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DOE Packaging Certification Program

Safety Evaluation Report

for

Certificate of Compliance No. 9390 Amendment for the Model OPTIMUS®-L Package

Docket No. 24-05-9390

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This Safety Evaluation Report (SER) documents the U.S. Department of Energy (DOE) Packaging Certification Program (PCP) independent review and confirmatory analysis of a revision to Safety Analysis Report for Packaging (SARP) Revision 0, prepared by NAC International (NAC) for the Sandia National Laboratory (SNL) on behalf of the Sandia Field Office (SFO) for amendment of DOE Certificate of Compliance (CoC) Number 9390, Revision 0, for the Model OPTIMUS®-L package design.

Summary

By letter [1] dated February 26, 2024, the DOE CoC 9390 certificate holder, NAC, requested a content amendment to DOE CoC No 9390, Rev.0, to authorize use of the OPTIMUS®-L package for shipment of an enriched UO_2-Gd_2O_3 mixture and other debris from SNL Degraded Core Coolability (DCC) experimental assemblies for disposal, and clarifications to the maximum activity limits for key individual gamma-emitting and neutron-emitting contents. There were no packaging design changes required for shipment of this new content. The amendment request is supported by supplemental information to SARP Revision 0, which is the safety basis for DOE CoC Revision 0. To demonstrate compliance with 10 CFR Part 71, for this content addition, NAC supplemented SARP Chapters 1, 2, and 4 through 7, with page changes (SARP Revs. 24A through 24D) and supporting calculations and references.

The initial safety basis document submitted by NAC in support of this amendment request was Revision 24A of the SARP [2], as supplemented March 19, June 6, and November 18, 2024, with SARP page-change Revisions 24B, 24C, and 24D [3-5], respectively. The federal sponsor, SFO, and its contractor, SNL, reviewed and concurred all NAC submittals related to this docket.

DOE PCP staff reviewed SARP Revision 24A and its supporting documentation for completeness and on February 29, 2024, requested [6] additional information omitted from Revision 24A needed for staff's independent technical review of SARP. On March 19, 2024, NAC submitted Revision 24B page changes with the omitted information. Staff concluded its completeness review and on April 23, 2024, issued a request [7] for supplemental information (Q0s) needed to proceed with its technical review. On June 6, 2024, NAC submitted Revision 24C page changes and responses to the Q0s. Staff completed their initial technical review and confirmatory analysis and on November 12, 2024, issued questions and comments (Q1s) [8] to NAC. On November 18, 2024, NAC submitted Revision 24D page changes and responses to the Q1s, which staff reviewed and found acceptable [9] pending implementation in the final application. On December 19, 2024, NAC submitted a consolidated final application, SARP Revision 1 [10], which staff reviewed and confirmed to be acceptable.

The applicant's package evaluation is conservative in that all contents from the three DCC experiments are evaluated in a <u>single</u> package for shipment, whereas the sponsor intends to divide the contents into two packages.

Based on the statements and representations in SARP Rev 1, and the conditions listed in this SER, DOE PCP staff independently confirmed by review and analysis that the package content changes have been adequately described and evaluated. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met and recommends amendment of the CoC by the DOE Headquarters Certifying Official (HCO).

Evaluation
This evaluation addresses the final SARP Rev. 1, which is a consolidation of SARP page changes Rev. 24A through 24D to SARP Rev.0. Editorial changes (format, grammar, etc.) in SARP Rev. 1. (tracked changes from SARP Rev. 0) were reviewed by DOE PCP staff and found to be acceptable but are not addressed in this evaluation.

The UO_2-Gd_2O_3 contents are from DCC Experiments, DCC-1, DCC-2 and DCC-3, conducted at SNL in the mid-1980s. For each experiment, the fuel matrix (debris bed) consisted of various size UO_2 particulate seeded with Gd_2O_3 to decrease thermal neutron sensitivity. The debris beds were contained in cylindrical vessels for experiments in the central irradiation cavity of the Annular Core Research Reactor (ACRR) at SNL-Albuquerque. Each debris bed was placed in a water bath and thoroughly instrumented with thermocouples so that the location of drying could be identified and monitored as reactor power was varied. Burn-up of the debris bed was limited with the longest experiment lasting only 10 days with average power a fraction of the 3.5 MW maximum, for example, most power readings were less than 50 kW for DCC-1, 500 kW for DCC-2 and 300 kW for DCC-3.

In 2017, SNL performed a nuclear criticality safety assessment (NCSA) [11] to establish nuclear criticality safety controls for facility operational activities associated with processing DCC-1, -2, and -3 assemblies for size reduction and repackaging for disposal. According to NCSA, Section 1, 3rd para., "As detailed in Sections 2.8 & 2.9, each DCC assembly contains a homogenous debris bed of 24 to 27 kg UO_2/Gd_2O_3 fuel mixture composed of small and medium sized particles, that is submerged in 9-12 liters of water. The uranium is enriched to less than 11 wt.% 235U and depending on the experiment, the fuel mixture contains between 1 and 5 atom percent Gd."

A thorough description of the assemblies is provided in NCSA, Section 2.8, *DCC ASSEMBLY DESCRIPTION*. In summary, the DCC Assemblies were all similar in design; a fuel matrix (debris bed) and water bath contained in a crucible and enclosed in a primary containment vessel. The primary containment was enclosed in a secondary containment vessel with instrumentation. Both vessels included a bulkhead to pass through instrumentation and/or piping. A cutaway view of the DCC Assemblies as shown in NCSA Figure 1: *General Schematic of DCC Experimental Assemblies*.

The debris bed is thoroughly described in NCSA Section 2.9, *FUEL MATRIX DESCRIPTION*. This information is organized in NCSA Table 1: *Specific Information for DCC Assemblies and Fuel Matrix*. Steps to remove the crucible and water from the primary containment of the DCC Assemblies are outlined in NCSA, Appendix B.

The UO_2-Gd_2O_3 contents for disposal consist of three crucibles with their debris beds, and contaminated DCC assembly parts. The applicant's package evaluation is conservative in that all the proposed radioactive material contents are evaluated in a single package for shipment, whereas the sponsor intends to use two packages.

The applicant proposes an amendment to the DOE CoC to authorize use of the package for shipment of UO_2-Gd_2O_3 contents under CoC Section 5(b)(1)(v), as Irradiated Fuel Waste (IFW).

This SER will use "SARP" for SARP Rev 1 unless otherwise noted.

1.0 General Information

The Model OPTIMUS®-L is a Type B fissile package design composed of the following components defined in Section 5(a)(3) of the CoC:

a) Cask Containment Vessel (CCV),
b) CCV bottom support plate,
c) Outer Packaging (OP) assembly, and
d) Shield Insert Assemblies (SIA - 1-in. or 2¼-in. thick carbon steel).

SIA is not used in the package for the UO_2-Gd_2O_3 content configuration.

The package is authorized for transport Type B quantities of normal and special-form solid fissile and non-fissile radioactive material by public highway.

1.1 Packaging

There are no changes to the packaging design authorized in Section 5(a) of the CoC, for shipment of the UO_2-Gd_2O_3 contents.

