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DOE Packaging Certification Program

Safety Evaluation Report for Certificate of Compliance No. 9516 Amendment for the Model 9516 Package

Docket No. 21-02-9516

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This Safety Evaluation Report (SER) documents the U.S. Department of Energy (DOE) Packaging Certification Program (PCP) independent technical review of the application and supplements submitted for the DOE Idaho Operations Office (ID) for amendment of DOE Certificate of Compliance (CoC) Number 9516 for the Model 9516 package design. This package is needed to support the mission of the Idaho National Laboratory (INL), Space Nuclear Power & Isotope Technologies Division.

Summary

By email [1] dated September 29, 2020, the certificate holder, ID requested an amendment of DOE CoC 9516 for the Model 9516 package design to authorize three new configurations of Pu-238 oxide powder defined as :

- Shipping Configuration 9 - Large Containers with PuO_2 Powder,
- Shipping Configuration 10 - Medium Overpack Containers and Small Containers with PuO_2 Powder), and
- Shipping Configuration 11 - Medium Overpack Containers with PuO_2 Powder.

The application [2] for package approval in support of the ID request was Addendum No. 2 to the Model 9516 Safety Analysis Report for Package (SARP). The application (hereinafter referred as the Addendum unless otherwise specified) was prepared for ID and INL by the Pacific Northwest National Laboratory (PNNL) and submitted by ID to DOE PCP on January 4, 2021 for review. DOE PCP staff performed a completeness review and on January 11, 2021 the DOE PCP Manager requested ID to provide additional information to demonstrate compliance with §71.43(d), for staff to proceed with their independent technical review and confirmatory analysis of the Addendum.[3] ID submitted the additional information [4] on February 1, 2021, which allowed staff's review to proceed.

On April 12, 2021, the DOE PCP Manager notified ID that DOE PCP staff completed their independent technical review and confirmatory analysis and had no regulatory compliance questions or additional comments, pending implementation of proposed changes submitted February 1, 2021 in a final Addendum.[5] The final Addendum [6] was submitted by ID on April 13, 2021 and staff confirmed the proposed changes were correctly implemented.

Based on the statements and representations in the final Addendum, DOE PCP staff independently confirmed that the package design has been adequately described and evaluated for Shipping Configurations 9 through 11. 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

This SER documents the independent technical review and confirmatory analysis by DOE PCP staff of the Addendum to the SARP, to the requirements of 10 CFR Part 71.

1.0 General Information

1.1 Introduction

The safety basis for current DOE CoC 9516, Revision 7 is SARP Rev. 2 and Addendum No. 1. DOE ID submitted Addendum 2 in support of an amendment to the DOE CoC to authorize use of the package for shipment of three new configurations of Pu 238 oxide powder defined as:

- Shipping Configuration 9 - Large Containers with PuO_2 Powder,
- Shipping Configuration 10 - Medium Overpack Containers and Small Containers with PuO_2 Powder), and
- Shipping Configuration 11 - Medium Overpack Containers with PuO_2 Powder.

1.2 Package Description

There were no changes to the previously approved package description in the Addendum, except to address the new content configurations.

The Model 9516 is a Type B(U)F package that is designed for transport of up to 500 watts of PuO_2 heat source material in any solid form (e.g., powder, pellets, granules, etc.).

The package has a maximum gross weight of 900 lb. (408 kg) and consists of a cylindrical cask that is housed within a personnel shield (frame and skid). The package contents consist of various quantities of plutonium heat source material (mostly Pu-238) and fissile material that may exceed 3,000 A_2. Since the package contains Pu in excess of 0.74 TBq (20 Ci) its contents must be in any solid form to meet the requirements §71.63.

The package as offered for consignment is shown in Figure 1 of the CoC.

1.2.1 Packaging

There are no design changes to the primary packaging components in the Addendum. The Model 9516 packaging consists of three basic components: a cask, a one-time use containment vessel (CV), and personnel shield. These components are classified in SARP Table 9.1 as Quality Level A items (Quality Category A), which are critical-to-safe operation of the package.

PuO_2 for Shipping Configurations 9 through 11 is packaged in a series of nested convenience containers for handling (and storage). These containers are supported within the CV by various spacers, fillers, plates, and support blocks to restrict movement within the CV. These components are classified in Addendum Table 9-1, *Q-List for Shipping*

Configurations 9, 10, and 11, as Quality Level C items (Quality Category C), which are minor to the operation of the package.

The list and drawings of all packaging components required for these shipping configurations is defined in Addendum Table 1-2, *9516 Package Content Shipping Configurations*.

1.2.2 Contents

There are no changes to the exiting authorized contents or their shipping configurations in the Addendum.

The contents for Shipping Configurations 9 through 11 are normal form solids, as PuO_2 powder. The powder is pressed to a density of approximately 6 g/cm^3.

Addendum Table 1-1 defines *Plutonium Initial Isotopic Limits* for Shipping Configurations 9 through 11 at the date of conversion to oxide. By comparison these limits are bounded by the limits for Shipping Configurations 1 through 6 authorized in CoC Table 1, *Plutonium Initial Isotopic Limits*.

The maximum weight of the contents for Shipping Configurations 9 through 11 is 63.5 lb. (based on Shipping Configuration 9) and is bounded by the weight of 69.3 lb. for Shipping Configurations 4 and 5.

The maximum decay heat load for Shipping Configurations 9 through 11 is 420 W per package (based on Shipping Configuration 9) and is therefore bounded by the package limit of 500 W.

Shipping Configurations 9 through 11 are described in Addendum Sections 1.2.2.1.1 through 1.2.2.1.3 and are summarized below.

