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DOE Packaging Certification Program

**Safety Evaluation Report for
Certificate of Compliance No. 9168 Letter of Authorization
for the Model 8-120B Package**

Docket No. 19-49-9168

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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) by the package Certificate Holder, EnergySolutions (ES), to authorize use of the Model 8-120B for shipments of two DOE legacy plutonium JE-899 V3XA spheres from the Nevada National Security Site (NNSS) to the Idaho National Laboratory (INL) for processing.

Summary

By application ^[1] dated April 28, 2020, superseded May 4, 2022 ^[2], the certificate holder, ES requested an amendment of DOE CoC 9168 for the Model 8-120B package design to authorize use of the package for shipment of two JE-899 V3XA (V3XA spheres), one sphere per package, from NNSS to INL for processing.

The spheres were one-time-use test vessels to tests high explosive assemblies for DOE in the late 1980s. The residue in the spheres is a non-homogenous mixture of dispersed plutonium, depleted uranium, beryllium, wood, steel, and aluminum debris all bound up in a coke-like matrix adhered on the sphere wall.

Each V3XA sphere is constructed of steel and is approximately 3 feet in diameter with wall thickness of 1.25 inches. Its gross weight is approximately 2,700 lb. Each sphere will be positioned within the 8-120B containment system in a two-piece wooden cribbing assembly. The total payload weight for the V3XA sphere configuration is approximately 3,408 lb.

The ES application is an addendum to *Safety Analysis Report for Model 8-120B Type B Shipping Packaging Consolidated Revision 11* (CSAR). The CSAR is the safety basis for DOE CoC 9168, Rev 4. The addendum provides structural, thermal, containment, shielding, and criticality evaluations of the package with the of V3XA sphere configuration, as well as package operations, acceptance tests and maintenance program, and quality assurance requirements for the V3XA sphere configuration.

Based on the statements and representations in the final Addendum, Revision 1, DOE PCP staff independently confirmed that the package design has been adequately described and evaluated for the V3XA sphere configuration. Therefore, staff has reasonable assurance that the regulatory requirements of Part 71 have been met and recommends amendment of the CoC by letter of authorization by the DOE Headquarters Certifying Official (HCO).

Evaluation

This SER documents the independent technical review by DOE PCP staff of JE-899 Type V3XA Spheres Shipping Addendum for Model 8-120B Type B Shipping Package, Atkins/ES 20-001, Rev. 1, April 2022 (hereinafter referred to as the “Addendum” unless otherwise specified) to the requirements of 10 CFR Part 71.

The following safety basis documents support the Addendum and supplement the CSAR as needed:

- JE-899 Type V3XA Spheres Shipping Addendum for Model 8-120B Type B Shipping Package, Atkins/ES 20-001, Rev 1 (Addendum Rev. 1)
- Transport of JE-899 V3XA Spheres within The 8-120B Shipping Cask – Structural Evaluation of the V3XA Vessel Wood Cribbing, CALC-5193806-ST-0001, Rev. 3 (Addendum Chapter 2, Ref. 1)
- JE899 V3XA Spheres Shipping Addendum – Hydrogen Generation and Pressure Analysis for the 8-120B Type B Shipping Cask, CALC-5193806-PR-0001, Rev. 1 (Addendum Chapter 3, Ref. 2)
- JE899 V3XA Spheres Shipping Addendum - Criticality Analysis for the 8-120B Type B Shipping Cask, CALC-5193806-NS-0001, Rev. 1 (Addendum Ref)

The initial application, Rev. 0 of the Addendum, and its supporting calculations for the structural evaluation, criticality analysis, and hydrogen generation and pressure analysis, were reviewed by DOE PCP staff and subsequently revised and superseded by Rev. 1 of the Addendum, with revisions to calculations supporting the structural evaluation and hydrogen generation and pressure analysis, in response to regulatory questions and comments identified from staff’s independent technical reviews and confirmatory analysis of the initial application and calculations. ^[3, 4, 5]

1.0 General Information

1.1 Introduction

The V3XA spheres were one-time use containment vessels used by DOE in the late 1980s to conduct tests of high explosive assemblies. The resultant product is a non-homogenous mixture of dispersed plutonium, depleted uranium, beryllium, wood, steel, and aluminum debris all bound up in a coke-like matrix on the sphere wall.

The V3XA sphere configuration is not currently authorized in the DOE CoC for shipment in the 8-120B. Based on the limited number of spheres proposed for shipment (Sphere #s 899-C and 899-L), the applicant, ES, requested a letter of authorization (LoA) to amend the CoC in lieu of a CoC and CSARP revision. This request for an LoA is appropriate based on the short duration of this mission and unique contents.