1.2 Contents

The new contents consist of UO_2-Gd_2O_3 as a normal form solid, enriched up to 11 wt.% U-235 along with contaminated metal components, for example, crucibles and other size reduced assembly components. These contents are added and described in SARP Section 1.2.2.2, under the IFW category, and include the type and form of material, maximum quantity per package, and loading restrictions. The package limits for nuclear criticality safety are shown in SARP Table 1.2-4 and the activity limit for each nuclide and the total A_2 for the mixture are shown in SARP Table 1.2-5. The maximum heat load of 2.03E-03 W shown as a table note for SARP Table 1.2-5 is incorrect, the actual heat load from the reference documents and used in the SARP analyses is 2.03E-02 W.

The crucibles and primary containments of the experiments, not the CCV, are cylindrical vessels fabricated from Inconel alloy 625. The secondary containments for DCC-1 and -2 were also fabricated Inconel alloy 625. The secondary containment for DCC-3 was fabricated from 316L stainless steel. For disposal, the crucibles and containments are not sealed.

Specific loading restrictions of the waste from DCC-1, -2, and -3 were added to Step 5 in Section 1.2.2.2. *Irradiated Fuel Waste* of the SARP: Step 5 and its sub steps identify the content configuration for each DCC waste item. These items are loaded in waste bags that are filter vented, open or unsealed, or vinyl mesh, or combination thereof, to ensure each layer of confinement is vented prior to loading in a secondary handling container.

Section 1.2.2.2, then describes the subsequent secondary container configuration for the DCC items and dunnage, which consist of the NTESS Burial Canister (container) and NTESS Basket (dunnage), respectively.

The secondary container is a filtered NTESS Burial Canister as shown in SARP Figure 1.3-2 *Burial Canister*. This canister is a specification DOT Type A 7A steel cylinder with internal dimensions of approximately 11-5/8 in. diameter by 42-in. height. Based on its fabrication drawing and test data [12-13], the canister has a maximum gross weight limit of 450 lb. (204.1 kg), and measured tare weight of

178 lb. (80.74 kg). Prior to loading bagged DCC waste items, each canister sidewall is lined with 5/8-in. thick sheet of flexible borated silicone that has a density of 1.64 g/cm^3. The liner provides neutron shielding for operations personnel when removing the canister from the basket at the disposal site and not is not required or credited for packaging and transportation safety. To minimize gas generation in the CCV, the SARP requires a minimum of 20% free volume in each canister and a maximum of 12 kg total plastic (bagging material) in the CCV, which includes the mass of the silicone liners in each canister.

Up to three canisters are loaded in the NTESS Basket. The basket is an open-top cylindrical steel dunnage rack described in SARP Section 1.3.4 and shown in Figure 1.3-1 *NTESS Basket*. The basket is fabricated from carbon steel with overall dimensions approximately 20-in. diameter by 40-in. height, with three canister slots 120-degrees apart, to house one-canister per slot. Based on its fabrication drawing [14], the basket weighs an estimated 1,125 lb. (510.29 kg).

The final content configuration for loading in the package CCV is one NTESS Basket with three NTESS Burial Canisters.

1.3 Drawings

There were no changes to the SARP or CoC drawings for this SARP revision.

1.4 Conclusion

Based on a review of the statements and representations in the SARP Rev. 1, DOE PCP staff concludes that the content changes in support of this CoC amendment 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, as supplemented by this application, includes 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 packaging design as certified in CoC. The applicant made minor changes to SARP Section 2.2.2 *Chemical, Galvanic or Other Reactions*, and subsection 2.2.2.1 *Reactions Among* Contents, to address UO_2-Gd_2O_3 content configuration. There were no technical changes in this Chapter of the SARP.

2.1 Structural Design

The maximum gross weight of the package is approximately 9,200 lb. (4,173.05 kg) and the maximum weight of the contents (including the CCV bottom support plate, SIA, and dunnage or shoring) is 3,500 lb. (1,587.57 kg). DOE PCP staff confirmed by document review and informal calculation that the UO_2-Gd_2O_3 content package configuration weight is bounded by the SARP and CoC.

DOE PCP staff estimates the maximum weight of the UO_2-Gd_2O_3 content configuration is 2,825 lb. (1281.4 kg), plus shoring. This estimate assumes DCC items in three NTESS Burial Canisters at 450 lb. max. gross wt./ea. (1,350 lb.), one NTESS Basket (1,125 lb. net), and one CCV bottom support plate (350 lb.), which would leave 675 lb. (306.17 kg) for shoring. SARP Section 2.7, recognizes that

CCV content weights lower than the max. weight of 3,500 lb. can produce higher package accelerations during the free-drop tests; however, the resulting drop forces (mass x acceleration) and stresses on the packaging are generally lower, which demonstrates, the maximum CCV weight is bounding for the structural evaluation of package performance under normal and accident conditions per §§ 71.71 and 71.73.

2.2 Materials

There were no changes to the packaging material of construction. The applicant asserts in SARP Section 2.2.2 *Chemical, Galvanic or Other Reactions*, that no significant interactions are expected to occur among the IFW contents and the packaging materials to which they are exposed, including UO_2-Gd_2O_3 contents.

DOE PCP concurs that the packaging materials evaluation previously documented in the SARP is essentially unaffected by the inclusion of UO_2-Gd_2O_3 contents.

Staff confirmed by document review the steel materials used for fabrication of the secondary containers (NTESS Burial Canisters) and dunnage (NTESS Basket) are similar and compatible materials as the packaging components per § 71.43(d).

The waste materials from the DCC experiments include the UO_2-Gd_2O_3 debris beds, which is solidified in unsealed crucibles (Iconel alloy 625), size reduced containment vessels (Iconel alloy 625 and 316L stainless steel), and other metal experiment components. By design, these materials are highly corrosion resistant and chosen for their compatibility and suitability for the experiments with UO_2-Gd_2O_3. Decades after the experiments concluded SNL staff confirmed by visual inspection that no significant chemical, galvanic, or other reactions of the materials has occurred.

These waste materials are packaged in direct contact with plastic bagging for waste handling and contamination control. The estimated decay heat for the UO_2-Gd_2O_3 contents per package is 2.03E-02 watts. SARP Section 3.1.2 *Content's Decay Heat*, used 50 watts of decay in their thermal analysis under normal conditions of transport (NCT) to estimate the average maximum CCV cavity air temperature of 248°F (120°C). Due to the much lower decay heat of the UO_2-Gd_2O_3 contents, the CCV cavity air temperature would be significantly lower than the SARP evaluation and therefore well below the 302°F (150°C) threshold temperature at which gas would be generated from thermal decomposition of the plastics and other polymer waste materials in air (Ref SARP Section 4.5.2 *Flammable Gas Calculations / Requirements*).

The effects of radiation from the UO_2-Gd_2O_3 contents on the packaging materials is negligible given that all three DCC experiments were irradiated for a very short period with the longest experiment duration being approximately 10 days, and the experiments have also decayed for over 30 years. Consequently, these waste materials are expected to have a low quantity of fission and activation products as compared with other neutron activated metals authorized as contents, for example, activated reactor components or segments of components of waste from a nuclear process or power plant.

2.3 Conclusion

Based on review of the statements and representations in the SARP, as supplemented by this application, 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 in the SARP, as supplemented, for the tests specified under NCT and HAC and that the package design satisfies the thermal requirements of 10 CFR Part 71.

There were no changes to the thermal design of the package.

