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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. 21-23-9516

Prepared by: James M. Shuler Digitally signed by James M. Shuler
Date: 2021.06.25 10:39:14 -04'00'

Dr. James M. Shuler
Manager, DOE Packaging Certification Program
Office of Packaging and Transportation

Approved by: Julia C. Shenk Digitally signed by Julia C. Shenk
Date: 2021.07.06 09:42:54 -04'00'

Julia C. Shenk
Headquarters Certifying Official
Director
Office of Packaging and Transportation

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 March 24, 2021, the certificate holder, ID requested an amendment of DOE CoC 9516 for the Model 9516 package design to authorize changes to the Shipping Configuration 3 – General Purpose Heat Source (GPHS) Module from the Step 0 design to the Step 2 design of the module. The Step 0 design of the module is obsolete. The Step 2 design differs from the Step 0 design by minor dimensional changes to the aeroshell housing that is part of the GPHS Module. This change required a commensurate minor design change to the *Graphite Support Block for GPHS Module* (Drawing 756184). The radioactive contents of the GPHS Module are unchanged.

The application ^[2] for package approval in support of the ID request was Safety Analysis Report for Packaging (SARP) for the 9516 Package April 2021, Revision 4a. The application was prepared for ID and INL by the Pacific Northwest National Laboratory (PNNL) and submitted by ID to DOE PCP on April 27, 2021 for review.

On May 24, 2021, the DOE PCP Manager notified ID ^[3] that DOE PCP staff completed their independent technical review and confirmatory analysis and had no regulatory compliance questions or additional comments, pending three editorial errors for their correction and implementation in a final SARP. The final SARP, Revision 4 ^[4] was submitted by ID on May 28, 2021 and staff confirmed the errors were corrected.

Based on the statements and representations in the final SARP Revision 4, DOE PCP staff independently confirmed that the package design has been adequately described and evaluated for the design change to the Shipping Configuration 3 - GPHS Module. 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 by DOE PCP staff of SARP Revision 4, to the requirements of 10 CFR Part 71.

1.0 General Information

1.1 Introduction

The GPHS Module is shown in SARP Figure 1-13 and is a 250 W (nominal) component of the radioisotope thermoelectric generator (RTG) that provides power for space missions. The radioactive contents of the module are ceramic pellets of Pu-238 oxide (PuO₂) that are encapsulated in a protective casing of iridium, forming a fueled clad assembly (FCA). Each GPHS Module is designed to hold four FCAs, that are nominally 63 W (each) at the time of pressing. Two pairs of FCAs are encased within nested layers of carbon-based material and placed within an aeroshell housing to comprise the complete GPHS module. Each pair of FCAs are enclosed in a single graphite impact shell (GIS), which is then overpacked in a carbon-bonded-carbon-fiber insulator sleeve (CBCF Sleeve), and then overpacked in the aeroshell housing that is made of fine-weave pierced fabric (FWPF). Layers of CBCF provide thermal insulation for the GPHS Module during the temperature extremes of space travel. The insulator also keeps the FCA temperature above the nil-ductility temperature of iridium to prevent brittle fracture while in space and below the melting point of iridium during reentry.

The GPHS Module design has three “steps” or revisions: Step 0, Step 1, and Step 2. These three designs were not explicitly discussed in the SARP prior to this application, but the Step 0 design (based on materials and dimensions) is evaluated in SARP Revision 3 and authorized for shipment in the package under the current DOE CoC#, 9516, Revision 8, as Shipping Configuration 3 – GPHS Module.

The applicant evaluated the Step 2 design in SARP Revision 4. The Step 2 design adds additional material to the aeroshell housing in order to improve the performance of the GPHS Module during accident scenarios. A side-by-side comparison of the Step 0 and Step 2 designs is provided in SARP Figure 1-13. SARP Section 1.3.1, Reference 1.18, *9516 SARP - Scope of Change to Shipping Configuration 3 (GPHS Module)* is the applicant’s background description and technical evaluation of the GPHS Module revisions and it summarizes the changes required to the SARP in order to demonstrate the package meets 10 CFR Part 71 with the GPHS Step 2 Module configuration.