- **Shipping Configuration 9 - Large Containers with PuO_2 Powder**
  See Addendum Section 1.2.2.1.1 and Addendum Figure 1-1, *Loading Arrangement for Large Containers with PuO_2 Powder in a CV*. In this configuration, the PuO_2 powder is packed in two large containers per package CV. The containers are constructed of a nickel chromium alloy specification KHN65MV (similar to Hastelloy® C-276 alloy). Internal components constructed of KHN65MV and tantalum within the containers constrain the movement of the PuO_2 powder within three PuO_2 cylinders. Up to three PuO_2 powder cylinders are centered axially within each of the containers and radially the three PuO_2 cylinders are tangent to each other, i.e., in the shape of a triangle.

  The large container is 2.59 in. high × 4.13 in. in diameter, with walls that are approximately 0.30 in. thick, and top and bottom lids that are approximately 0.39 in. thick. The container is a welded enclosure. Some containers may have a 0.63 in. high × 0.71 in. diameter handle in the center of the lid. Each container loaded with PuO_2

powder weighs approximately 7.7 lb. and will have a maximum heat generation of 210 W, for a total decay heat load of 420 W per package.

Each large container loaded with PuO_2 powder is overpacked in a large stainless steel can, hereafter referred to as large radiography can (Drawing SKNEN2-5663). The radiography can is constructed of Type 304 stainless steel and Graphite 2020, with each radiography can having these materials alternated in a unique pattern as a means to identify each container for material control. The radiography can is 3.03 in. high × 4.73 in. in diameter and weighs approximately 3.5 lb. The lid of the large radiography can has a 2 in. diameter hole in the top, and if the large container has a handle, the handle will protrude through the top of the large radiography can. Stainless steel shims are placed in the top of the radiography can to ensure a tight fit of the large container. The radiography can closure consists of six, #6-32 × 0.25 in. long stainless steel socket head screws. Through-holes are provided in three alternate screws for installing tamper-indicating devices (TIDs).

The CV will be loaded with two large graphite support blocks, spacers, and fillers. Each large radiography can will be placed in a large graphite support blocks. If a large graphite support block includes a radiography can with a handle protruding through the top of the can, that filler block must be the first (lower) filler block loaded for the handle to also pass through the spacer weldment opening. For loading the CV, a spacer plate is placed in the bottom of the CV, followed by a large graphite support block, a spacer weldment, a 2nd large graphite support block, 2nd spacer plate, and topped off by the top graphite filler block. The spacer plate is ASTM A240, Type 304/304L stainless steel and the spacer weldment wall and ends are ASTM A312, Type 304/304L stainless steel pipe and ASTM A240, Type 304/304L stainless steel plate respectively.

- **Shipping Configuration 10 - Medium Overpack Containers and Small Containers with PuO2 Powder**
  See Addendum Section 1.2.2.1.2, Addendum Figure 1-2, *Loading Arrangement for Two Medium Overpack Containers And Two Small Containers with* PuO_2 *Powder in a* CV, and Figure 1-3, *Loading Arrangement for One Medium Overpack Container and Two Small Containers with* PuO_2 *Powder in a CV*. In this configuration, PuO_2 powder is packed in a small container (up to 4 containers/per CV), and then the container may be overpacked in a nested configuration of a medium overpack container and medium radiography can (1 or 2 per CV), or overpacked directly in a small radiography can (2 per CV). Both the medium overpack containers and the small containers are constructed of the nickel chromium alloy specification KHN65MV. Internal components constructed of KHN65MV and tantalum constrain movement of the PuO_2 powder within a cylinder centered radially and axially within the small containers.

  The small container is 2.90 in. high × 1.81 in. in diameter, with walls that are approximately 0.16 in. thick, and top and bottom lids that are approximately 0.24 in. thick. The container is a welded enclosure. Each small container loaded with PuO_2

powder weighs approximately 1.8 lb. and has a decay heat of 90 W. The package may be used to ship three or four small containers, so the maximum decay per CV is 360 W.

The medium overpack container is 3.78 in. high × 2.44 in. in diameter, with walls that are approximately 0.28 in. thick, and top and bottom lids that are approximately 0.39 in. thick. The container is a welded enclosure. Each medium overpack container will hold one small container. The loaded medium overpack container weighs approximately 4.6 lb.

Each small container or medium overpack container is overpacked in a stainless steel can, hereafter referred to as the small (Drawing SKNEN2-5665) and medium (Drawing SKNEN2-5664) radiography can. Both radiography cans are constructed of Type 304 stainless steel and Graphite 2910, having these materials alternated in a specific pattern as a means to identify each container for material control. The small radiography can is 3.36 in. high × 2.38 in. in diameter with a 1.00 in. diameter hole in the lid and weighs approximately 1.4 lb. The medium radiography can is 4.21 in. high × 3.01 in. in diameter with a 1.25 in. diameter hole in the lid and weighs approximately 2.2 lb. Stainless steel shims are placed in the top of radiography cans to ensure a tight fit of the container. The radiography can closure consists of six, #6-32 × 0.25 in. long stainless steel socket head screws. Through-holes are provided in three alternate screws for installing TIDs.

The CV will be loaded with one small graphite support block, two medium graphite support blocks, and spacers. Two small radiography cans are placed in one small graphite support block, and each medium radiography can is placed in a medium graphite support block. For loading the CV, the medium graphite support block is placed in the bottom of the CV, followed by a stainless steel filler block spacer, the second medium graphite support block, another stainless steel filler block spacer, the small graphite support block, and topped off by the tall top graphite filler block. The stainless steel filler block spacers are ASTM A479 or ASTM A240, Type 304/304L. For shipments where only one medium radiography can, instead of two, are loaded in the CV with the two small radiography cans, the upper medium graphite support block is empty.

- **Shipping Configuration 11 - Medium Overpack Containers with PuO_2 Powder**
  See Addendum Section 1.2.2.1.3 and Addendum Figure 1-4, *Loading Arrangement for Medium Overpack Containers with PuO_2 Powder in a CV*. This configuration is the same as Shipping Configuration 10, except the three medium overpack containers are loaded in the CV. The maximum decay per CV is 270 W.