The estimated decay heat load of UO_2-Gd_2O_3 contents, 2.03E-02 watts, is significantly bounded by the thermal evaluation in the SARP of 50 watts per package for un-inerted contents; consequently, there are no changes in Section 3 of the SARP for these contents with respect to package temperatures and pressures as summarized in SARP Tables 3.1-1 - *Summary of Packaging Temperatures for NCT*, 3.1-2 - *Summary of Packaging Temperatures for HAC*, and 3.1-3 - *Summary of Maximum Pressures*.

The applicant evaluated potential gas generation and pressurization in Section 4 of the SARP.

3.1 Conclusion

Based on review of the statements and representations in the SARP, as supplemented by this application, DOE PCP staff has reasonable assurance that the package thermal design has been adequately described and evaluated and that the package continues to meet the thermal 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 design of the package, which is the CCV. The CCV is "leaktight" by design, which means "the degree of package containment that, in a practical sense, precludes any significant release of radioactive materials", as defined in ANSI N14.5, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment.*

There was no damage to the CCV under NCT or HAC per the structural and thermal evaluations in the SARP; therefore, the CCV is expected to remain leaktight under these conditions and therefore continues to meet the containment requirements of § 71.51(a).

The applicant revised the following SARP Sections to include and evaluate the new contents:

- Added Section 4.5.1, Reference [4.11] *NAC International, Hydrogen Generation Rate for UO_2-Gd_2O_3 Waste in the OPTIMUS-L*, 50076-4001, Rev. 0, 5/22/2024,
- The text in Section 4.5.2 *Flammable Gas Calculations / Requirements*, was revised to expand the scope of gas generating contents from "TRU waste" to "radioactive contents combined with hydrogenous and organic materials",
- Added Section 4.5.2.3 *UO_2-Gd_2O_3 Contents Flammability Calculation* to evaluate the new contents,
- The text in Sections 4.5.3 *Chemical Compatibility of Contents* and 4.5.4 *Hydrogen*

Concentration Calculations was revised to add UO_2-Gd2O_3 contents to the scope of these sections, and
- The text in Section 4.5.4.3 *Hydrogen Gas Accumulation Calculations* was revised to expand the scope from "TRU waste" to "waste".

4.1 Containment Evaluation under NCT

The calculated maximum normal operating pressure (MNOP) for the package is 100 psig (690 kPa) per SARP Section 3.1.4 *Summary Table of Maximum Pressures*. Under NCT, with 50-watts of content decay heat load, the calculated maximum internal average air temperature is 248°F (120°C) per SARP Table 3.3-2 - *Maximum Package Temperatures for NCT Heat* and is used to calculate the maximum total internal pressure of 15.8 psig per SARP Table 3.3-3 *Summary of Maximum Pressures for NCT*.

The calculated decay heat for the $UO_2Gd_2O_3$ contents is only 2.03E-02 watts; therefore, the internal temperature and pressure for this configuration under NCT is bounded by the SARP. For gas generation calculations per SARP Reference [4.11], the applicant used the calculated maximum internal average air temperature of 160°F (71°C) under NCT from a 1-watt content-decay load [15] to calculate the maximum internal pressure for the new contents of 13.4 psig, to demonstrate the new contents are bounded by the SARP.

4.2 Containment Evaluation under HAC

The calculated maximum pressure for the package is 225 psig (1,551 kPa) per SARP Section 3.1.4 *Summary Table of Maximum Pressures*. Under HAC, with 50-watts of content decay heat load, the calculated maximum internal average air temperature is 281°F (139°C) per SARP Table 3.4-1 - *Maximum Package Temperatures for HAC* and is used to calculate the maximum total internal pressure of 26.3 psig per SARP Table 3.4-2 - *Summary of HAC Pressures*.

The calculated decay heat for the $UO_2Gd_2O_3$ contents is only 2.03E-02 watts; therefore, the internal temperature and pressure for this configuration under HAC is bounded by the SARP. For gas generation calculations per SARP Reference [4.11], the applicant used the calculated maximum internal average air temperature of 281°F (139°C) under HAC per SARP Table 3.4-1, from 50-watts of content decay heat load to calculate the maximum internal pressure for the new contents of 63.3 psig, to demonstrate the new contents are bounded by the SARP.

4.3 Flammable Gas and Associated Pressure Calculation Review

SARP Section 4.5.2.3 *UO_2-Gd_2O_3 Contents Flammability Calculation*, summarizes the assumptions, methods, and results of the calculations in SARP Reference 4.11 *Hydrogen generation rate for UO_2-Gd_2O_3 Waste in the OPTIMUS-L*. The purpose of this calculation is to determine the hydrogen generation rate and pressure calculations in the CCV for the UO_2-Gd_2O_3 waste.

DOE PCP staff reviewed this calculation to confirm the applicant sufficiently demonstrated the internal CCV pressures from gas generation are bounded by the SARP and hydrogen and other flammable gases will not result in a flammable mixture within any confined volume of the package. This package content configuration relies on "filters" on the confinement layers, that is, plastic bagging and NTESS Burial Canisters, and 20% void space in each canister to prevent gas accumulation more than 2.5% concentration in these layers.

Methods of Analysis

The methods of analysis are in Section 3 of the calculation for NCT and HAC pressure in the CCV (Section 3.1 *CCV Pressure Analysis*) and gas generation (Section 3.2 3.2 *Hydrogen Generation*).

To conservatively estimate CCV internal pressure under NCT and HAC, the applicant maximized the initial moles of gas by assuming the initial temperature in the CCV at closure is -40 ºF. The applicant also assumes that all the hydrogen generation is accompanied by a stoichiometric quantity of oxygen so that hydrogen generation from water vapor does not have to be distinguished. The pressures calculated for NCT and HAC assuming 5% hydrogen gas has been generated are well within existing package pressure limits.

The applicant's conservatism in determining the hydrogen gas generation rate is the assumption that the radioactive material (UO_2) is in direct contact with the polymer bagging material, which has a greater potential for gas generation, since its G value (4.1 molecules/100 eV) is more than twice that of water (1.7 molecules/100 eV) per Table 4-2 *Appendix D Bounding G-value as Function of Material,* of the calculation. The UO_2 is in greater contact with moisture absorbed in the debris bed than with the polymer bagging materials which is separated from the debris bed by other materials such as the crucible, stainless steel, and other metals. In DOE PCP staff's judgement, based on review of the DCC experiments, the repeated drying and rewetting of the debris bed, its varied particle size distribution, and any other physical or chemical changes resulting from the experiments, this content configuration is not likely to produce a higher hydrogen gas generation rate than those determined in applicant's calculation.

Design Inputs

The design inputs are in Section 4 of the calculation and include water vapor pressure under NCT and HAC temperatures, calculating CCV and NTESS Burial Canister free volumes, CCV internal pressure limits under NCT and HAC, package temperatures from contents at 1-watt under NCT and 50-watts under HAC, UO_2-Gd_2O_3 waste decay heat, filter properties (diffusion rates), material G-values for flammable gas generation rate with temperature correction under NCT, and flammable gas generation rate equation. DOE PCP staff reviewed and concurred with applicant's design inputs.