1.2 Package Description

The Model 8-120B is a Type B(U)F-96 package certified by DOE for shipment of fissile and other radioactive materials. The package evaluated in the Addendum and this SER is the Model 8-120 packaging with the V3XA sphere content configuration.

The maximum gross weight of the package is approximately 74,000 lb., and the maximum weight of the contents is 14,150 lb. (including shoring and secondary containers). The maximum decay heat of the contents is 200 watts and maximum activity is not to exceed 3,000 A₂.

1.2.1 Packaging

There were no design changes to the primary packaging components described in the CSAR and authorized in the CoC.

The internal packaging components for the V3XA sphere configuration consists of:

- A single V3XA sphere defined by drawing *Vessel V3XA – Storage Configuration*, AAA-90-100065-00 and
- The two-piece wooden cribbing assembly defined by drawing *V3XA Transport Cribbing Overall Assembly*, DWG-5193806-ST-0001, Revision 2.

Each sphere is approximately three feet in diameter with two ports on opposite sides: one port 9 inches in diameter and the other is 3 inches in diameter.

The overall dimensions of the cribbing assembly is 60 inches in diameter and 72-3/4 inches in maximum height.

The safety functions of the sphere are dunnage and confinement of the radioactive material. The safety function of the cribbing assembly is dunnage and to protect the packaging containment system and sphere from structural damage under normal conditions of transport (NCT) and hypothetical accident conditions (HAC).

In addition, the shipper must verify the sphere is vented prior to loading in the 8-120B containment system to ensure that flammable gas generation does not accumulate in the sphere.

The list and drawings of all packaging components required for the V3XA sphere configuration are defined in Addendum Section 1.3.

1.2.2 Contents

All contents within the sphere were weighed before they were assembled for high explosive (HE) testing. Each sphere initially contained 1,052 grams of high explosives that were completely burned during the HE test. The pre-test mass of all contents in the

sphere are listed in Addendum, Table 1-1, *Total Contents within JE-899 V3XA Sphere (#899-C)*.

The radioactive contents are a mixture of 443 grams of plutonium and 3,660 grams of depleted uranium (D-38) in normal form. The applicant used process knowledge and legacy DOE facility safety basis documents from spheres #899-C and #899-L to characterize and age decay the initial material from 1987 to 2020 to determine the maximum mass of plutonium isotopes with in-growth of Am-241, (441.74g), radioactivity (69.93 Ci), and decay heat (1.16 watts) as shown in Addendum Table 1-2. The A_2 values and aggregate activity ($A_2 = 1373.68$ Ci) for the plutonium isotopes, with Am-241, are calculated and shown in Addendum Table 1-3.

The applicant omitted D-38 in Addendum Tables 1-2 and 1-3. By definition (§71.4), D-38 means uranium containing less uranium-235 than the naturally occurring distribution of uranium isotopes (i.e., approximately less than approximately 0.7 weight percent U-235, and the remainder by weight essentially uranium-238).

The isotopes in natural uranium (<https://www.iaea.org/topics/spent-fuel-management/depleted-uranium>), by weight percent, are U-238 (99.28), U-235 (0.72), and U-234 (0.0057) whereas D-38 is typically U-238 (99.8), U-235 (0.2) and U-234 (0.001).

Based on 3,660 grams of D-38, the fissile mass of U-235 in the D-38 would be 7.3 g (which is equivalent to 4.7g of Pu-239 in accordance with the WIPP/ANS-8.1/ANS-8.15 conversion factor of 0.643 from the ratio of their subcritical mass limits), decay heat (4E-5 watt), and aggregate activity ($A_2 = 1.38E-3$ Ci) are not significant compared with the plutonium in the sphere; therefore, DOE PCP staff concurs that the D-38 can be omitted from the package evaluation for thermal, containment, and criticality safety.

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.

1.3 Evaluation Findings

Based on review of the statements and representations in the Addendum, DOE PCP staff concludes that the package in support of the CoC amendment request has been described in sufficient detail to provide an adequate basis for staff to evaluate it for compliance with 10 CFR Part 71.

2.0 Structural Evaluation

The objective of this structural evaluation 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. DOE PCP staff's structural review concentrated primarily on the cribbing and its capacity to absorb impact during NCT and HAC without damaging the 8-120B packaging or sphere.

There are no changes to the existing 8-120B package design or structural evaluation of the package in the CSAR. The maximum estimated weight of the proposed V3XA sphere configuration (3,408 lb.) will not exceed the maximum weight authorized in the CoC (14,150 lb.).

