alternative to Kaolite, in:
    - SARP Table 8.1. *Acceptance tests for the drum assembly*,
    - SARP Section 8.1.7 *Thermal Tests* (for acceptance): a thermal test is not required for acceptance, but this section addresses the Packcrete specifications for the QA and technical requirements for weighing, mixing, pouring, vibrating, curing and baking the Packcrete material,
    - SARP Section 8.2.3.2 *Thermal insulation and neutron-absorber material* (for maintenance): The drum assembly and top plug will be weighed prior to first use and during periodic maintenance to evaluate density variations in the Packcrete insulation or the Cat 277-4.
- Nylon and Teflon bagging material in the CV were added to the list of packaging components in SARP Chapter 8, and SARP Table 8.3. *Acceptance tests for packing materials,*
- SARP Table 8.1. *Acceptance tests for the drum assembly* and Table Note "e" were revised to the remove the rough-handling for the structural and pressure test requirements for acceptance of the *Double open head drum*. This change was also implemented in SARP Sections 8.1.3 *Structural and Pressure Tests* and 8.1.3.3 *Pressure tests*, to remove the "rough handling" test (MIL-D-6054F, Para. 4.6.2) as a prerequisite for the drum pressure test (MIL-D-6054F, Para. 4.6.1). The rough-handling test is not required to demonstrate compliance with 10 CFR Part 71 at that stage of drum fabrication,
- SARP Section 8.1.1.4 *Gauging* was revised to clarify that the "Diamond S" symbol is used on the drawings or equipment specifications to designate significant dimensions or features, which are specifically inspected and documented in the inspection reports,
- SARP Section 8.1.3.3 *Pressure tests* was updated to revise the MNOP from 16.518 to 15.567 psig, based on the new pressure calculations in SARP Chapter 3, and to correct the reference for the hydrostatic pressure test from SARP Section 3.7 to 3.6.
- SARP Section 8.1.4 *Leakage Tests* was revised to correct the reference for the fabrication leakage rate test from SARP Section to 3.9. to 3.7.
- SARP Section 8.2.5.4 *Drum fastener inspection* was revised to correct the description of the drum lid fasteners (nut) from "5/8-11 UNC" to "5/8-11 UNC-2B",
- SARP Section 8.2.2 *Leakage Tests*, Step 13 was revised to allow use of the badge number to identify the person who performed the testing or certified the test results, in lieu of the person's signature on the leakage test labels,

- The example helium leakage test procedure in SARP Appendix 8.3.2, Y51-01-B2-R-140Y, Revision B.2 was superseded by Revision C.3. The change history from B.2 to C.3 is not documented in the procedure.

Based on the review of the statements and representations in the SARP, DOE PCP staff concludes that the acceptance tests for the packaging meet the requirements of 10 CFR Part 71, and that the maintenance program is adequate to assure packaging performance during its service life.

9.0 QUALITY ASSURANCE

The objective of this review is to verify that the SARP demonstrates that the applicant's Quality Assurance (QA) program description and package specific QA requirements comply with the requirements of 10 CFR Part 71, Subpart H, *Quality Assurance*.

The applicant's QA program for Type B or fissile packaging, *Packaging and Transportation Quality Assurance Program Plan (QAPP)*, QAP-Y-91-273860-1 000, Revision 16, was approved by the National Nuclear Security Administration Certifying Official (NNSA CO) on August 24, 2016, and endorsed by the DOE Headquarters Certifying Official (HCO) on February 16, 2017 (https://rampac.energy.gov/docs/default-source/qa/approval_0019_r2.pdf). QAPP Revision 16 is the basis for the SARP. QAPP Revision 17 was approved by the NNSA CO and endorsed by the DOE HCO subsequent to the submittal of this SARP and will be incorporated in the next SARP revision.

DOE PCP staff reviewed the SARP Chapter 9 *Quality Assurance* to ensure the QA program changes in QAPP Revision 16 were implemented and package specific QA program requirements for Packcrete were added and appropriate based on its importance to safety.