  The CV will contain three medium graphite support blocks. For loading the CV, a medium graphite support block is loaded in the bottom of the CV, followed by stainless steel filler block spacer, 2nd medium graphite support block, 2nd stainless steel filler block spacer, 3rd medium graphite support block, 3rd stainless steel filler block spacer, and topped off by the top graphite filler block.

1.3 Evaluation Findings

Based on a review of the statements and representations in the Addendum, 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 Addendum, 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 structural performance features of the package design.

DOE PCP staff review and evaluation focused on the total gross weight of the loaded package for Shipping Configurations 9 through 11, the maximum temperatures and pressures under NCT and HAC, and the Shipping Configuration 9 spacer weldment buckling, and material compatibility.

Shipping Configuration 9, 10, and 11 have maximum heat generation rates of 420 W, 360 W, and 270 W per package, and a loaded CV weight of 63.5 lb., 55.7 lb., and 58.4 lb., respectively. The heat generation for all three shipping configurations is below the package thermal design heat loading of 500 W and the loaded CV weight range of 63.7 lb. to 72.2 lb. given in SARP Table 2-3. Therefore, these shipping configurations are bounded by the structural evaluation presented in SARP Chapter 2.

The cask is constructed to the requirements of ASME BPVC, Section VIII, Division 1, with a design pressure of 300 psig. The CV is constructed to the requirements of ASME BPVC, Section III, Division 1, Subsection NB, with a design pressure of 200 psig. As summarized in Addendum Table 3-2, the maximum normal operating pressures (MNOP) of the CV three years after closure is 25.9 psig, and the maximum CV internal pressure under HAC is 161.7 psig, which are below the maximum bounding MNOP of 37.6 psig (52.3 psia) in the SARP and the maximum CV design pressure of 200 psig. The cask internal pressures under NCT and HAC are 7.4 psig and 29.5 psig, respectively, far below the cask design pressure of 300 psig. Addendum Table 3-1, shows the NCT and HAC maximum temperatures for the CV and the cask for Shipping Configuration 9, which are all below the allowable temperature limits for these components.

In Addendum, Appendix 2.12.2, *Shipping Configuration 9 Spacer Weldment NCT and HAC Buckling Assessment buckling analysis under NCT and HAC* the applicant performed an analysis of the spacer weldment (Drawing 853328) used in Shipping Configuration 9, by determining the maximum allowable compressive stress following the requirements of ASME Boiler and Pressure Vessel Code (BPVC), Section III, Division 1, Subsection NB, Paragraph NB-3133. The external longitudinal compressive load exerted on the spacer weldment tube was calculated by multiplying the mass on top of the spacer weldment by the maximum acceleration during the 4-ft. drop under NCT (SARP Table 2-22) and the 30-ft. drop under HAC (SARP Table 2-28), to calculate the compressive stresses. DOE PCP staff reviewed Appendix 2.12.2, SARP Tables 2-22 and 2-28, and ASME BPVC Paragraph NB-3133, and performed a confirmatory analysis, and found the applicant's method and results in Addendum Appendix 2.12.2 appropriate and acceptable.

No chemical, galvanic, or other reactions are expected to occur between the various materials of the package for Shipping Configurations 9 through 11. As discussed in Addendum Section 2.2.1, the nickel chromium alloy specification KHN65MV, material for construction of PuO_2 powder small containers, medium overpack containers, and large containers, is a nickel-molybdenum-chromium wrought alloy, similar to Hastelloy® C-276 alloy. The small, medium, and large radiography cans are constructed of Type 304 stainless steel and graphite with Type 304 stainless steel shims. The stainless steel filler block spacer, stainless steel spacer weldment, and stainless steel spacer plate materials, which are Type 304/304L stainless steel, and the graphite support block and filler block materials are identical to the materials authorized for use with Shipping Configurations 4 and 5. The internal components that constrain the movement of the PuO_2 powder within the small containers and the large containers are constructed with same nickel chromium alloy specification KHN65MV and alloyed tantalum. In addition, the CV is back-filled with argon gas before welding closure and remains leaktight during transport, and there is no moisture present inside the CV.

2.1 Evaluation Findings

Based on review of the statements and representations in the Addendum, DOE PCP staff has reasonable assurance that the package structural design 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 500 Watts for the package thermal design. This limit remains the bounding case for the structural, thermal, and containment evaluations in the SARP. The package is designed for transport of up to 500 watts of PuO_2 heat source material in any solid form (e.g., powder, pellets, granules, etc.). Administrative controls are placed on the shipping configurations to ensure that the maximum package wattage is not exceeded. The source of decay heat from the PuO_2 payloads is from the alpha decay of Pu-238.

DOE PCP staff review and evaluation are focused on the maximum temperatures of the package components and the maximum pressures in the cask and the CV cavities under

NCT and HAC, and potential hydrogen generation within confined volumes inside the CV.

The package design is intended for exclusive-use shipment of PuO_2 heat source material with a maximum decay heat limit of 500 W. Shipping Configuration 9, 10, 11 have maximum decay heat loads of 420 W, 360 W, and 270 W, respectively. Addendum Chapter 3 demonstrates that these shipping configurations are bounded by the thermal evaluation in the SARP. The fuel age of the PuO_2 is up to 25 years old prior to shipment, and it is expected by the applicant that from the time of closing the CV (welding) to the arrival at the final destination could be up to three years. Since the package maximum normal operating pressure is based on the maximum gauge pressure that would develop in the containment system in a period of 1 year under the heat condition specified in §71.71(c)(1), the applicant needed to demonstrate in the Addendum a MNOP for a period of 3 years to justify an extended shipping window.

The applicant evaluated the packaging temperatures and pressures under NCT and HAC by analysis using computer code ANSYS. Shipping Configuration 9 has the most decay heat load of 420 W and is the bounding case for applicant's thermal analysis in the Addendum. The applicant's thermal analysis model includes the bolted cask (with lid, base plate, and metal O-ring), the welded CV, the graphite blocks and the stainless steel spacers inside the CV, and the PuO_2 large containers with the large radiography cans. For the pressure calculations, the applicant assumes a leak path from the welded PuO_2 containers into the CV (i.e., the decay-generated helium released from the welded containers into the CV void volume).