As in similar applications from this certificate holder, the applicant designed and evaluated a two-piece wood cribbing structure to support a single V3XA sphere at the center of the 8-120B containment cavity. The applicant used a quasistatic analysis based on G-loads determined from CSAR to determine the response of the cribbing to impacts during NCT and HAC. The cribbing is a sacrificial major-to-safety (QL-2) component used as dunnage to protect the 8-120B packaging and sphere.

Each sphere is a 3-ft. diameter vessel used for HE testing. Its wall thickness is greater than 1 inch of HY-80 high strength steel with 80 ksi minimum yield stress. Although the sphere will be shipped in a vented configuration, it is capable of handling pressure that could develop if the filter vent(s) were to clog.

The V3XA sphere configuration weighs approximately 3,408 lb.: 2,700 lb. (sphere), 650 (cribbing assembly), and 58 lb. (nylon straps). The applicant rounded the weight to 4,000 lb. in their structural calculations.

The applicant reported the material properties of the V3XA sphere configuration at 300°F, in Addendum Table 2-1, which is the maximum 8-120B internal temperature under HAC (rounded from 295.5°F) in CSAR Table 3-2 from a decay heat payload of 200 watts. Since the V3XA sphere configuration payload decay heat is less than 2 watts, DOE PCP staff concurs that evaluating the material properties and allowable stresses of the V3XA sphere configuration at 300°F is acceptable without requiring a detailed thermal analysis under NCT and HAC. The material from which the V3XA sphere configuration is fabricated will not cause chemical, galvanic or other reactions in air, nitrogen or water atmosphere with the 8-120B packaging.

The applicant's structural calculation:

- a.) evaluated the structural performance of the package under NCT and HAC using a finite element analysis (FEA) of the 8-120B packaging with a fully modeled sphere.
- b.) estimated of the required sphere skin thickness to withstand puncture by a 2x8 lumber member of the cribbing,
- c.) evaluated end cap bolt loading from inertial forces, and
- d.) evaluated lifting the bottom cribbing frame with the sphere.

Drop Test Orientations

Only the HAC end-drop (both ends) orientations from 30 ft were modeled in the applicant's finite element analysis of the sphere. The cribbing was analyzed for NCT end and side drop as well as HAC end and side drops. The corner-drop orientation was not evaluated by the applicant because the deceleration loading in the corner-drop is bounded by the loading in the end and side drops for both NCT and HAC.

Sphere Model

The applicant's FEA model includes the complete sphere with a 1.3 inches of wall thickness and both the large and small end caps. The applicant increased the density of the sphere's steel from 483 lb./ft³ to 546 lb./ft³ to account for the weight of the sphere contents. The FEA model figures indicate the sphere end caps are modeled as solid material continuous with the sphere skin. This model was subjected to top and bottom end-drops with the sphere constrained by a single circular line restraint near the interface with the respective end cap. For the top end-drop under HAC, the circular restraint is just outside the large end cap bolting boss which has a diameter of 20.7 inches, and for the bottom end-drop, the restraint is just outside the small end cap boss which has a diameter of 10 inches. The inertial loading for both end-drop impacts is derived from the scaled cask end drop acceleration of 186.3 g which is the maximum for all orientations. As expected, the stresses and strains for the bottom end-drop are greater than the top end-drop as the constraint is more concentrated in the bottom end-down orientation.

According to the description in the structural calculation, these are quasistatic analyses so that the 186.3 g acts as a mass multiplier. DOE PCP staff notes that in the final revision of the calculation, the author appears to have reversed the direction of the inertial force in Addendum Figures 4.1 and 4.2, as indicated by the yellow arrow in the figures. The inertial force in a quasistatic analysis should generally be in the same direction as the weight. With the inertial force in the direction shown in the final revision, the restraint at line A in these figures would cause tension in the sphere above the restraint instead of compression that would be experienced in the actual drop. Regardless of the direction of the inertial force, the FEA indicates that the sphere will not experience plastic strain based on an extremely concentrated restraint excluding dynamic impacts. The structural calculation also includes an estimated sphere skin thickness to withstand puncture by a 2x8 lumber member. This closed form calculation assumes the wood is crushed to its ultimate stress, estimated at 6 ksi, and then analyzes the sphere skin in double shear. This analysis estimates that the minimum sphere thickness to withstand puncture from the cribbing during impact is only about one tenth of an inch; therefore, the actual sphere thickness of 1.25 inches is sufficient.

End-Cap Bolts

Retention of the sphere ends caps is important to confinement of material in the sphere. The bolts holding the large end-cap are evaluated in the structural calculation by comparing the force on the end-cap from the internal design pressure of 260.2 bar (3773.9 psi) to the inertial load of the end cap in a top end-drop assuming a peak 185.4 g loading. The applicant assumed an end-cap weight of 500 pounds to calculate a force of

9.27 x E4 lb. on the bolts, which is only about a third of the force on the bolts from the sphere design pressure loading of 2.96 x E5 lb.