The applicant selected and applied the methodology in NUREG/CR-6673, *Hydrogen Generation in TRU Waste Transportation Packages*. Although the UO_2-Gd_2O_3 contents are not transuranic waste, the energy limiting approach of NUREG/CR-6673, where the radiolytic energy of the contents is applied to the materials within the content configuration or packaging that have the highest potential for gas generation, is an acceptable method to DOE PCP staff and should provide bounding results when applied appropriately. In this case, the radiolytic energy from the contents is applied to the plastic bagging (initial G value of 4.1 molecules/100 eV, for polymers). This initial G value was then corrected for the NCT temperature (160°F based on 1-watt of decay heat) to 4.9 molecules/100 eV using Equation 4-2 of the calculation (Equation 2.2 of NUREG/CR-6673). The applicant then used Equation 4-3 of the calculation (Equation 4.6 from NUREG/CR-6673, as modified for the correct units) and the actual content decay heat 2.03E-02 watts, to determine a flammable gas generation rate of 1.03E-08 mols/s, as shown in Table 6-2 of the calculation, or 3.25E-01 mols/yr of H_2.

Assumptions

The assumptions and basis to determine internal pressure and gas generation are listed in Section 5 of the calculation. These include - CCV temperatures at 1-watt under NCT and 50-watts under HAC, minimum of 20% void volume in each NTESS Burial Canisters, and hydrogen gas generation from mechanisms (such chemical, thermal, and biological) other than radiolysis of plastic is insignificant, and for pressure calculations water vapor pressure contributes to the total pressure inside the CCV. DOE PCP staff reviewed and concurred with applicant's assumptions and finds them reasonable and conservative.

Pressure and Gas Generation Calculations
The methods of analysis, design inputs, and assumption are applied in the Section 6 of the calculation.

Table 6-1 *Calculated and Estimated Waste Maximum Pressure Calculations* demonstrates the NCT and HAC pressures are bounded by the SARP.

Table 6-2 *Total Flammable Gas Generation Rate for the UO_2-Gd_2O_3 Waste* is based on the bounding G-value of 4.9 molecules/100 eV and content decay heat of 2.03E-02-watts, which results in gas generation rate of 1.03E-08 mol/s or 3.25E-01 mol/yr (applicant rounds to 3.3E-01 mol/yr). The applicant then uses the filter (of the three filters) with the lowest diffusivity rate and at the lowest service temperature (-40 °F) to calculate a "bounding" minimum bounding diffusivity rate of 1.17E-07 mol/s, which compared with the gas generation rate demonstrates the filter diffusion rate is sufficient to prevent accumulation of flammable gas in any layer of confinement and ensures that gas will pass into the NTESS Burial Canister and CCV free volume.

The applicant then calculates a total free volume of 21,130 in^3 (applicant rounds to 346,258 cm^3) in the CCV including 20% free volume in each NTESS Burial Canister. The gas generation rate, 3.3E-01 mol/yr, is then divided by the 346,258 cm^3 free volume, to determine the moles of H_2 per unit volume is 9.53E-07 mol/yr/cm^3 (applicant rounds to 9.6E-07 mol/yr/cm^3) in the CCV.

Finally, the applicant calculated the initial moles of H_2 per unit volume in the CCV by assuming the package is loaded at 90 ºF (305 K rounded) and using the ideal gas law calculates 4.00E-05 mol/cm^3. Therefore, the volume percentage of H_2 is approximately 2.4% per year [9.6E-07/(4.00E-05 + 9.6E-07)) x 100]. DOE PCP staff concurs that the applicant sufficiently demonstrated that no shipping time restriction due to gas generation is required for the UO_2-Gd_2O_3 contents, since the combustible gas inventory within any confined volume does not exceed 5% by volume in less than two-years (reference NRC Information Notice 84-72).

4.4 Conclusion

Based on review of the statements and representations in the SARP, as supplemented by this application, DOE PCP staff has reasonable assurance that the package containment design has been adequately described and evaluated and that the package continues to meet the containment 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) meets the external radiation requirements in 10 CFR Part 71.

There were no changes to the packaging shielding design for the UO_2-Gd_2O_3 content configuration and neither SIA configuration (1-in. thick or 2¼-in. thick) is used for shipment of these contents.

For content configurations without an SIA, SARP Table 7.5-1 *Bare Cask Dose Rate/Ci Values* provides a look-up table of NCT and HAC package dose rates per curie for each radionuclide listed in the table (Note - this table aligns with radionuclides listed in Appendix A of 10 CFR Part 71 and includes parent/daughter chains from Appendix A and parent/daughter branching fractions from *Origen-S Decay Data Library and Half-Life Uncertainties*, ORNL/TM-13624). To determine package NCT and HAC dose rates for the UO_2-Gd_2O_3 contents, the applicant multiplied the activity (Ci) for each radioisotope from SARP Table 1.2-5 by its dose per curie value from SARP Table 7.5-1 and presented the results and sum in SARP Table 5.5.4-1. This table demonstrates package dose rates for the UO_2-Gd_2O_3 contents are well below the external radiation limits §§ 71.47(a) and 71.51(a)(2).

The applicant revised the following SARP Sections to evaluate and incorporate the new content configuration in SARP Section 5:

- Added paragraph to SARP Section 5.2 *Source Specification* to include radioisotopes in the UO_2-G_d2O_3 content configuration.
- Added SARP Section 5.5.4 *UO_2-Gd_2O_3 Fuel Material* which describes how the applicant calculated dose rates and content decay heat.
- Added SARP Table 5.5.4-1 *UO_2-Gd_2O_3 Curie List and Dose Rate Calculation* which shows the package dose rates estimates under NCT and HAC based on nuclide distribution.
- SARP Section 5.5.4 is supported by *OPTIMUS-L Source/Shielding Evaluation for NTESS Materials (DCCs)*, NAC International, Calculation Number 50076-5001, Rev. 0, 1/17/2024. [16]

DOE PCP staff reviewed and confirmed that the applicant's source specification in SARP Section 5.2 and SARP Table 5.5.4-1 is consistent with the SARP Table 1.2-5 and calc. 50076-5001, and that there were no changes to the shielding model and shielding evaluation. Staff confirmed that the applicant correctly applied their method (acceptable to NRC) for calculating package dose rates under NCT and HAC. Staff also reviewed Calculation 70000.14-5104 which was the basis for minor modifications in the values in the final Table 5.5.4-1 in SARP Revision 1.

The estimated NCT dose rate at the surface of the package is 5.2 mrem/hr., per SARP Table 5.5.4-1, and the estimated transport index is 1.5, based on the using the estimated HAC dose rate at 1-meter of 1.43 mrem/hr.; therefore, the applicant sufficiently demonstrates that the package meets the external radiation standards of §§ 71.47(a) and 71.51(b).

The applicant used ORIGEN-S within the SCALE 6.2.4 package to determine the heat load for the UO_2-Gd_2O_3 radionuclides is less than 2.0E-02 W.

5.1 Conclusion

Based on review of the statements and representations in the SARP, as supplemented by this application, DOE PCP staff has reasonable assurance that the package shielding design has been adequately described and evaluated and that the package continues to meet the external radiation standards 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 meets the requirements in 10 CFR Part 71 for nuclear criticality safety (NCS).

There are no specific nuclear criticality safety control features in the packaging design or changes to the packaging affecting nuclear criticality safety. Package loading limits for NCS are listed in SARP Table 1.2-4 *Criticality Limits for UO_2-Gd_2O_3 Fuel Material*. In addition to the UO_2-Gd_2O_3 mass limit of 75 kg/package, mass enrichment of 11 wt.% of U-235, there must be at least 0.2 atom % of Gd dispersed evenly throughout the debris bed for the package to remain subcritical, based on the worst-case geometric configurations analyzed in the SARP.