1.2 Package Description

There were no changes to the previously approved package description in the SARP, except to address the revision to Shipping Configuration 3 in SARP Section 1.2.2.1.3 for the GPHS Step 2 Module.

The Model 9516 is a Type B(U)F package that is designed for transport of up to 500 watts of PuO₂ 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 A₂. 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. 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.

The packaging in the CV for Shipping Configuration 3 is shown in SARP Figure 1-15, *Typical Containment Vessel Loading Arrangement for GPHS Module*. The packaging components required for this shipping configuration are: Liners (5.00-inches tall, 2 qty.), Graphite Support Blocks (2 qty.) and a Graphite Filler Block (4.88-inches tall). The safety function of these components is to restrict movement within the CV. These components are classified in SARP Table 9-1, *Q-List for the 9516 Packaging Design, Procurement, and Fabrication*, as Quality Level C items (Quality Category C), which are minor to the safe operation of the package.

There are no design changes to the Liner and Graphite Filler Block; however, the Graphite Support Block design was modified in Drawing 756184, Rev.1 to accommodate the slightly larger length and width of the GPHS Step 2 Module. The packaging function of the Graphite Support Block is to fill the internal void volume in the Liner and position the GPHS Module. The overall dimension of the Graphite Support Block were unchanged, but the housing for the GPHS Step 2 Module was enlarged from 2.25 in. by 3.94 in. to 2.36 in. by 4.00 in., and the void volume holes were enlarged from 0.75 in diameter to 0.81 in. to offset the weight gain of the Aeroshell design change. The modified dimensions are shown in SARP Figure 1-14, *Graphite Support Block for GPHS Module*. These design modification reduced the estimated weight of the Graphite Support Block from 3.5 lb. to 3.1 lb. (Drawing 756184, Rev. 0 vs. Rev. 1).

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

1.2.2 Contents

There are no changes to the exiting authorized radioactive contents or significant changes to the basic loading for Shipping Configuration 3 with the GPHS Step 2 Module.

The aeroshell housing design was modified to increase its overall dimensions from 2.09 in. × 3.67 in. × 3.83 in. for the Step 0 design to 2.29 in. × 3.67 in. × 3.92 in. for the Step 2 design. Internal webbing was also between the GIS in the Step 2 design. The design modifications to the aeroshell housing are intended to improve its performance during accident scenarios. These modifications resulted in a weight increase to the aeroshell housing and marginal separation between the two GIS within the housing.

The GPHS Step 2 Module is marginally heavier than the Step 0 design: 3.55 lb. vs. 3.15 lb.; however, the additional 0.4 lb. added by the additional material in the aeroshell housing of the GPHS Step 2 Module is offset by the 0.4 lb. lost by removal of material from the Graphite Support Block; therefore, there is no net weight change to the loading configuration for Shipping Configuration 3.

The internal webbing in the aeroshell housing added by 0.094 in. of horizontal separation between the two GIS. The difference is shown in SARP Figure 1-13 by comparing the centerline to centerline distance between GPHS FCA for the Step 0 and Step 1 designs: 1.726 in. for Step 0 vs. 1.820 in. for Step 2.

DOE PCP staff confirmed by document review that the changes to the GPHS Module (SARP References 1.16, 1.17, 1.19, and 1.20) and Graphite Support Block (Drawing 756184, Revision 1 and SARP Appendix 1.3.2) has been correctly implemented in the SARP.

1.3 Evaluation Findings

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

2.0 Structural Evaluation

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

There were no significant changes to the structural performance features of the package design.

DOE PCP staff's review and evaluation focused on the effect of the minor change to the GIS spacing and the overall GPHS Step 2 Module dimensions, the total gross weight of the package for Shipping Configuration 3, and the maximum temperatures and pressures under NCT and HAC.