Cribbing Assembly

The cribbing is analyzed by calculating a crush pressure based on the number of lumber members resisting the payload force. If the crush pressure exceeds the wood crush strength, the applicant uses the Metz equation to estimate wood crush distance and then compares this result to determine capacity and that lock-up (i.e., crushing strain less than 75% of capacity) does not occur which would invalidate the applicant's method of analysis. In similar cribbing designs (e.g., for the Model 10-160B) the contents could be restrained by the cribbing with very little wood crush. However, due to the shape of the V3XA sphere it is more effective in crushing the cribbing than non-spherical payloads. Based on the applicant's structural calculations wood crush occurs in the NCT end-drop and in all HAC drop test orientations.

For the structural properties of the wood cribbing assembly, the applicant used eastern white pine and assumed a crush strength of 4,800 psi for loads parallel to the wood grain and 335 psi for loads perpendicular to the grain. For package side drop orientations the load is parallel to the grain of the wood beam members and for top and bottom end-drops orientations the load is applied perpendicular to grain. Once crushing is initiated during the end-drop orientations, the applicant raised the crush strength perpendicular to the grain from 335 psi to 1,550 psi in the Nelms equation to calculate the amount of wood crush.

The applicant's initial cribbing design included 8 radial dimensional lumber members per layer. DOE PCP staff's noted that this design is inadequate to prevent the wood from reaching crush capacity under scaled HAC g-loading for the package during a side-drop. The applicant revised the design in center layers (Layers 2, 3, 4, 5) to include 16 radial lumber members. With this design change, the wood crush depth from the side-drop went from greater than 100% of capacity to about 75% of capacity. Staff notes that the applicant's wood crush calculations are conservative in that they do not credit the plywood layers. The plywood layers at the top and bottom of Layers 3 and 4 add more than 100 in² to the side-drop crush area which is sufficient to reduce the average wood stress below the 4,800 psi crush strength – parallel to the grain.

For HAC top end-drop, the applicant determined that the total crush depth of 3.77 inches would occur in the 8 radial beam members at the top of the top cribbing assembly in Layer 7. DOE PCP staff noted that the secondary lid pocket would only allow 2.5 inches of crush depth and that achieving a crush depth of 3.77 inches would require that the center of Layer 7 would fail into the secondary lid pocket. The applicant provided a supplemental calculation that evaluates the bending and shear strengths of the Layer 7 wood ligament and plywood sheets directly under the sphere's large end cap, which demonstrates the center of Layer 7 would completely fail from contact with the sphere's

large endcap assuming only $\frac{1}{4}$ of the sphere weight at 184.5 g were applied. The applicant concluded it is unlikely that the wood directly under the end cap could reach lockup before causing bending/shear deformation of this section into the secondary lid cavity. Staff performed a calculation which determined the crush depth of 3.8 inches in the outer part of Layer 7 is less than the allowable calculated deflection of 4.4 inches, which confirms the applicant's conclusion that wood lock-up will not occur. These calculations and analysis assume the lifting eye is removed from the top end cap of the sphere prior to shipment; therefore, its removal must be a condition of approval in the LoA.

Lifting Evaluation

The applicant evaluated the cribbing assembly design, by calculation, to ensure it has the requisite strength and rigidity to lift the V3XA sphere configuration. The criterion for the cribbing design is it must pass a load test of 125% of the rated load, per ASME B30.20. In this case the applicant evaluated a load of 5,000 lb. (4,000 lb. x 1.25). The applicant selected material properties from the 2012 edition of ANSI/AWC NDS, *National Design Specification for Wood Construction* and calculated the bending, shear, and compression load properties of the wood to compare them with the material specifications listed in Table 3.1 of the structural calculation. The applicant demonstrated that the calculated stresses are less than the allowable stresses, so the cribbing design is satisfactory. DOE PCP staff confirmed the applicant's results by document review and agrees the cribbing design is satisfactory for the intended load.

NCT and HAC

The structural evaluation of the package under applicable NCT (§71.71) and HAC (§71.73) requirements remains valid for the V3XA sphere configuration, since it is bounded by the CSAR, as demonstrated in the Addendum and its structural calculation (CALC-5193806-ST-0001).

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, subject to the condition that the lifting eye is removed from the V3XA sphere prior to shipment.

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. DOE PCP staff's review focused on the potential of flammable gas generation from the sphere contents.

There were no changes to the 8-120B package thermal design. The CSAR only credits conduction through air in the package cavity; consequently, the wood cribbing assembly has little effect on heat transfer properties.