The applicant revised the following SARP Sections to evaluate and incorporate the new content configuration in SARP Section 6.

- Added paragraph to Section 6 6 *Criticality Evaluation* to incorporate UO_2-Gd_2O_3 content configuration,
- Added Section 6.9.2 *Criticality Evaluation of UO_2-Gd_2O_3 Fuel Material,*
- SARP Section 6.9.2 is supported by:
    - *OPTIMUS-L Criticality Evaluation for Uranium Oxide/Gadolinium Oxide Mixture*, NAC International, Calculation Number 50076-6001, Rev 1, 11/21/2023.[17]
    - *Nuclear Criticality Safety Assessment for Assessment for AHCF Campaign Plan #16 Activities,* Sandia National Laboratory, NCS-CSA-020, Rev 1, 9/21/2017.

SARP Section 6.9.2 is based on its supporting calculation, 50076-6001. DOE PCP staff performed a technical review and confirmatory analysis of this calculation, and ensured the results were properly implemented in the SARP. Staff also requested NCS-CSA-020, as a review reference of the Sandia facility nuclear criticality safety assessment and controls for processing this material for disposal.

6.1 Description of Criticality Design

There are no specific nuclear criticality safety control features in the packaging design or changes to the packaging affecting NCS for the UO_2-Gd_2O_3 content configuration per SARP Section 6.9.2.1. The criticality design evaluated by the applicant for NCS is simplified to consist of the CCV, and a sphere representing the UO_2-Gd_2O_3 debris bed. The outer packaging, secondary containers, and dunnage are omitted in the evaluation, since the simplified criticality design is more reactive. The package achieves NCS by limiting the amount of fissile, moderator, and reflector material, and a minimum atom fraction of Gd. The neutron multiplication factor, "k-effective" (k_{eff}) will be less than 0.9 during all normal and accident conditions.

The most reactive cases are shown in SARP Table 6.9.2-1 *Summary of UO_2-Gd_2O_3 Criticality Evaluations* and show k_{eff}+2σ is less than 0.9 for single package and package array evaluations and the upper subcritical limit (USL = 0.9386). The criticality safety index is 0 (zero).

6.2 Fissile Material Contents

SARP Section 6.9.2.2 *Package Contents* defines the fissile materials as 75 kg of UO_2-Gd_2O_3 enriched to a maximum of 11 wt.% U-235. The atom fraction of Gd ranges from 1-5% (that is, the ratio of Gd atoms to U atoms) for the three DCC experiments. The SARP description is a bounding summary for Section 4.2 *Fuel Information* of 50076-6001.

Since Gd is a parasitic neutron poison, the applicant began their initial NCS evaluation with the most reactive Gd atom fraction of 1%. The UO_2-Gd_2O_3 debris bed (a.k.a., fuel material) is analyzed in both homogeneous and heterogeneous spheres at varying radii, based on both minimum and maximum particle sizes for the oxides used in the experiments, to identify the most reactive configuration.

6.3 General Considerations for Criticality Evaluations

Although the CCV is leaktight, the applicant's evaluation assumes in leakage of water into the CCV and sphere(s).

The applicant's analysis in Section 6 of 50076-6001 is divided into four basic stages. Stage 1 sets up the baseline MCNP model with 75 kg of material. Stage 2 evaluates this configuration varying sphere radius, Gd content, and homogeneous or heterogeneous model types as well as moderator density for both single package and arrays. Stage 3 compares the validated range of applicability with that of the most reactive configuration. Stage 4 compares the most reactive case to an alternative Upper Subcritical Limit (USL) computed using Whisper-1.1.

6.3.1 Model Configuration

SARP Section 6.9.2.3.1 *Model Configuration* describes the applicant's package model configuration for the UO_2-Gd_2O_3 contents. For all models, the package configuration consists of the CCV and contents, without NTESS Burial Canisters (secondary containers) and NTESS Basket (dunnage). The outer packaging, inner secondary containers, and dunnage are omitted to simplify and bound the analysis; therefore, there is no distinction between applicant's NCT and HAC package model.

SARP 6.9.2.3.2 *Material Properties* describes the material properties used in the MCNP models – the CCV is stainless steel 304, per SARP Table 6.9.2-3 – *UO_2-Gd_2O_3 Fuel Material: Nuclear Properties of Type 304 Stainless Steel*, the fissile content is UO_2, and the moderator and reflector are light water per SARP Table 6.9.2-4 – *UO_2-Gd_2O_3 Fuel Material: Nuclear Properties of Materials*. These tables are consistent with Tables 4-4 *Steel Material Compositions* and Table 6-1 *Master Material List* of 50076-6001.

For the single package evaluation, the model is analyzed with 20 cm of close, full-density water reflection on all sides of the CCV. The CCV array is modeled as an infinite array with either 20 cm or 0.5 cm of water reflection on all sides. A side and top view of the model is shown in SARP, Figure 6.9.2-1 - *MCNP Model Geometry for UO_2-Gd_2O_3 Fuel Material.*

The initial CCV content configuration model is described in SARP Section 6.9.2.4 *Criticality Evaluation* and consists of a homogenized fuel sphere, with 75 kg of UO_2-Gd_2O_3 at 11 wt. % U-235, Gd atom fraction of 1.0%, CCV with 20 cm reflector, flooded sphere, flooded CCV, and void exterior (that is, no outer packaging).

6.3.2 Demonstration of Maximum Reactivity

To determine the most reactive configuration of the fissile material, the applicant varies the sphere radius, % Gd, fuel form (homogeneous or heterogeneous), and moderation/reflection in their NCS analysis.

The fuel composition with a 0.2% Gd atom fraction is shown in Table 6-2 *Fuel Composition at Gd Atom Fraction of 0.2%* of 50076-6001. The fraction of UO_2 is 0.99866 and the fraction of Gd_2O_3 is 0.00134, resulting in a density of 10.956 g/cm^3 based on the smallest homogenized sphere. Water densities (moderator) for the sphere, CCV cavity, and outside the CCV cavity are listed in Table 6.1

of 50076-6001.

Homogeneous Fuel Sphere

Section 6.2.1 of 50076-6001 evaluates the homogenous fuel sphere by varying the radius of a flooded sphere from approximately 11.8 to 40 cm. Table 6-3 *System Reactivity Variation with Homogeneous Sphere Radius 1% Gd* shows a 15 cm sphere is most reactive ($k_{eff} + 2\sigma = 0.55085$). At this radius, the competing effects of water moderation and parasitic absorption by Gd are optimized.

Next, the applicant evaluates the flooded sphere with Gd atom fractions at 0.2% and 0.1% and varying the sphere radius from 11.8 to 40 cm. Table 6-4 *System Reactivity Variation with Homogeneous Sphere Reduced Gd Fraction* and Figure 6-4 *System Reactivity vs. Homogeneous Sphere Radius*, shows when the Gd atom fraction is 0.2%, a 24 cm sphere is the most reactive configuration ($k_{eff} + 2\sigma = 0.76184$). At this radius, the reduced parasitic absorption by Gd allows for improved moderation as the radius increases until moderation transitions to absorption.