DOE PCP staff reviewed the construction materials of the package components and their allowable temperature limits, the shipping configurations, decay heat load, potential hydrogen generation, pressure calculations, and conducted a confirmatory analysis. The allowable temperature limits for the package components under NCT and HAC have been established in Addendum Section 3.2.2. Staff reviewed these limits and found them appropriate and acceptable.

3.1 Normal Conditions of Transport (NCT)

The maximum calculated temperatures of the package components under NCT with a decay heat load of 420 W and the corresponding allowable temperature limits are shown in Addendum Table 3.6. All the calculated maximum component temperatures are within their corresponding allowable limits.

DOE PCP staff verified the input/output files for the applicant's NCT thermal analysis. The analyses were performed for an ambient temperature of 38 °C (100 °F) with solar insolation, as specified in §71.71(c)(1), i.e. solar insolation was imposed directly on the external surfaces of the 9516 packaging for 12 hours. The internal decay heat of 420 W was assumed to be uniformly distributed in the PuO_2 containers. Staff concluded that the analysis was properly implemented and the analysis results are reasonable.

Based on §71.43(g), the accessible surface temperature of the package in still air at 100 °F and in the shade, shall not exceed 185 °F in an exclusive use shipment. For the Model 9516 package, the wire mesh panel of the personnel shield is the accessible external surface. The SARP thermal analysis was conducted with a heat load of 500W and showed that maximum personnel shield surface temperature is 128 °F; therefore, an analysis of accessible surface temperature is not conducted in Addendum 2 for the Shipping Configuration 9 through 11 contests. By comparing the maximum temperatures of the cask under NCT hot conditions, as shown in Addendum Table 3-6 and SARP 3-9, DOE PCP staff confirmed that the maximum accessible surface temperature for Shipping Configuration 9 is bounded by the SARP evaluation of a configuration with decay heat load of 500 W.

3.2 MNOP

Pressure within the cask cavity is caused by thermal expansion of air, and pressure inside the CV is caused by thermal expansion of gas mixture of the back-filled argon and the decay-generated helium. Based on the SARP, the maximum cask internal pressure under NCT is 23.6 psia (8.9 psig) based on a maximum cask gas temperature of 390 °F. The maximum internal CV pressure under NCT (a.k.a., MNOP) is 35.9 psia (21.2 psig) when it is welded and 52.3 psia (37.6 psig) at 1 year after closure based on a maximum CV temperature of 388 °F. This pressure was calculated under the NCT hot condition with a decay heat of 500 W. These pressures are all below the design pressure of 300 psig for the cask and 200 psig for the CV.

For Shipping Configuration 9, the calculated maximum cask pressure under NCT is 22.1 psia (7.4 psig) based on a maximum cask gas temperature of 335 °F. The maximum internal CV pressure under NCT (MNOP) is 31.8 psia (17.1 psig) and 40.6 psia (25.9 psig) at 1 year and 3 years after closure, respectively. These pressures were calculated under NCT hot condition with a decay heat of 420 W. The calculated average gas temperature in the CV is 501 °F, and the MNOP is conservatively calculated by using a maximum CV bulk gas temperature of 525 °F.

DOE PCP staff performed confirmatory calculations of the cask internal pressure, the CV void volumes , initial pressure at CV welding (backfilled with argon gas at 70 °F), and CV pressure at 1 and 3 years after closure. Staff confirmed that the applicant's pressure calculations in Addendum 2 are accurate and all calculated pressure results shown in Addendum Table 3.7 are bounded by the MNOP in the SARP and below the CV design pressure of 200 psig.

DOE PCP staff also performed calculations for the PuO_2 fuel ages to confirm that the calculated maximum fuel ages in the Addendum Table 3-8 of 23.15, 25.00 and 32.91 years at the end of shipment for Shipping Configurations 9, 10, and 11, respectively, are appropriate.

3.3 HAC

The package configurations for thermal evaluation under HAC are the same as those used for NCT, except for the personnel shield is omitted from the HAC thermal evaluation of the package design.

The initial conditions of the package prior to the HAC thermal test are the steady-state temperatures at 100 °F ambient with solar insolation and an internal decay heat load of 420 W. The surface absorptivity of all external surfaces of the cask are 0.8, which is consistent with §71.73(c)(4). The convective heat transfer coefficients are calculated based on the forced convection correlations with gas velocities of 32 ft./s during the 30-minute fire at 1475 °F.

The calculated HAC peak temperatures of the package components are shown in Addendum Table 3-9, *Maximum HAC Temperatures for Shipping Configuration 9*, and demonstrates they are all below their corresponding allowable temperature limits.

DOE PCP staff reviewed the applicant's HAC thermal evaluation model and results, and conducted an analysis to confirm that the peak temperatures of the components listed in Addendum Table 3-9 are accurate.

3.4 Maximum Pressure

The maximum cask internal pressure is 44.2 psia (29.5 psig) under HAC based on a maximum cask gas temperature of 1,132 °F, which is lower than the cask design pressure of 300 psig. The maximum CV internal pressure under HAC is 176.4 psia (161.7 psig) based on a maximum CV bulk averaged gas temperature of 1,006 °F, which is lower than the CV design pressure limit of 200 psig. The calculation is conservative because the initial CV pressure prior to HAC fire is assumed to have reached the maximum allowable pressure of 118.5 psia under NCT, which is much higher than its NCT pressure of 30.8 psia and 40.6 psia at 1 year and 3 years after closure, respectively. DOE PCP staff conformed by calculations that the pressures in the cask and the CV in Addendum Table 3-10, *Maximum Package HAC Pressures*, are accurate.