The maximum decay heat load of the V3XA sphere configuration (1.2 watts) is identified in Table 3.1 of the Addendum and does not exceed the maximum decay heat authorized in the CoC (200 watts). DOE PCP staff confirmed the applicant's results by document review.

Gas Generation

The applicant submitted calculation *Hydrogen Generation and Pressure Analysis for the 8-120B Type B Shipping Cask*, CALC-5193806-PR-0001 in support of the Addendum. This calculation assumes the CSAR determined maximum package interior average gas temperatures of 200°F for NCT and 275°F for HAC are the conditions to evaluate the V3XA sphere configuration. This assumption is very conservative since the maximum decay heat of the V3XA sphere configuration contents (1.2 watts) is only a small fraction (0.006) of the 200 watts package decay heat load at which the maximum temperatures are determined in the CSAR.

The applicant determined the hydrogen generation rate from the V3XA sphere configuration from two sources:

- a.) gamma radiation from the sphere to the wooden cribbing and nylon webbing in the package containment cavity,
- b.) interaction of the radiological materials with the other material in the sphere.

The calculations in CALC-5193806-PR-0001 assume that the sphere is not a confined volume which requires the valves on the sphere are open and filters allow hydrogen to communicate between the sphere inner void volume and the net void volume in the package containment system. The applicant used G values and methods from *Hydrogen Generation in TRU Waste Transportation Packages*, NUREG/CR-6673, which is acceptable to DOE PCP staff.

Energy deposition in the cribbing assembly and nylon webbing from gamma radiation results in a hydrogen gas generation rate of $2.366E-12$ mols/sec..

The gas generating materials inside the sphere are identified in Table 2 of CALC-5193806-PR-0001. The applicant used a volume-weighted average in determining a bounding effective G value (Mols H₂/100eV). The applicant also used pre-detonation masses of the materials because the density of the post-detonation masses are not well characterized. The final calculated hydrogen generation rate in the sphere is $2.302E-7$ mols/sec., and is only slightly less than the rate calculated of $3.85E-7$ mols/sec. which assumed all the alpha interaction was with the material with the highest G value (i.e., wood); therefore, the hydrogen generation rate in the sphere is not sensitive to the

assumed density of the gas generating constituents nor the overall interaction among its constituent material. This conclusion is not affected by the possibility that the spheres have been stored in a vented condition for the last 30 years, since any moisture absorbed in the sphere during that time would not change the hydrogen generation rate since this rate is limited by the energy of radioactive material.

The hydrogen gas generation rate in the cribbing and nylon webbing is five orders of magnitude less than the gas generation from the material in the sphere and thus is an insignificant contributor.

Based on the calculation results, it would take approximately 239 days to reach 5% hydrogen, by volume, in the containment boundary; consequently, the safe shipping window for the V3XA sphere configuration is 119 days (i.e., ½ time to reach 5% flammable gas by volume in any confined space) based on NRC Information Notice 84-72, *Clarification of Conditions for Waste Shipments Subject to Hydrogen Gas Generation*. DOE PCP staff reviewed the applicant's calculation and concurs with the results.

Pressure

The applicant evaluated maximum normal operating pressure (MNOP) and pressure under HAC for the V3XA sphere configuration in CALC-5193806-PR-0001, and compared the result to the package MNOP and pressure from HAC in the CSAR. The results are presented in Addendum Sections 3.3.2 and 3.4.3 respectively.

The package MNOP and HAC pressures are based on temperatures in the package interior of 200°F and 275°F, respectively and resulting pressures of 35.0 and 155.0 psig, respectively.

The MNOP and HAC pressures for the V3XA sphere configuration are 2.26 and 4.185 psig respectively. In addition, the applicant assumed 3 kg of water that was originally in the sphere prior to detonation was available and recalculated the pressures. The results are 13.78 psig (MNOP) and 64.01 psig (HAC), which are still bounded by the CSAR results. DOE PCP staff concurs with the applicant's calculation results.

3.1 Evaluation Findings

Based on review of the statements and representations in the Addendum, DOE PCP staff has reasonable assurance that the thermal design of the package continues to meet the requirements of 10 CFR Part 71, subject to the condition that the V3XA sphere is vented prior to loading for shipment and that the shipping period does not exceed 119 days from the time the 8-120B is closed.

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 8-120B package containment design. The maximum allowable quantity of A₂s for the 8-120B, since it is a Category II shipping package (per *Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers up to Four Inches Thick*, NUREG/CR-1815) is 3,000A₂s. The maximum A₂s for the V3XA sphere configuration is sphere #899-L with 1,374 Ci; therefore, the existing containment evaluation in Chapter 4 of the CSAR remains bounding under NCT and HAC. DOE PCP staff confirmed the applicant's results by document review.