When the Gd atom fraction is lowered to 0.1%, system reactivity exceeded 0.9 for sphere radii between 22 and 35 cm, and the maximum reactivity occurred when the sphere radius is approximately 28 cm ($k_{eff} + 2\sigma = 0.93641$), which is close to the USL = 0.9386. DOE PCP staff concurs that this sensitivity analysis provides sufficient justification for using the Gd atom fraction on 0.2% as a content limit. And that further analysis of the Gd atom fraction at 0.1% is not necessary.

Finally, after establishing Gd atom fraction of 0.2% as a defensible minimum, the applicant varied moderator density for six radii (11.8, 20, 25, 30, 35 and 40 cm) as well as a case for 1% Gd atom fraction in a 15 cm radius sphere for comparison. The 11.8 cm sphere is the approximate size of a solid fuel mixture at 10.96 g/cm^3 while the 40 cm sphere is close in size to the radius of the CCV wall (41.3 cm). Full moderator density (0.9982 g/cm^3) in the sphere results in maximum system reactivity for all cases as shown in Tables 6.5 through 6.10 and Figure 6-5 *System Reactivity vs. Homogeneous Sphere Cavity Moderator Density* of 50076-6001.

DOE PCP confirmed 50076-6001 results are sufficiently summarized and implemented in SARP Section 6.9.2.4.1, *Homogeneous Fuel Sphere*.

Heterogeneous Fuel Sphere

Section 6.2.2 of 50076-6001 evaluates heterogeneous fuel sphere models using the smallest (0.0075 cm) and largest (1.2 cm) fuel particle diameters from the experiments, which are listed in Table 4.3 *NTESS Fuel Material Summary* of 50076-6001. In the x/y plane, particles are modeled in an infinite hexagonal array while a finite rectangular lattice is used in the z direction. The applicant's model for the large fuel particle configuration, of 17 cm radius, is shown in Figure 6-6 of 50076-6001. For a consistent H/U-235 comparison, hexagonal pitch is computed using the volume fraction of fuel for the homogeneous sphere. The Excel Solver was used to calculate the unique hexagonal pitch for each heterogenous sphere radius for both small and large particle cases. The applicant notes the heterogeneous model inherently truncates particles for smaller sphere radii such that the minimum radius for a physically realistic model is 14 cm. The infinite hexagonal array also truncates particles at the periphery of the sphere in the x/y plane. This affects system reactivity in the large particle configuration for large radii, as the lost mass of the truncated particles at the periphery of the sphere becomes a larger and larger effect.

A summary of the system reactivity, from Tables 6-4 and 6-13, at 0.2% Gd with radii of 25 cm and 15 cm is shown in Table 6-12 *System Reactivity Variation with Heterogenous Spheres* of 50076-6001 for the homogenous fuel sphere, and large and small particle heterogeneous fuel sphere models. Note – the 15 cm row in Table 6-12 is incorrect for Gd: it shows 1.0% whereas the fraction is 0.2% (per Tables 6-4 and 6-13).

The applicant evaluated reactivity of the large and small particle heterogeneous fuel sphere models with 0.2% Gd at radii from 15 cm to 40 cm. The results are shown in Table 6-13 *System Reactivity Variation with Heterogenous Sphere Radius* of 50076-6001. The large particle sphere radius at 20 cm is the most reactive case ($k_{eff} + 2\sigma = 0.76846$) and 25 cm for the small particle sphere model ($k_{eff} + 2\sigma = 0.76346$).

Since the large particle sphere radius at 20 cm is the most reactive case, and bounding for the small particle sphere, the applicant varied moderator density per Table 6-14 *System Reactivity Variation with 20 cm Heterogeneous Sphere Cavity Moderator Density* of 50076-6001 to confirm the results for the homogeneous sphere, that is, that the system remains undermoderated as shown in Figure 6-8 *System Reactivity vs. Homogeneous/Heterogeneous Sphere Cavity Moderator Density* of 50076-6001.

DOE PCP confirmed 50076-6001 results are sufficiently summarized and implemented in SARP Section 6.9.2.4.2 *Heterogeneous Fuel Sphere*.

Preferential Flooding

Section 6.2.3 of 50076-6001 evaluates preferential flooding of the fuel sphere relative to the CCV cavity. The applicant modeled an infinite CCV array with the large particle heterogeneous fuel sphere at 0.2% Gd. The infinite CCV array is modeled by assigning a reflecting right-circular-cylinder boundary surrounding the CCV. With a flooded CCV cavity (flooded sphere and cavity), neutronic interaction in the array would be limited due to water outside the fuel sphere in the CCV cavity; with preferential flooding in the CCV (flooded sphere and void/dry cavity) the neutronic coupling between adjacent CCVs in the infinite array is significantly more reactive. The sphere radii from 15 cm to 40 cm for the flooded and preferential flooded models and system reactivities shown in Table 6-15 *System Reactivity Variation with Heterogeneous Sphere Radius – Infinite Array, Flooded Sphere/Cavity* and Table 6-16 *System Reactivity Variation with Heterogenous Sphere Radius – Infinite Array, Flooded Sphere and Void Cavity* of 50076-6001. The flooded sphere/cavity at a radius of 20 cm is the most reactive case ($k_{eff} + 2\sigma = 0.76851$) and for the preferential flooded sphere/dry cavity at a sphere radius at 19 cm is the most reactive case ($k_{eff} + 2\sigma = 0.84213$). The results are plotted on Figure 6-9 *System Reactivity vs. Heterogeneous Sphere Radius - Preferential Flood* of 50076-6001.

The applicant then varied the moderator density in the large particle sphere radius at 19 cm for both the flooded and preferential flooded CCV cavity, with results shown in Table 6-17 *System Reactivity Variation with 19 cm Heterogeneous Sphere Moderator Density - Infinite Array, Flooded Sphere/Cavity*, and Table 6-18, *System Reactivity Variation with 19 cm Heterogeneous Sphere Moderator Density - Infinite Array, Flooded Sphere/Void Cavity*, and plotted on Figure 6-10 *System Reactivity vs. Heterogeneous Sphere Radius - Preferential Flood* of 50076-6001. The system remains undermoderated. Figure 6-10 also illustrates the difference in interaction between CCVs in the infinite array for the intervening moderation/absorption of the CCV cavity when sphere/cavity moderator density is equal. This reactivity behavior at low moderator density has an initial inverse relationship with moderator density until approximately 0.1 g/cm^3, when system reactivity is proportional to moderator density. System reactivity is essentially equal at a void moderator density for the sphere/cavity. This indicates that even a small amount of water outside of the sphere initially isolates the CCV from the array, followed by an increase in reactivity as moderation in the sphere increases.

Table 6-19 *System Reactivity Summary with Preferentially Flooded Sphere* of 50076-6001 summarizes the infinite array and single CCV system reactivity for flooded and preferentially flooded conditions of the large particle sphere model at 0.2% Gd and 19 cm radius, and the homogenous sphere model at 1% Gd and 15 cm radius. For each case with infinite arrays and single CCV, the most reactive conditions occur when the sphere is fully flooded. An infinite array of CCVs with the large particle sphere, preferential flooding in the CCV, and 0.5 cm reflecting boundary is the most reactive condition ($k_{eff} + 2\sigma = 0.84659$) and the same for the infinite array with the homogenous sphere ($k_{eff} + 2\sigma = 0.64121$). The most reactive condition for the single CCV with the large particle sphere is when full flooding occurs in the CCV and outside it ($k_{eff} + 2\sigma = 0.76859$) and the same for the single CCV the homogenous sphere ($k_{eff} + 2\sigma = 0.55094$). The potential differences in bounding radius for the infinite array partial flooding scenario are not significant relative to the 0.2% Gd results.