3.5 Hydrogen Generation

The PuO_2 content contains no organic or other hydrogenous material as it is prepared through a process of separation, precipitation, and high-temperature calcination. Prior to loading in containers, the PuO_2 is maintained in an argon gas atmosphere, and any water or water vapor present in the PuO_2 would dissipate due to the significant heat generation and open porosity of the PuO_2. The small containers, medium overpack containers, and the large containers used for Shipping Configurations 9 through 11 do not rely on seals and do not contain materials (e.g., plastics) that would decompose and generate hydrogen or other gases within these containers. The only known source of gas generation in these containers is decay-generated helium. PuO_2 containers are welded in an inert atmosphere and filled with argon and/or helium gas. Each container is tested for leaktightness after the closure is welded. The containers to be offered for shipment in the package were recently examined by methods including visual, dimensional, and radiographic, and there was no evidence of deterioration, change of exterior dimensions, distortion due to pressurization, or diminishing container integrity. The containers are stored in a radiological facility that is monitored for contamination (e.g., air monitoring, swipes), and any contamination indicative of a leaking container would be readily identified. After loading PuO_2 containers in the CV, the CV is back-filled with argon gas and closed by welding, and tested for leaktightness. In addition, as discussed in Addendum 2 and Section 2 of this SER, there is no chemical or galvanic reactions between the materials of the package. DOE PCP staff confirms there is no hydrogen generation from radiolytic, chemical, or thermal reactions.

3.6 Evaluation Findings

Based on review of the statements and representations in the Addendum, 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 performance features of the package design in order to use the package for Shipping Configurations 9 through 11.

The package containment boundary is a one-time use CV, which is a welded stainless steel can. The CV provides a tested leaktight containment boundary for the contents of the package under NCT and HAC.

The structural and the thermal performance features of the package design are not affected by Shipping Configurations 9 through 11 and the CV remains intact under NCT and HAC; consequently, the containment performance features of the package design are not affected either.

4.1 Evaluation Findings

Based on review of the statements and representations in the Addendum, DOE PCP 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 shielding performance features of the package design to use the package for Shipping Configurations 9 through 11.

The personnel shield is a cage-like engineering control that provides a physical barrier (i.e., fixed distance) from heat and radiation generated at the cask surfaces.

DOE PCP staff review and evaluation focused on the applicant's shielding evaluation of the Shipping Configuration 9, since this configuration includes the most PuO_2 mass of the three new configurations. For this Addendum, the applicant's dose rates are based on mass of PuO_2 of 1143.2 g with a Pu-238 enrichment range of 74-90 wt. %, and neutron emission rate of 18,000n/s-g-Pu-238.

5.1 Shielding Design

A detailed description of the package is provided in SARP Section 1.2.1 and description of Shipping Configurations 9 through 11 is provided in Addendum Section 1.2.2.1. The package does not contain materials specifically intended for shielding. However, the stainless steel cask, stainless steel CV, radiography cans, various size containers, and graphite packing materials provide some radiation attenuation.

For NCT dose rates, the applicant considers the surface of the personnel shield as the external surface of the package, since it's the only accessible surface under NCT. HAC dose rates are considered at the external surface of the cask surface, since the HAC evaluation does not credit the safety features of the personnel shield under HAC (i.e., assumes the shield is damaged from the HAC performance tests).

5.2 Source Specification

The maximum photon spectrum was calculated for 1143.2 g of PuO_2 (74 wt.% Pu-238, 2.0 ppm Pu-236), powder and density 6.0 g/cm^3, after 17.5 years of decay as a function of 27 energy groups. The neutron spectrum was calculated after 17.5 years of decay as a function of 27 energy groups with the total neutron source strength based on the specific neutron emission rate of 18,000 n/s/g-Pu-238 and 738.8 g of Pu-238. The 74 wt.% Pu-238 enrichment was used in the applicants shielding evaluation although the actual Pu-238 enrichment for Shipping Configurations 9 through 11 is above 80 wt.%. The applicant's evaluation is conservative in that it results in higher neutron dose rates due to the increased neutron multiplication from the larger amount of Pu-239 present in 74 wt.% Pu-238 powder vs. 80 wt.% Pu-238 powder.

The applicant's shielding evaluation was also performed with individual actinide impurities (Am-241, Np-237, U-234, and Th-232) at average concentrations based on historic assay data. None of these impurities are major contributors to the neutron or photon source terms. Sensitivity cases performed in the SARP Chapter 5 with all of the individual actinide impurities set to 1 wt.% resulted in very small (<1%) increases in the overall dose rates outside the package. Therefore, from a practical shielding standpoint, the individual actinide impurities could be as high as 1 wt.% of the total plutonium content with a negligible impact on the overall dose rates. Table 5-1 below shows the PuO_2 isotopic composition used to calculate the photon and neutron source terms for Shipping Configuration 9.

Table 5-1. PuO_2 Powder Isotopic Composition for Shipping Configuration 9

Isotope	Mass (g)
Pu-238	738.8
Pu-239	235.9
Pu-236	0.001997
Pu-240	20.6
Pu-241	2.79
Pu-242	0.219
Am-241	0.10
Np-237	1.6
U-234	4.193
Th-232	3.595
O	135.35
Total	1143.20

DOE PCP staff used ORIGEN module of the Standardized Computer Analysis for Licensing Evaluation package (SCALE) Version 6.2.4 and the ENDF/B-VII.1 decay data for the confirmatory evaluations.

5.3 Shielding Model

Shipping Configuration 9 includes two large graphite support blocks, with each large graphite block holding a large container to 571.6 g of PuO_2 powder overpacked in a large radiography can. One large graphite support block is placed at the bottom of the CV, on top of a stainless steel spacer plate. A stainless steel spacer weldment is placed on top of the lower large graphite support block. The second large graphite support block is located on top of the spacer weldment. A second stainless steel spacer plate is placed directly on top of the upper large graphite support block and a top graphite filler block is then placed at the top of the CV. There are internal components within the large container to constrain the movement of the PuO_2 powder within three cylinders.