The GPHS Step 2 Module has minor changes to the GIS spacing and the overall module dimensions, but no weight change to the loading configuration in the 5.00-in. Liner. DOE PCP staff reviewed these changes and finds that they have no impact on the existing structural evaluation of the package. The geometry of the GPHS Module within the Liner is not a factor in the structural evaluation of the package. The weight increase of the aeroshell housing is offset by the weight decrease in the Graphite Support Block; consequently, there is no weight increase to Liner loading configuration for Shipping Configuration 3. The CV load for Shipping Configuration 3 for the GPHS Step 2 Module is unchanged and remains bounded by SARP Table 2-3 *CV Assembly Weights*.

The applicant provided a reasoned argument in SARP Section 3.1.2.3 *Shipping Configuration 3—GPHS Module* that the GIS geometry changes do not significantly impact the component temperatures, as the two GIS being moved further apart would slightly lower the internal temperature of the GPHS Module and would not affect the Liner, CV, and Cask temperatures under NCT and HAC, the maximum normal operating pressure (MNOP), and the maximum HAC pressure.

2.1 Evaluation Findings

Based on review of the statements and representations in the SARP, 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 PuO₂ 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 PuO₂ payloads is from the alpha decay of Pu-238.

There was no change to maximum heat load per CV (500 W) or Liner (233 W), or the CV or Liner void volumes and mass loadings for shipment of the GPHS Step 2 Module design.

The GPHS Step 2 Module design changes from the Step 0 design were previously addressed in Section 1.2.2 of this SER. The applicant demonstrated in SARP Appendix 3.5.5, Table 3.5.5-1 that there is no change in the net free volume in the CV or the internal 5.00-in. Liner for the GPHS Step 2 Module design due to the volume changes to

the Graphite Support Block and the aeroshell housing. In addition, the applicant provided a reasoned argument in SARP Section 3.1.2.3 *Shipping Configuration 3—GPHS Module* that the GIS geometry changes do not significantly impact the component temperatures, as the two GIS being moved further apart would slightly lower the internal temperature of the GPHS Module.

DOE PCP staff confirmed by document review and evaluation the void volumes in the Liners and CV, the maximum decay heat loading, the maximum temperatures of the package components, and the maximum pressures in the CV under NCT and HAC for the GPHS Step 2 design are bounded the thermal evaluation in the SARP for the Step 0 design.

3.1 Evaluation Findings

Based on review of the statements and representations in the SARP, DOE PCP 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 radioactive contents or to the containment performance features of the package design in order to use the package for GPHS Step 2 Module design.

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 Configuration 3 for the GPHS Step 2 Module design 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 SARP, 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 radioactive contents or the shielding performance features of the package design to use the package for the Shipping Configuration 3 for the GPHS Step 2 Module design.

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.

The applicant's shielding model of the GPHS Step 0 Module and loading configuration are shown in SARP Figures 5-2, *Cross-Section of the Shipping Cask Containing Two GPHS Modules in the X-Y Plane* and 5-3, *Cut-Away of the Shipping Cask with Two GPHS Modules*. These models were not updated for the Graphite Support Block (Rev. 1) or the GPHS Step 2 Module.

The applicant makes a reasonable argument in SARP Sections 5.4.4.1 and 5.4.4.3.1, considering the large margin between the calculated package dose rates and the regulatory limits listed in SARP Tables 5.19 *Calculated Maximum NCT Dose Rates for Two GPHS Modules for Exclusive Use Shipments* and 5.20 *Calculated Maximum HAC Dose Rates for Two GPHS Modules*, and the marginal dimensional changes for the GPHS Step 2 Module design and loading configuration, that the GPHS Step 0 Module design is essentially bounding for the Step 2 Module design and loading configuration and does not change the conclusions of the SARP (Rev. 3) shielding evaluation.

DOE PCP staff concurs that the small differences between the GPHS Step 0 Module and the GPHS Step 2 Module designs and loading configuration only cause marginal changes in the calculated dose rates outside the package. Therefore, the existing shielding design and performance described in SARP Chapter 5 is acceptable for the change to Shipping Configuration 3 for the GPHS Step 2 Module design and loading configuration.