The sphere provides confinement of the radioactive materials during transport but is not important-to-safety in order to meet the package containment performance requirements of §71.51 under NCT and HAC.

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 8-120B package shielding design. The maximum measured contact dose rates at the sphere skin are listed in Addendum Table 5-2. The maximum dose rate is from sphere #899-L at 19.04 mrem/hr. (total) based on 0.8 mrem/hr. (gamma) and 18.24 mrem/hr. (neutron). The applicant did not submit a shielding calculation of the of the package for the V3XA sphere configuration due to the low contact dose rate on each sphere and the structural evaluation and calculation in the Addendum that demonstrate that the sphere will remain intact during NCT and HAC. Given the low dose rate and the intact sphere, the applicant reasoned by the inverse square law that package dose rates under NCT and HAC will be significantly less than the regulatory does rates, without accounting for the package shielding. DOE PCP staff confirmed the applicant's results by document review and concurs that compliance with §71.47 and §71.51 is demonstrated without further analysis (i.e., shielding calculation) as the contents are adequately shielded by the V3XA sphere itself under NCT and HAC.

The sphere provides radiation shielding of the contents during transport but is not important-to-safety in order to meet the package radiation performance requirements of §71.47 and §71.51 under NCT and HAC.

5.1 Evaluation Findings

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

6.0 Criticality Evaluation

The purpose of the criticality review is to confirm that the package together with its contents meet the requirements in 10 CFR Part 71 for nuclear criticality safety (NCS). DOE PCP staff's review focused on the review and confirmatory analysis of the applicant's NCS calculation and its implementation in the Addendum.

There were no changes to the 8-120B package criticality design. Nuclear criticality safety is provided by mass and geometry control of the contents. The CSAR only evaluated the 8-120B for Type B quantities of radioactive material but not fissile radioactive material. The safety basis document to certify the package for shipment of fissile material is Supplement 1 of the CoC (*Idaho Cleanup Project Shipping Addendum for Model 8-120B Type B Shipping Package*, ATKINS/DOE 17-001, Attachment 1, Rev 1). The CoC authorizes use of the package for shipments of radioactive material, not to exceed a 2,200 fissile-gram-equivalent (FGE) of Pu-239 for Payload Types 1 and 2, and 325 FGE for Payload Types 3,4, and 6. The V3XA sphere configuration is a new fissile content.

The maximum FGE for the V3XA sphere configuration is 443 grams, with 101 grams of beryllium (Be). The applicant performed both single package as well as HAC array criticality evaluations in CALC-5193806-NS-0001, Rev. 1, to demonstrate that the package is subcritical under NCT and HAC. The results are summarized in Addendum Table 6-1.

An Upper Subcritical Limit (USL) of 0.9382 is determined Section 6.5, *Benchmark Evaluations* of the calculation and reported in Addendum Section 6.7 and which accounts for calculation bias, bias uncertainty, and additional subcritical margins.

Model Descriptions

The applicant created two reference models to evaluate NCS, one model of V3XA sphere and another model of the sphere in the center of the 8-120B package. These reference models are shown in Figures 1 and 2 of CALC-5193806-NS-0001 and duplicated in Figures 6.1 and 6.2 of the Addendum. Both reference models assumed the sphere's contents conformed on the inside of the sphere wall in a layer approximately 5 inches thick.

The applicant created three additional models of the V3XA sphere contents as a homogeneous slumped mixture, a homogeneous mixture as sphere, and a heterogeneous fissile sphere inside a homogenous mixture as sphere (i.e., concentric spheres) as shown in Figures 3 through 5 of the calculation. The model in Figure 5 shows the innermost

fissile sphere with and without a shell of Be. Based on the structural evaluation, the applicant assumes the X3VA sphere structure remains intact, and the contents are confined within the sphere in all evaluated cases for NCS.

Sphere and Single Package Evaluation under NCT and HAC

The applicant evaluated twenty content configurations of the X3VA sphere models as described in Table 9 of CALC-5193806-NS-0001 and Table 6-10 of the Addendum to identify the most reactive configuration. The applicant found Configuration 20 to be the most reactive configuration with ($k_{eff}+2\sigma$) of 0.82173. This content is represented by the Figure 5 model and consists of a fissile sphere of Pu-239 (443 g) mixed with water (3,000 g), within a Be shell (101 g), and all within and centered in a homogenous sphere of the remaining non-Pu content mass. Reactivity results are shown in Table 11 of the calculation and Table 6-12 of the Addendum.