MCNP 6.2 was used by the applicant to model the geometry of the package including the shipping cask, the CV, the large radiography cans, large containers, and the PuO_2 powder. A 6-inch thick concrete slab was placed 48 inches below the bottom of the trailer to account for radiation scattering from the ground.

The applicant used a simplified model to evaluate package dose rates under HAC. The applicant assumed a sphere of PuO_2 in the CV with no other Shipping Configuration 9 components in the CV. The sphere was positioned at the bottom, top, and side of the CV cavity to determine the highest dose location.

For exclusive-use shipments of six packages, the applicant's model consisted of a row of packages spaced apart by a distance of 172.72 cm (68 in.) from the centerline to centerline, starting at a position no closer than 121.92 cm (48 in.) from the front forward position of the trailer. The row of packages were also positioned in the middle of the trailer bed.

5.4 Shielding Results

The applicant and DOE PCP staff dose rates were calculated in accordance with the American National Standards Institute (ANSI)/American Nuclear Society (ANS)-6.1.1-1977*, Neutron and Gamma-ray flux-to-dose-rate factors*. Staff calculated the dose rates for each contribution (neutrons with secondary photons and photons) include three standard deviations.

Table 5-2 below compares the applicant's maximum NCT and HAC dose rates from Addendum Tables 5-13 and 5-14 with the staff's confirmatory analysis results, for a single package evaluation. The results are consistent.

Table 5-2 Maximum Dose Rates for Exclusive Use Shipment of a Single 9516 Package

Normal Conditions of Transport – Exclusive Use Shipment								
	Package surface [a] (mrem/h)		Outer surface of vehicle [b] (mrem/h)		2m from vehicle external surface [c] (mrem/h)		Normally occupied position in vehicle (mrem/h)	
	Addendum	Staff	Addendum	Staff	Addendum	Staff	Addendum	Staff
Photon	48.8	55.9	34.9	39.7	0.3	0.4	0.4	0.5
Neutron	208.8	210.6	149.0	150.1	1.4	1.4	2.0	2.0
Total	257.6	266.6	183.9	189.8	1.7	1.8	2.5	2.5
§71.47(b) Limits	1000		200		10		2	
Hypothetical Accident Conditions, 1m from package surface								
	Side (mrem/h)		Top (mrem/h)		Bottom (mrem/h)			
	Addendum	Staff	Addendum	Staff	Addendum		Staff	
Photon	5.0	5.1	5.7	5.9	4.1		4.1	
Neutron	16.6	16.9	19.4	19.6	16.9		17.3	
Total	21.6	22.0	25.1	25.5	20.9		21.4	
§71.51(a)(2) Limit	1000		1000		1000			

[a] For NCT, the package surface is the personnel shield (cage) exterior
[b] Bottom of the trailer bed.
[c] 2 m from the trailer sidewall.

Table 5-3 below compares Addendum Table 5-15 with DOE PCP staff's calculated maximum dose rates for an exclusive use conveyance of six packages.

Table 5-3 Maximum Dose Rates for Exclusive Use Shipment of Six 9516 Packages

Normal Conditions of Transport – Exclusive Use Shipment						
	Outer surface of vehicle [a] (mrem/h)		2m from vehicle external surface [b] (mrem/h)		Normally occupied position in vehicle (mrem/h)	
	Addendum	Staff	Addendum	Staff	Addendum	Staff
Photon	35.9	41.8	1.1	1.5	0.4	0.6
Neutron	149.1	153.3	5.2	5.3	2.2	2.2
Total	184.9	195.1	6.3	6.8	2.6	2.8
§71.47(b) Limit	200		10		2	

a. For NCT, the package surface is the personnel shield (cage) exterior
b. Bottom of the trailer bed.
c. 2 m from the trailer sidewall.

Based on the Addendum and PCP staff's independent confirmatory analysis, the package continues to meet the external radiation requirements of §§71.47(b) and 71.51(a)(2), except for 71.47(b)(4). The calculated dose rate for the nearest normally occupied position (i.e., the truck cab) exceeds 2 mrem/hour [§71.47(b)(4)], so the exception to this limit must be included (i.e., retained) as a condition in the DOE CoC (Condition 7) retained.

5.5 Evaluation Findings

Based on review of the statements and representations in the Addendum and DOE PCP staff's confirmatory analysis, staff has reasonable assurance that the package shielding design continues to meet the requirements of 10 CFR Part 71, subject to Condition 7 of the CoC.

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).

For Shipping Configurations 9 through 11, the maximum concentration of the fissile isotopes Pu-239 + Pu-241 is no more than 20 wt.%, and the total Pu mass is less than 1,000 grams/package; therefore, these shipping configurations are exempted from being classified as fissile material per §71.15(f) and no criticality evaluation for these configurations is required.

6.1 Evaluation Findings

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

7.0 Operating Procedures

The Addendum 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.

There were no changes in the Addendum to the basic operating procedures of the package described in the SARP. The Addendum provides operating procedures specific to using the package for Shipping Configurations 9 through 11.

DOE PCP staff confirmed by document review that the package operating requirements in the Addendum are consistent with those for other shipping configurations described in SARP Chapter 7. For Shipping Configurations 9 through 11, the CV liner is not used and the components internal to the CV will not be reused. In Addendum Section 7.1.2 the operating procedures for loading of content for Shipping Configurations 9, 10 and 11 are specified separately since the graphite blocks and the stainless-steel spacers used for these configurations are different.

In the preparation for transport, Addendum 7.1.3, the maximum fuel age of the PuO_2 content must be verified so that at the end of the shipment, the fuel age does not exceed 23.15 years for Shipping Configuration 9, 25.00 years for Shipping Configuration 10, and 32.91 years for Shipping Configuration 11, as listed in Addendum Table 3-8. The identity, quantity, and wattage of each radioactive material must be verified to meet the requirements of Addendum Section 1.2.2 and documented as a part of the package shipment record.

7.1 Evaluation Findings

Based on review of the statements and representations in the Addendum, DOE PCP staff concludes that the combination of the engineered safety features of the package 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.