The SARP changes to *Quality Assurance* include:

- Each Section of Chapter 9 was revised by the applicant for consistency with QAPP Revision 16,
- SARP Section 9.1, *INTRODUCTION* was expanded to address the relationship of the QAPP with respect to the applicable regulations and certifying authorities,
- SARP Section 9.2, *SCOPE*, was updated to add § 71.106, *Changes to quality assurance program*,
- SARP Section 9.3, *QUALITY ASSURANCE PLAN*, was updated to clarify the relationship of the QAPP to the applicant's *Quality Assurance Program Description*, E-SD-0002,
- SARP Section 9.3.1 *Quality Assurance Organization* and Fig. 9.1. *Y-12 Packaging and Transportation Engineering organizational support*, were updated for organization changes,
- SARP Section 9.3.2 *Quality Assurance Program*, was updated to:
    - Clarify the program description,
    - Add Packcrete and nylon or Teflon bagging material to SARP Table 9.2. *Quality category for ES-3100 packaging components*, and

    - Add a reference to the training and qualification plan *Enterprise Training and Qualification*, Program E-PROC-3028.
- SARP Section 9.3.9, *Control of Special Processes*, was revised to clarify the special processes required for fabrication and maintenance of ES-3100 packaging components,
- SARP Section 9.3.10, *Internal Inspection*, was revised to clarify the scope of the internal inspections and add qualification requirements for non-destructive examinations.
- SARP Section 9.3.16, *Corrective Action*, was updated to incorporate the reporting requirements from DOE Order 460.1D consistent with §71.95 *Reports*,
- SARP Section 9.3.17, *Quality Assurance Records* and Table 9.3. *Typical quality assurance records*, were revised to clarify and expand the description of package QA records and record processing, and
- SARP 9.3.18, Audits, was revised to condense the scope to audits

DOE PCP's staff review confirmed:

- Chapter 9 Section revisions are consistent with QAPP Rev. 16.,
- SARP Section 9.1 changes that address the relationship of the QAPP with respect to the applicable regulations and certifying authorities are accurate and complete,
- SARP Section 9.2, addition of § 71.106 to the list of Subpart H requirements is acceptable, but DOE did not adopt this change per DOE Order 460.1D,
- SARP Section 9.3, update to clarify the relationship of the QAPP to E-SD-0002 is acceptable,
- SARP Section 9.3.1 update for organization changes is acceptable and continues to demonstrate QA organization independence,
- SARP Section 9.3.2 updates are acceptable and the addition Packcrete and nylon or Teflon bagging material to SARP Table 9.2 and QA Categories is consistent with their component use and evaluation in the SARP,
- SARP Section 9.3.9, updates to clarify the special processes required for fabrication and maintenance of ES-3100 packaging components are acceptable,
- SARP Section 9.3.10, updates to clarify the scope of the internal inspections and add qualification requirements for non-destructive examinations are acceptable,
- SARP Section 9.3.16, updates to are consistent with the reporting requirements from DOE Order 460.1D and §71.95, as applicable,
- SARP Section 9.3.17, to clarify and expand the description of package QA records and record processing is acceptable, and
- SARP 9.3.18, updated to condense the scope to audits is acceptable.

DOE PCP staff finds that the changes made to these sections in SARP Chapter 9 do not reduce the commitments to QAPP Revision 16, approved by the NNSA CO and HCO, and these revised sections are compliant with DOE Order 460.1D and the corresponding 10 CFR 71 Subpart H requirements specified in §71.103 to §71.137.

Based on review of the statements and representations in the SARP, DOE PCP staff has reasonable assurance that the package-specific requirements are consistent with their DOE approved QAPP, meet the requirements of 10 CFR 71 Subpart H, and are therefore adequate to assure the package will be operated in a manner consistent with its evaluation for approval.

Conditions of Approval

The following changes to the CoC are required to implement SARP Revision 3, and conditions in this SER.

- Section 3, Block (2) – The safety basis document is *Safety Analysis Report For Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, SP-PKG-801940-A001 000 03 (Rev. 3), January 21, 2021.
- Section 5(a)(2), Packaging Description:
  - Replace "Kaolite™" with "Kaolite®1600 or Packcrete" (2 places)
  - Update Figure 1.0 with SARP Figure 1.1
- Section 5(a)(3), Drawings – Update Table 1.0 with drawing revisions as follows:

Table 1.0. Package Design Drawings

Drawing No.	Revision	Title
M2E801580A037	J	Consolidated Assembly Drawing (3 sheets)
M2E801580A001	D	Drum Assembly
M2E801580A002	C	Body Weldment
M2E801580A004	C	Double Open Head Reinforced Drum
M2E801580A008	D	Top Plug Weldment
M2E801580A010	G	Data Plate Details
M2E801580A011	H	Containment Vessel Assembly
M2E801580A012	D	Containment Vessel Body Assembly (2 sheets)
M2E801580A014	C	Containment Vessel Lid Assembly
M2E801580A024	D	Containment Vessel Vibration Absorbing Silicone 4.25" Can Pad
M2E801580A043	C	Heavy Can Spacer Assembly (SST)