Note – the last paragraph in Section 6.2.3 is not substantiated in 50076-6001, that is, there is no table/evaluation showing the reactivity of the large (or small) particle single CCV model with 1.0% Gd, at any radius.

DOE PCP confirmed 50076-6001 results are sufficiently summarized and implemented in SARP Section 6.9.2.4.3 *Preferential Flooding*.

Partial Loadings

Since it is likely that only a portion of the 75 kg (8.25 kg of U-235) will be loaded for shipment in a single package, the applicant submitted NCS-CSA-20 to address reactivity at partial UO_2-Gd_2O_3 fissile mass loadings. NCS-CSA-20 evaluated optimal moderation of approximately 22.73 kg (2.50 kg of U-235) in an unconstrained sphere, and demonstrated critical configurations are possible with partial loading, unless at least 0.1% atom fraction of Gd is present. The results are shown in Figure 2 of NCS-CSA-20. DOE PCP staff finds this analysis in NCS-CSA-20 by comparison with 500076-6001 sufficient to address partial loadings, since the 0.2% minimum Gd atom fraction for the full loading cases evaluated in 500076-6001 would provide greater parasitic neutron absorption for partial loading cases.

6.4 Confirmatory Analysis

DOE PCP staff performed confirmatory analysis for the three cases shown in Table 6-1 of 50076-6001. In each case, as shown in Table 1 below, the “Applicant Results” are higher than those obtained by staff, indicating their result are conservative.

Table 1 – Confirmatory Analysis Applicant vs. DOE PCP Staff

Sphere Density (g/cc)	CCV Cavity Density (g/cc)	CCV Exterior (g/cc)	Array reflector thickness	Applicant's results ($K_{eff} + 2\sigma$)	DOE PCP staff Results ($K_{eff} + 2\sigma$)	USL
0.9982	0.0001	0.0001	0.5 cm	0.84659	0.82454	.9386
0.9982	0.9982	0.9982	N/A -Single Package	0.76859	0.76013	
0.9982	0.9982	0.0001	N/A - Single Package	0.76846	0.75994	

6.5 Single Package Evaluation

The applicant's single package evaluation and cases are described by DOE PCP staff in Section 6.3 of this SER. The applicant demonstrated that a single package is subcritical under both NCT and HAC.

The heterogenous large particle sphere model cases bound the homogeneous sphere model cases for the single package evaluation. The most reactive cases are when the large particle sphere radius is 20 cm and flooded, the Gd atom fraction is 0.2%, and the CCV cavity flooded. When the CCV exterior is 0.0001 g/cc, system reactivity is 0.76846 (k_{eff} +2σ). When the sphere radius is 19 cm and CCV exterior is flooded (0.9982 g/cc), system reactivity peaks at 0.76859.

6.6 Evaluation of Package Arrays under Normal Conditions of Transport

The applicant's package array evaluation and cases are described by DOE PCP staff in Section 6.3 of this SER. The applicant demonstrated that an array of packages is subcritical under both NCT (and HAC).

The heterogenous large particle sphere model cases bound the homogeneous sphere model cases for the package evaluation. The most reactive cases are when the large particle sphere radius is 19 cm and flooded, the Gd atom fraction is 0.2%, the CCV cavity is void, and space between CCVs is void (that is, no interstitial water). When the infinite array is reflected on all sides by 20 cm of water, system reactivity is 0.84213 (k_{eff} +2σ). When array is reflected on all sides by 0.5 cm of water, the system reactivity peaks at of 0.84659.

6.7 Evaluation of Package Arrays under Hypothetical Accident Conditions

The package array configuration under NCT and HAC are identical given the assumptions of the evaluation, that is, only the CCV and UO_2-Gd_2O_3 debris bed models were evaluated.

The CSI is 0.0 given an that unlimited (infinite) number of packages are subcritical, that is, the value of "N" is effectively equal to infinity per 71.59(b).

6.8 Computer Codes and Code Benchmarking

The applicant used MCNP6.2 for criticality calculations using ENDF/B-VIII.0 continuous-energy neutron data libraries and applicable thermal S (α,β) cross-sections, and Whisper Version 1.1, which is based on ENDF/B-VII.1 cross-sections and corresponding S (α,β) thermal scattering libraries, to check the applicability of the applied USL. These codes are referenced and described in SARP Section 6.9.2.3.3 *Computer Codes and Cross-Section Libraries* and Section 3.3 *Computer Codes*

Used of 50076-6001. Input/output (i/o) file listing is included in Section A.3 *Input/Output File Listing* of 50076-6001. In addition, the applicant provided representative i/o files to DOE PCP staff.

The applicant's code benchmark evaluation is addressed in SARP Section 6.9.2.5 *Benchmark Evaluation* and in Sections 4.1 *USL, Range of Applicability, and Validated Libraries*, 6.3 *Range of Applicability Assessment*, and 6.4 *Whisper USL* of 50076-6001.

The LEU benchmark evaluation documented in SARP Section 6.8 was repeated with MCNP6.2 and ENDF/B-VIII.0 cross sections. The applicant's results are shown in SARP Tables 6.9.2-7 – *USL Functions for Low-Enriched Uranium Critical Benchmarks, MCNP6.2 ENDF/B-VIII.0*, and 6.9.2-8 – *UO_2-Gd_2O_3 Fuel Material: MCNP6.2 Range of Applicability Summary*, based on Table 4-1 *MCNP Validation Range of Applicability* and Table 6-20 *MCNP Range of Applicability Summary* of 50076-6001. The results are similar with those in SARP Section 6.8 in that the $H/^{235}U$ ratio had the strongest correlation of the trended parameters and the minimum USL (0.9387). The minimum USL, 0.9386, over the validated range is at the maximum $H/^{235}U$ ratio.

A comparison of the most reactive case (MRC) parameters at 0.2% Gd to the MCNP6.2 range of applicability from SARP Table 6.9.2-7 is shown in SARP Table 6.9.2-8. The applicant noted that none of the trended parameters fall within the validated ranges. However, none of the parameters showed a strong statistical trend; therefore, any relative changes in USL postulated from extrapolating outside the validated ranges are not significant. Therefore, it is acceptable to apply the minimum USL of 0.9386 to the evaluations performed herein. This USL is conservative when compared to the USL of 0.9414 for an $H/^{235}U$ ratio ≤ 872.18.

DOE PCP staff concurs that the applicant performed appropriate benchmarking, selected appropriate uranium experiments, and calculation of bias and uncertainty in their determination of the USL (k_{safe}).

6.8 Conclusion

Based on review of the statements and representations in the SARP, as supplemented by this application, DOE PCP staff has reasonable assurance that the package nuclear criticality safety design has been adequately described and evaluated and that the package meets the nuclear criticality safety requirements of 10 CFR 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.

The applicant revised SARP Section 7 to incorporate the UO_2-Gd_2O_3 content configuration limits with respect to package dose, decay heat, combustible gases, criticality, and maximum weight. There are no additional changes to the SARP Operating Procedures for use of the package to ship these contents.