There were no changes in the Addendum to the acceptance test and maintenance program described in the SARP for primary packaging components. The components used internal to the CV for Shipping Configurations 9 through 11 are listed in Addendum Table 1-2 and classified in Addendum Table 9-1 as minor to safety (Q-Category) and their safety function is to restrain the contents within the CV.

The acceptance criteria for these components consist of visual and dimensional inspections, and material verification per drawings listed Addendum Appendix 1.3.2 *Drawings*. This criteria is consistent with the SARP, Section 8.1.1.3 for acceptance of internal components.

The internal CV components for Shipping Configurations 9 through 11 are intended for one-time use, so the maintenance program requirements in the SARP Section 8.2.3.1 for reuse of internal graphite components is not applicable.

8.1 Evaluation Findings

Based on the review of the statements and representations in the Addendum, 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, as supplemented by the Addendum 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 10 CFR 71 Subpart H Quality Assurance Program (QAP) is approved by DOE (https://rampac.energy.gov/docs/default-source/qa/approval_0010_r1.pdf).

The addition of Shipping Configurations 9 through 11 as authorized package contents does not affect the existing QA Program of the packaging. The Quality Levels for the components for these configurations are all classified as Quality Level C items (Q-Cat C), as shown in Addendum Table 9-1. DOE PCP staff reviewed Table 9-1 for the functions, failure effects and quality levels of these components, and found them appropriate and acceptable. The primary safety function of these components is to "restrict movement" of the contents or content overpacks with in the CV under NCT. These components are credited in the shielding model to evaluate package dose rates under NCT, but omitted from shielding model to evaluate package dose rates under HAC. DOE PCP staff finds the shielding model assumptions consistent with the applicant's Q-Cat-C classification of these components.

9.1 Evaluation Findings

Based on review of the statements and representations in the Addendum, DOE PCP staff has reasonable assurance that the package-specific requirements are consistent with their DOE approved QAP, 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 Addendum 2 supplements to the SARP and evaluated in this SER.

- Packaging Description 5.(a)(2) added text:
    - "Contents for Shipping Configurations 9 through 11 are packaged in welded cylindrical containers. There are three sizes of content containers (Small, Medium Overpack with Small Container, and Large). Each content container is overpacked in an unsealed can (small, medium and large) constructed of graphite and stainless steel that is used to identify CV contents via radiography. Various graphite support and filler blocks, and stainless steel spacers are used to position the contents within the CV. Various graphite support and filler blocks, and stainless steel spacers are used to position the contents within the CV. The internal component arrangements in the CV for Shipping Configurations 9 through 11 are shown in Figures 1-1 through 1-4 of SARP Addendum 2."

- Drawings 5.(a)(3) added:

Drawing No.	Rev	Title/Notes
SKNEN2-5663	B	Stainless Steel Can, Large (2 Sheets)
SKNEN2-5664	B	Stainless Steel Can, Medium (2 Sheets)
SKNEN2-5665	B	Stainless Steel Can, Small (2 Sheets)
853326	0	Top Graphite Filler Block (1 Sheet)
853327	0	Stainless Filler Block Spacer (1 Sheet)
853328	1	Spacer Weldment (1 Sheet)
853329	0	Large Graphite Support Block (1 Sheet)
853330	0	Medium Graphite Support Block (1 Sheet)
853331	0	Small Graphite Support Block (1 Sheet)
853332	0	Tall Top Graphite Filler Block (1 Sheet)
853333	0	Spacer Plate (1 Sheet)

- Contents 5.(b)(1): consolidate redundancies from the PuO_2 descriptions.
    - Added "For the contents described below, as the initial ^{238}Pu weight percent is increased in a mixture of plutonium dioxide, the ^{239}Pu and ^{241}Pu weight percentages are reduced. Almost all the activity in these mixtures of plutonium dioxide is from the alpha decay of ^{238}Pu; therefore, ^{238}Pu is the decay heat source and the curie content (amount of ^{238}Pu) is directly proportional to the decay heat. Because ^{234}U is an insignificant contributor to the neutron and gamma source, the neutron and gamma dose contribution associated with ^{238}Pu will decrease as the ^{238}Pu decays. Administrative controls shall be placed on the loading arrangements to ensure that the maximum wattage is not exceeded.
    - Removed this information from paragraphs for Shipping Configurations 1 through 6, and 7 and 8.

- Contents 5.(b)(1), added text:
  - Shipping Configurations 7 and 8, 2nd paragraph: "… The total plutonium mass is less than 1000 g per package and the maximum concentration of the fissile isotopes $^{239}Pu + ^{241}Pu$ do not exceed 20.0 wt.%. Therefore, per 10 CFR 71.15(f), Shipping Configurations 7 and 8 are exempt from classification as fissile material and from the fissile material package standards of §§71.55 and 71.59." (this change was approved in Docket 16-28-9516, CoC Rev. 3)
  - Shipping Configurations 9 through 11:
    The contents for Shipping Configurations 9 through 11 consist of plutonium dioxide powder. The principal isotope in the plutonium dioxide is ^{238}Pu, which has an initial composition of 80 – 90 weight percent (wt.%) of the total plutonium in the mixture. The powder is pressed to a density of approximately 6 g/cm^3. The total plutonium mass is less than 1000 g per package and the maximum concentration of the fissile isotopes $^{239}Pu + ^{241}Pu$ is 20.0 wt.%. Therefore, per 10 CFR 71.15(f), Shipping Configurations 9 through 11 exempt from classification as fissile material and from the fissile material package standards of §§71.55 and 71.59.

    Limiting the amount of decay heat in the package to 420 W establishes the activity limit, which is approximately 13,000 Ci. The composition of the plutonium shipped in the package for Configuration 9 through 11 are shown in Table 1. The maximum neutron emission rate for the plutonium dioxide powder is 18,000 n/s g ^{238}Pu.