- Section 5(b), Contents – Update as follows:
  - Revise 1st paragraph to "The authorized contents … the form of oxide [UO_2, UO_3, U_3O_8, U_3O_8-Al, UO_2-Mg, and product oxides (UO_2, UO_3, U_3O_8) mixed with ThO_2, ZrO_2, and Th metal]." (revised for new contents definitions and Th)
  - Delete from 1st paragraph "…; and HEU metal or alloy turnings, fines or powders with an enrichment of ≤ 100%." (redundant)
  - Delete Table 1.2a *Maximum impurities in uranium silicide* and Table 1.3, Note "n." (reference to Table 1.2a)
  - Revise paragraph before Table 1.2b to "… according to the limits shown Table 1.2b, and requirements for air transport of plutonium in §71.88." (clarification)
  - Renumber Table 1.2b to 1.2a. (previous table deleted)
  - Revise Table 1.3 and Table 1.3-Notes e through g, k, and n, per SARP Table 1.3 *Authorized content and fissile mass loading limits for ground transport*. (numerous content changes)
  - Revise Table 1.3b and Table 1.3b-Notes k through m, per SARP Table 1.3b *Authorized content and fissile mass loading limits for air transport*. (numerous content changes)

- Section 5(d), Conditions – Replace with:
  - (7) "… (e.g., polyethylene containers or bagging, silicone rubber pads, nylon or Teflon bags, etc.)…" (to authorize Teflon bagging material) and "… the user shall verify at least 43 cubic inches …" (new void volume).
  - (9) "… be bagged or wrapped in polyethylene, nylon, Teflon,…" (to authorize Teflon bagging material)
  - (11) "… For air transport, the total amount of free water in the package is limited to 12 lb. (5,443 g), which is water absorbed in the encapsulated Kaolite or Packcrete." (added Packcrete)
  - (12) "… of Chapter 9 of SARP, Revision 3, as supplemented …" (update to SARP Rev. 3)
  - (13) "Revision 17 of the certificate may be used until February 28, 2022." (allow 12 months for user procedure updates and shipments in process)
- Section 5(d), Conditions – add:
  - (20) Notwithstanding Drawings M2E801580A011 Revision H and M2E801580A012 Revision D, the change in M2E801580A011 for "Company Approved Equal" is not authorized for the CV body assembly, which is a Quality Category A component (SARP Table 9.2), and the change in M2E801580A012 to allow machining the CV body from a solid billet of steel is not evaluated in the SARP and therefore is not authorized.
- Section 5(e), Supplements – Replace with: "None."

Conclusion

Based on the statements and representations contained in the SARP and the conditions listed above, DOE PCP staff concludes that the Model ES-3100 package design has been adequately described and evaluated and the package meets the requirements of 10 CFR Part 71.

References

[1] *Future Amendment Items for the ES-3100 Package, CoC USA/9315/B(U)F-96, (DOE)*, Letter, Kilmartin to Shuler, March 20, 2019.

[2] *Amendment Items for the ES-3100 Package with Bulk HEU Content, US DOE Certificate of Compliance USA/9315/B(U)F-96 (DOE)*, Letter, Kilmartin to Shuler, February 28, 2020.

[3] Safety Analysis Report For Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents, SP-PKG-801940-A001 003 02 (Rev. 2, Page Change 3), February 28, 2020.

[4] *Response to Comments on the Safety Analysis Report for Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, RP 801940-0025 000 00, July 23, 2020

[5] *Response to Comments on the Safety Analysis Report for Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU* Contents, RP 801940-0025 000 01, September 22, 2020.

[6] *FW: [External] RE: Docket # 19-11-9315, ES-3100* SARP, Email, Thomas to Gelder, November 12, 2020.

[7] *Response to Comments on the Safety Analysis Report for Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, RP 801940-0025 000 02, December 17, 2020.

[8] *Response to Comments on the Safety Analysis Report for Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, RP 801940-0025 000 03, January 12, 2021 (received January 21, 2021)

[9] *Safety Analysis Report For Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, SP-PKG-801940-A001 000 03 (Rev. 3), January 21, 2021.