5.5 Evaluation Findings

Based on review of the statements and representations in the SARP, DOE PCP 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).

There were no changes to the radioactive contents or the NCS performance features of the package design to use the package for the Shipping Configuration 3 for the GPHS Step 2 Module design.

The applicant makes a reasoned argument in SARP Section 6.3.1 *Model Configuration*, that the increased distance between the two GIS will likely decrease the neutron interaction, and as a result marginally decrease k_{eff} . The addition of the small amount of

material to the faces and internal webbing of the aeroshell housing will also have a negligible effect on the reactivity considering the large amount of graphite already present in the Liners and the CV. SARP Sections 6.4.2.1 *Single-unit Results for the Three GPHS Modules* and 6.6.2.1 *Infinite Array Results for the Three GPHS Modules* were revised to address SARP Section 6.3.1 argument for the Step 2 design.

DOE PCP staff concurs that the differences between the GPHS Step 0 Module and the GPHS Step 2 Module designs and loading configuration will have negligible impact on the NCS of the package. Therefore, the existing NCS design and performance described in SARP Chapter 6 is acceptable for the change to Shipping Configuration 3 for the GPHS Step 2 Module design and loading configuration.

6.1 Evaluation Findings

Based on review of the statements and representations in the SARP, 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 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.

There were no changes in the SARP to the basic operating procedures or loading steps for Shipping Configuration 3 to ship the GPHS Step 2 Module design, since it is essentially identical to the Step 0 design.

7.1 Evaluation Findings

Based on review of the statements and representations in the SARP, 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 SARP to the acceptance test and maintenance program for packaging components. The components internal to the CV for Shipping Configuration 3 are listed in SARP Table 1-2 and classified in SARP 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 the drawings listed SARP Appendix 1.3.2 *Drawings*.

8.1 Evaluation Findings

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

9.0 QUALITY ASSURANCE

The objective of this review is to verify that the SARP, 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 changes in the Shipping Configuration 3 from the GPHS Step 0 Module design to the Step 2 Module design and loading configuration did not affect the existing QA Program of the packaging. The Quality Level for the components internal to the CV for this shipping configuration (i.e., Liners, Graphite Support Blocks, and a Graphite Filler Block) 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 within 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. The minor design change to the Graphite Support Block did not change its safety classification or function. 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 SARP, 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 the SARP Rev. 4 changes evaluated in this SER.

- Drawings 5(a)(3) revise 756184 Rev 0 to Rev 1 for Graphite Support Block for GPHS Module. (Drawing change required for the GPHS Module Step 2 design)
- Contents 5(b)(2), replace 1st two sentences in Shipping Configuration 3 with the following text to update the information for the Step 2 module design.
 - The GPHS Module Assembly (Step 2) is a component of the radioisotope thermoelectric generator (RTG). The overall dimensions of the module are 2.290 inches by 3.668 inches by 3.920 inches (see SARP Rev. 4, Reference 1.20, Drawing R1032-0225-ED-01).
- Conditions 5.(d) revised:
 - (10) Added “Revisions 8 of this certificate may be used until July 31, 2022. ”
- Supplements 5.(e) added:
 - (4) “Safety Analysis Report for Packaging (SARP) for the 9516 Package, R1033-0062-ES, Rev. 4, May 2021.”

Conclusion

Based on the statements and representations contained in SARP Rev. 4 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] *FW: Request for Docket number for 9516 SARP change*, Email Carl Friesen to Shuler, March 24, 2021.
- [2] *Safety Analysis Report for Packaging (SARP) for the 9516 Package*, R1033-0062-ES, Rev. 4a (page changes), April 2021.
- [3] *Docket 21-23-9516 Technical Review Complete*, Memorandum Shuler to Friesen, May 24, 2021.
- [4] *Safety Analysis Report for Packaging (SARP) for the 9516 Package*, R1033-0062-ES, Rev. 4 (complete), May 2021.