- Contents 5.(b)(1), revised Table 1 Plutonium Initial Isotopic Limits:
  - Added table footnote 5 "superscript" to Shipping Configurations 7-8
  - Added Shipping Configurations 9-11

Source specification:	^{236}Pu (ppm)[1]	^{238}Pu (wt.%)[2]	$^{239}Pu + ^{241}Pu$ (wt.%)[3]	Other ΣPu (wt.%)[3]	Individual actinide impurities (wt.%)[4]	^{95}Zr (Bq/g-PuO_2)
Shipping Configurations 7-8[5]	≤ 6.0	80-92	20.0-5.9	≤ 4	≤ 1	1E+7
Shipping Configurations 9-11[5]	≤ 2.0	80-90	20.0-7.9	≤ 4	≤ 1	N/A

  - NOTE revised to "…and the limits in Table 1-1 of Addendum 2 apply to the initial composition for Shipping Configurations 9 - 11 at date of conversion to oxide."
  - Added Table Footnote 5, "Shipping Configurations 7 through 11 are exempt from classification as fissile material per §71.15(f)."

- Contents 5.(b)(2), Maximum Quantity of Material per Package revised:
  - 1st paragraph revised to "… Descriptions of the eleven shipping configurations from the SARP and SARP Addendums 1 and 2 are summarized below."

- Added:
  “Shipping Configuration 9— Large Containers with PuO_2 Powder. PuO_2 powder for Shipping Configuration 9 is packaged in Large Containers that are constructed of a Hastelloy C-276 equivalent. Each Large Container has a maximum total plutonium mass of 453 g. The Large Container is a welded enclosure. Each Large Container is overpacked in an unsealed large can (Drawing SKNEN2-5663). Two Large Containers are loaded in each CV. Various graphite support and filler blocks, and stainless steel spacers are used to position the contents within the CV. The internal component arrangements in the CV is shown in Figure 1-1 of SARP Addendum 2. The maximum amount of plutonium in the CV is limited to 1000 g, which limits the number of Large Containers with PuO_2 Powder to two. The heat load of a Large Container with PuO_2 powder is nominally 205 W. The total heat load is limited to 210 W per Large Container and 420 W per package.”

  “Shipping Configuration 10— Medium Overpack Containers and Small Containers with PuO_2 Powder. The PuO_2 powder for Shipping Configuration 10 is packaged in Small Containers that are constructed of a Hastelloy C-276 equivalent. Each Small Container has a maximum total plutonium mass of 194 g. A Small Container may also be overpacked in a Medium Overpack Container. The Small Container and Medium Overpack Container are welded enclosures. Each Small Container or Medium Overpack Container is overpacked in an unsealed can (Drawings SKNEN2-5665 or SKNEN2-5664, respectively). Two Small Cans and one or two Medium Overpack Containers are loaded in each CV. Various graphite support and filler blocks, and stainless steel spacers are used to position the contents within the CV. The internal component arrangements in the CV are shown in Figures 1-2 and 1-3 of SARP Addendum 2. The heat load of a Small Container or Medium Overpack Container with PuO_2 powder is nominally 86 W. The total heat load is limited to 90 W per container and 360 W per package.”

  “Shipping Configuration 11— Medium Overpack Containers with PuO_2 Powder. The PuO_2 powder for Shipping Configuration 11 is packaged in Small Containers that are constructed of a Hastelloy C-276 equivalent. Each Small Container has a maximum total plutonium mass of 194 g. Each Small Container is overpacked in a Medium Overpack Container. The Small Container and Medium Overpack Container are welded enclosures. Each Medium Overpack Container is overpacked in an unsealed can (Drawing SKNEN2-5664). Three Medium Overpack Containers are loaded in each CV. Various graphite support and filler blocks, and stainless steel spacers are used to position the contents within the CV. The internal component arrangement in the CV is shown in Figure 1-4 of SARP Addendum 2. The heat load of a Medium Overpack Container with PuO_2 powder is nominally 86 W. The total heat load is limited to 90 W per container and 270 W per package.”

- Conditions 5.(d) revised:
    - (2) Added "…The maximum allowable age of PuO_2 powder at the end of the shipping period for Shipping Configurations 9 - 11 is 23.15, 25.00, and 32.91 years, respectively (SARP Addendum 2)."
    - (2) Revised "… The maximum allowable fuel age for configurations not addressed in SARP Table 3-13 shall be determined following the methodology in Chapter 3, Section 3.3.2.2 of the SARP."
    - (3) Revised "… Except for shipments made under the auspices of the Office of Secure Transportation, under the conditions provided in Chapter 7 of the SARP and Addendums 1 or 2."
    - (10) Replaced with "Revisions 6 and 7 of this certificate may be used until April 30, 2022."
- Supplements 5.(e) added:
    - (3) "Safety Analysis Report for Packaging (SARP) for the 9516 Package, Addendum No. 2, R1033-0067-ES, Revision 0, April 2021."

Conclusion

Based on the statements and representations contained in Addendum 2 to the SARP and the conditions listed above, DOE PCP staff concludes that the package design has been adequately described and evaluated, and the Model 9516 package continues to meet the requirements of 10 CFR Part 71.

References

[1] *9516 Shipping Package Amendments Request*, Email Carl Friesen to Shuler, September 29, 2020.

[2] *Safety Analysis Report for Packaging (SARP) for the 9516 Package, Addendum No. 2*, R1033-0067-ES, Revision a, Idaho National Laboratory, December 2020.

[3] *Q0 Comment from Department of Energy Packaging Certification Program Independent Review of Addendum*, Memorandum Shuler to Friesen, January 11, 2021.

[4] *Response to Q0 from DOE PCP (Docket 21-02-9516)*, Email Carl Friesen to Shuler, February 1, 2021.

[5] *Docket 21-02-9516 Technical Review Complete*, Memorandum Shuler to Friesen, April 12, 2021.

[6] Safety Analysis Report for Packaging (SARP) for the 9516 Package, Addendum No. 2, R1033-0067-ES, Revision 0, Idaho National Laboratory, April 2021.