For the NCT single package evaluations, the applicant used Configuration 20, with the X3VA sphere centered in the package cavity and suspended in air. With the package surrounded by 12 inches of water for reflection, the maximum reactivity ($k_{eff}+2\sigma$) is 0.82112 which is in the statistical variation of the V3XA sphere-only Configuration 20.

For the HAC single package evaluations, the applicant used Configuration 20, and ran seven cases of the V3XA sphere at various locations within the package cavity, with water at varying densities and without water in-leakage in the cavity, and with the package surrounded by 12 inches of full water reflection to simulate crushed limiters and maximum reflection. Maximum reactivity ($k_{eff}+2\sigma$) of 0.82287 occurs when the X3VA sphere is against the wall in the bottom of the package cavity and there is no water in-leakage in the cavity. The reactivity of this configuration is within the acceptance criteria of subcriticality. This case was also executed with additional particles (5000 neutrons per cycles for 1000 cycles) to reduce bias and statistical error, resulting in a ($k_{eff}+2\sigma$) is 0.81976.

The applicant did not run cases with additional in-leakage of water in the sphere beyond the 3 kg already present in the sphere contents. An applicant is obligated to explore cases with water in-leakage into the sphere if it leads to credible configurations with higher reactivity. Since the sphere is vented during shipment, it cannot be credited as an important-to-safety component that would prevent water in-leakage per §71.55(c); however, DOE PCP staff recognizes that the conservative assumptions used in the Figure 5 optimal configuration for reactivity results in the maximum content sphere diameter that will fit within the X3VA sphere without interference from the large port which extends into sphere cavity. Furthermore since the Figure 5 optimal configuration assumes the Pu is separated from the other contents and mixed with 3 kg of water, adding more water to the Pu-water core would change the optimized geometry leading to lower reactivity. Finally, staff recognizes that adding the small amount of U-235 (7 grams) from the depleted uranium to this configuration would contribute minimally, if at all, to the k_{eff} (i.e., fissile equivalent mass is 0.45 grams of Pu-239) and separation and concentration of U-235 from the depleted uranium is not a credible configuration.

HAC Array

Even though only one sphere will be shipped one at a time, the applicant evaluated ten cases, as shown in Table 13 of the calculation and Addendum Table 6-14, of an infinite array of packages identify the most reactive configuration and to calculate a criticality safety index (CSI). The applicant's array calculations demonstrate that an infinite array of packages with maximum credible damage from HAC with optimal moderation is shown to be subcritical in all cases; therefore, "N" is effectively equal to infinity and CSI is 0.0 (i.e., $CSI = 50/N$ where $N = \infty$). The applicant reasoned that since single package reactivity under NCT is less than the single package reactivity under HAC, an infinite NCT array would also result in an infinite value for N. Therefore, the value for N is equal for the NCT and HAC arrays and it is not necessary to model NCT arrays.

For HAC array calculations, the applicant modified the most reactive HAC case and places a mirror reflecting close fitting cuboid (i.e., rectangular parallelepiped) around the package instead of the 12 inches thick water reflector. The cuboid is sized only slightly larger than the outer package diameter and the water is modeled inside the cuboid and outside the package. This configuration results in an infinite square-pitch array in all directions with the spheres modeled in the same location in each package (i.e., at the bottom against the side wall). Array cases were run with varying water density between the packages (i.e., interstitial moderation) or the density of the sphere steel (HY-80), and one case with 105% of the Pu.

The most reactive HAC array configuration occurs with 75% water outside the package, no water in-leakage in the package, and with the sphere at the bottom against the side of the package. The maximum reactivity for this case is $(k_{eff} + 2\sigma)$ is 0.82191. This case was also executed with additional particles of 5000 neutrons per cycles for 1000 cycles to reduce the bias and statistical error, resulting in a reactivity $(k_{eff} + 2\sigma)$ of 0.81957. DOE PCP staff ran a case run with void between the package positions resulting in reactivity $(k_{eff} + 2\sigma)$ of 0.822 which is not statistically significant from the k_{eff} determined by the applicant. All configurations evaluated are below the USL and are therefore subcritical.

6.1 Evaluation Findings

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

7.0 Operating Procedures

The CSAR 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 or loading steps in the CSAR. PCP staff reviewed the operating procedures described in Chapter 7 of the CSAR and Addendum. Procedures for package loading, package unloading, preparation of empty packages for transport, and other operations were implemented in the Chapter 7 of the Addendum for the V3XA sphere configuration. The loading procedure does include specific steps for loading the package the Nevada National Security Site (NNSS).