The applicant revised SARP Section 7 attachments as follows:

- Attachment 7.5-1 Demonstration of Compliance with Dose Rate Limits: Tables 7.5-1 -

Bare Cask Dose Rate/Ci Values (6 Pages) and Table 7.5-2 - OPTIMUS-L SIA Configuration Dose Rate/Ci Results (9 Pages) were updated by NAC calculation OPTIMUS®-L Isotope Collapse Dose Rate/C Results and Activity Limits, calculation number 70000.14-5104, Rev 1 [18], which determines dose rate/Ci results and activity limits for the package using 10 CFR 71 Appendix A to collapse parent and short-lived daughter decay chains. The methods used in the calculation conservatively increase the dose-per-curie of parent isotopes thus making it unnecessary to include the daughters. DOE PCP staff reviewed calculation 5104 and its results, verified that the results were correctly implemented in SARP Tables 7.5-1 and 7.5-2, and properly used and applied in SARP Table 5.5.4-1 UO_2-Gd_2O_3 Curie List and Dose Rate Calculation.

- Attachment 7.5-2 *Example CCV Pre-Shipment Inerting Procedure:* This procedure was revised to clarify Step 12. DOE PCP staff concurs that this clarification improves the procedure.

- Attachment 7.5-3 *Procedure for Determination of Flammable Gas Concentration and Shipping Time*: This procedure was revised to clarify and simplify the scope and description and clarify or correct the grammar in several procedure steps (1a., 1b., and 3b.). DOE PCP staff concurs that these changes improve the procedure.

7.1 Conclusion

Based on review of the statements and representations in the SARP, as supplemented by this application, DOE PCP staff has reasonable assurance that the package operating procedures meet the requirements of 10 CFR Part 71 and that these procedures are adequate to ensure the package will continue to be operated in a manner consistent with its evaluation for approval.

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 ensure packaging performance during its service life.

There are no changes required to the packaging acceptance tests and maintenance program to authorize use of the package for shipment of the UO_2-Gd_2O_3 content configuration.

Based on review of the statements and representations in the SARP, as supplemented by this application, DOE PCP staff has reasonable assurance that the packaging acceptance tests, and maintenance program meet the requirements of 10 CFR Part 71 and are adequate to assure packaging performance during its service life.

9.0 QUALITY ASSURANCE

This application does not include Section 9 on Quality Assurance; however, the applicant's Subpart H Quality Assurance Program is approved by the DOE Headquarters Certification Official (HCO) (https://rampac.energy.gov/docs/default-source/qa/approval_0004_r6.pdf). In addition, there are no packaging specific quality assurance requirements for the UO_2-Gd_2O_3 content configuration as the secondary container and dunnage are not important-to-safety components/items.
The applicant provided the quality classification categories for the package, secondary container, and

dunnage used for this content configuration in SARP Table 1.2.6 - *Quality List of Structures, Systems and Components Important to Safety for the NTESS Transportation Project*. DOE PCP staff concurs that the NTESS Burial Canister (container) and NTESS Basket (dunnage) are not-important-to-safety items.

Based on the DOE HCO approval of the applicant's Subpart H Quality Assurance Program, DOE PCP staff has reasonable assurance the package will be operated in a manner consistent with its evaluation for approval.

Conditions of Approval
The following conditions are required in a letter of authorization issued by the DOE HCO to authorize use of the package for limited shipments of these contents, for disposal.

DOE CoC No. 9390, Revision 0, for the Model No. OPTIMUS®-L package is amended to authorize the use of the package for limited shipments of UO_2-Gd_2O_3 subject to the conditions below:

1. The contents must not exceed the limits in Tables 1.2-4 *Criticality Limits for UO_2-Gd_2O_3 Fuel Material,* and 1.2.5 *UO_2-Gd_2O_3 Bounding Allowed Content Per* Package of the SARP, Revision 1.
2. The contents must be prepared per the Loading Restrictions in Section 1.2.2.2 *Irradiated Fuel Wast*e of the SARP for UO_2-Gd_2O_3.
3. All other conditions of DOE CoC No. 9390 shall remain the same.
4. This authorization expires on July 31, 2027.

Conclusion
Based on the statements and representations contained in the SARP, as supplemented, and the conditions listed above, DOE PCP staff concludes that the Model OPTIMUS-L® package design has been adequately described and evaluated and continues to meet the requirements of 10 CFR Part 71.

References

[1] *Submission of a Request to Revise the NAC OPTIMUS®-L Transportation Package, DOE Certificate of Compliance 9390*, Letter Baldner (NAC) to Shenk, February 26, 2024.

[2] *OPTIMUS-L® (OPTImal Modular Universal Shipping Cask) SAFETY ANALYSIS REPORT for Packaging*, Revision 24A, January 2024.

[3] *OPTIMUS-L® (OPTImal Modular Universal Shipping Cask) SAFETY ANALYSIS REPORT for Packaging*, Revision 24B, pages changes, March 2024.

[4] *OPTIMUS-L® (OPTImal Modular Universal Shipping Cask) SAFETY ANALYSIS REPORT for Packaging*, Revision 24C, pages changes, May 2024.

[5] *OPTIMUS-L® (OPTImal Modular Universal Shipping Cask) SAFETY ANALYSIS REPORT for Packaging*, Revision 24D, pages changes, October 2024.

[6] *RE: Request to Revise the NAC OPTIMUS®-L Transportation Package DOE CoC (Part 2 of 2)*, Email Gelder to Baldner, February 29, 2024.

[7] *Request for Supplemental Information Model No. OPTIMUS®-L*, Q0 Letter with enclosure, Shenk to Baldner, April 23, 2024.

[8] *Request for Additional Information Model No. OPTIMUS®-L*, Q1 Letter with enclosure, Cable to Baldner, November 12, 2024.

[9] *Request for Final SARP - Technical Review Complete,* Letter, Cable to Baldner, December 2, 2024.

[10] *OPTIMUS-L® (OPTImal Modular Universal Shipping Cask) SAFETY ANALYSIS REPORT for Packaging*, Revision 1, December 2024.

[11] *Nuclear Criticality Safety Assessment for AHCF Campaign Plan #16 Activities*, NCS-CSA-020, Rev 1, September 21, 2017.

[12] *CONTAINER ASSEMBLY SSB-2.69-0.25-7 A-TCRN*, NTESS Burial Canister, Container Products Corporation Drawing 31-4813-2-01, Revision B, December 21, 2023

[13] *Certificate of Conformance*, NTESS Burial Canister, with enclosed test reports, Container Products Corporation, May 15, 2024.

[14] NTESS BASKET, OPTIMUS-L NTESS, NAC Drawing 50076-002, Revision 0, November 16, 2023.

[15] *OPTIMUS-L NCT Heat Thermal Analysis - CCV Content Temperature vs. Decay Heat Load*, NAC Calculation Number: 70000.14-3002, Revision 0, October 20, 2022.

[16] *OPTIMUS-L Source/Shielding Evaluation for NTESS Materials (DCCs)*, NAC International, Calculation Number 50076-5001, Rev. 0, 1/17/2024.

[17] *OPTIMUS-L Criticality Evaluation for Uranium Oxide/Gadolinium Oxide Mixture*, NAC International, Calculation Number 50076-6001, Rev 1, 11/21/2023.

[18] *OPTIMUS-L Isotope Collapse Dose Rate/Ci Results and Activity Limits*, NAC Calculation Number: 70000.14-5104, Revision 0, November 20, 2023.