DOE PCP staff confirmed the applicant added a step in Section 7.1.8.b. to ensure the sphere is vented prior to shipment. The safe shipping period, 119 days –beginning when the 8-120B package is closed, is not addressed in Chapter 7 of the Addendum but is addressed in Section 1.2.2.3 *Loading Restrictions*. Venting the sphere and the safe shipping period will be conditions to the Letter of Authorization.

The applicant also neglected to remove lifting eye in Section 7.1.10.3 as a prior to shipment step, so it will be added as condition to the Letter of Authorization, rather than require another revision to the Addendum. Shipment with the lifting eye in-place would invalidate the structural evaluation of the package under HAC.

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, subject to the conditions that the lifting eye is removed prior to shipment, the V3XA sphere is vented prior to loading for shipment, and that the shipping period does not exceed 119 days from the time the 8-120B is closed.

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 of the package for the V3XA sphere configuration. The components internal to the package containment for the V3XA sphere configuration are the cribbing assembly and sphere. Acceptance testing consists of a visual examination for both components per Section 8.1.1 of the Addendum and structural test (i.e., proof test) of the cribbing assembly per Section 8.1.2. There are no maintenance requirements for either component.

The Addendum requires proof testing the upper and lower cribbing assemblies at 125% of the proposed payload, to meet proof-testing requirements of ASME B30.20, *Below-the-Hook Lifting Devices*, to ensure the cribbing will function prior to its use for the

V3XA sphere configuration. DOE PCP staff confirmed the proof test requirements are incorporated on the assembly drawings.

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_0001_r6.pdf). There were no changes to the 8-120B packaging design or QA requirements so DOE PCP staff's review focused on the specific QA requirements for the V3XA sphere configuration.

The applicant defined quality categories for the V3XA Sphere and Wooden Cribbing in Section 9.3.2.2 and Table 9-2 of the Addendum relative to their importance-to-safety. The sphere is defined as a QL-1 component (critical to safe operation) because initially the sphere was assumed to be sealed and credited for containment, shielding, and criticality safety. The cribbing assembly is defined as a QL-2 component (a major impact on safety) whose safety function is dunnage.

The applicant overstates the safety function of sphere by neglecting to downgrade its importance-to-safety when the Addendum was revised based on confirmation by real-time-radiography that the sphere was not sealed. The actual safety functions of the sphere are dunnage and confinement of the radioactive material (i.e., QL-2 or QL-3 minor to safety). The applicant's safety evaluation of the structural, thermal, containment, shielding, and criticality performance of the package is consistent with QL-2; consequently, a revision is not required to correct the Addendum. The safety function of the cribbing assembly is dunnage and to protect the packaging containment system and sphere from structural damage under NCT and HAC. DOE PCP staff concurs with the QL-2 designation.

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 conditions are required in the Letter of Authorization to amend the CoC this SER.

1. In addition to the requirements of Subparts G and H of 10 CFR Part 71:
 - a. The package must be prepared for shipment and operated in accordance with the Operating Procedures of Chapter 7 of the Safety Analysis Report for Model 8-120 Shipping Package (SARP), Consolidated Revision 11, as supplemented by ATKINS/ES 20-001, Rev.1.
 - b. The packaging must be tested and maintained in accordance with acceptance tests and maintenance program described in the Acceptance Tests and Maintenance Program of Chapter 8 of the SARP, as supplemented by ATKINS/ES 20-001, Rev.1. The shipper must verify the V3XA sphere is vented prior to loading in the package.
2. The lifting eye must be removed from the sphere prior to package closure for transport.
3. Safe shipping period is 119 days – shipping period begins when the 8-120B package is closed.
4. All other conditions of the certificate 9168 Rev. 4 remain unchanged.
5. This authorization shall expire on July 31, 2024.

Conclusion

Based on the statements and representations contained in the Addendum and the conditions listed above, DOE PCP staff concludes that the package design has been adequately described and evaluated, and the Model 8-120B package continues to meet the requirements of 10 CFR Part 71, and recommends amendment of the CoC by letter of authorization by the DOE Headquarters Certifying Official (HCO).

References

- [1] *JE-899 Type V3XA Spheres Shipping Addendum for Model 8-120B Type B Shipping Package*, ATKINS/ES 20-001, Initial Issue, April 2020 (submitted April 28, 2020).
- [2] *JE-899 Type V3XA Spheres Shipping Addendum for Model 8-120B Type B Shipping Package*, ATKINS/ES 20-001, Rev.1, April 2022 (submitted May 4, 2022).
- [3] *Q1 comments from staff's review*, Shuler to Gelfond, Letter, July 27, 2020.
- [4] *Staff disposition of ES comment response*, Shuler to Gelfond, Letter, October 19, 2020.
- [5] *Acceptance of ES responses*, Shuler to Gelfond, Letter, March 24, 2022.