Safety Evaluation Report for Certificate of Compliance No. 9341 Renewal and Amendment for the Model BEA Research Reactor (BRR) Package

Docket No. 20-02-9341

Prepared by: James M. Shuler

Digitally signed by James M. Shuler
Date: 2021.06.15 17:08:43 -04'00'

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 09:34:55 -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 submitted for the DOE Idaho Operations Office (ID) for renewal and amendment of DOE Certificate of Compliance (CoC) Number 9341 for the Model BRR package design. This package is needed to support the mission of the Idaho National Laboratory (INL), Space Nuclear Power and Isotope Technologies Division.

Summary

By email [1] dated October 3, 2019, the certificate holder, ID requested an amendment of DOE CoC 9341 Rev. 0 for the Model BRR package design to authorize use of the package for shipment of Pu-238 Production Targets.

Pu-238 will be generated by irradiation of Np-237 targets at INL. Unirradiated Np-237 (NpO_2/Al) targets will be prepared at the Oak Ridge National Laboratory (ORNL) and shipped to INL in the BRR package, and the irradiated targets will be shipped back to the ORNL in the BRR package for processing.

The initial application [2] for package approval in support of the ID request was *BEA Research Reactor Package Safety Analysis Report* (SARP) , *Docket 71-9341, Revision 1 DOE*. The application was prepared for ID and INL by Orano Federal Services, LLC and submitted to DOE PCP on June 17, 2020 for review. Due to delay of the SARP Rev. 1 submittal, the scope of this docket was expanded to include renewal of the CoC and to change the certificate holder from ID to Orano.

On August 21, 2020, the DOE PCP Manager notified Orano that DOE PCP staff completed their initial independent technical review and confirmatory analysis of SARP Rev.1 and provided a list of regulatory compliance questions (Q1s) regarding the contents, structural evaluation, and thermal evaluation to Orano for response.[3]

Orano submitted responses to the Q1s, along with proposed implementation of the responses in the SARP, on November 12, 2020.[4] The Orano responses and proposed implementation were reviewed and dispositioned by DOE Packaging Certification Program staff and found acceptable, pending staff verification in the final submittal of the SARP.[5]

The final SARP (Rev 2) [6] was submitted by Orano on December 9, 2020. DOE PCP staff confirmed the proposed changes were correctly implemented.

Based on the statements and representations in the SARP, DOE PCP staff independently confirmed that the package design has been adequately described and evaluated for shipment of Pu-238 Production Targets. Therefore, staff has reasonable assurance that the regulatory requirements of Part 71 have been met and recommends renewal and amendment of the CoC by the DOE Headquarters Certifying Official (HCO).

Evaluation

This SER documents the independent technical review and confirmatory analysis by DOE PCP staff of SARP Revision 2, to the requirements of 10 CFR Part 71. All subsequent references to the SARP will be to SARP Rev. 2, unless otherwise stated.

1.0 General Information

1.1 Introduction

The safety basis for DOE CoC 9341, Revision 0 and the Nuclear Regulatory Commission (NRC) CoC 9516, Rev. 8, is *BEA Research Reactor Package Safety Analysis Report*, Docket No. 71-9341, Revision 16, August 2019 (SAR Rev. 16).

DOE CoC Rev. 0 was issued to endorse NRC CoC 9516, Rev. 8, in anticipation of subsequent amendments to the DOE CoC to authorize use of the package for shipment of DOE materials.

Orano duplicated SAR Rev. 16 and renamed the new document as *BEA Research Reactor Package Safety Analysis Report*, Docket No. 71-9341, Revision 1 DOE, June 2020 (SARP Rev. 1), and then revised it to evaluate shipments of Pu-238 Production Targets. The BRR packaging and component drawings were likewise duplicated and renamed for subsequent revisions in support of use of the BRR Package for DOE shipments.

SARP Rev. 1 was revised to implement changes from the DOE PCP independent technical review and confirmatory analysis. The final submittal and safety basis for renewal and amendment of the DOE CoC 9341 is *BEA Research Reactor Package Safety Analysis Report*, Docket No. 71-9341, Revision 2 DOE, December 2020 (SARP Rev. 2).

1.2 Package Description

There were no changes to the package design, except to address the new content configuration for Pu-238 Production Targets, also know as Plutonium Fuel Service Targets (PFS Targets).

The Model BRR Package is a Type B(U)F-96 package that is designed for transport of irradiated fuel elements or loose plates of a square fuel element from various test and research reactors.

The gross weight of the package, including the cask, impact limiters, personnel barrier, and maximum payload, is 32,000 lb. Since the package with PFS Targets contains Pu in excess of 0.74 TBq (20 Ci), the targets are in solid form to meet the requirements §71.63.

1.2.1 Packaging

The packaging is comprised of a lead-shielded package body, payload basket, square loose plate box, an upper shield plug, a closure lid, upper and lower impact limiters, and uses American Society for Testing and Materials (ASTM) Type 304 stainless steel as its primary structural material. The packaging is a right circular cylinder with a dimension of 77.1 inches in length and 38 inches in diameter, not including the impact limiter attachments and the thermal shield. Lead shielding is located between two circular shells, in the lower end structure, and in the shield plug. The payload cavity has a diameter of 16 inches and a length of 54 inches.

The thermal shield is not required for shipping PFS Targets.

The payload basket configuration required shipment of PFS Targets is the Square Fuel Basket Assembly (Drawing 3022948-A5), with the Pu-238 Target Rack (Drawing 3022948-A6). Each Target Rack can hold an array of 16 targets. The Target Rack is a lightweight, compact aluminum structure that fits into the Square Fuel Basket Assembly with nominal operational clearances. The Target Rack with is defined in SARP Table 9.1-1 - *Quality Categories for BRR Packaging Components* as Quality Category B safety component, for providing structural support of the PFS Targets.

The list and drawings of all packaging components required for shipping PFS Targets is defined in SARP, Appendix 1.3.3, *Packaging General Arrangement Drawings.*

1.2.2 Contents

There are no changes to the exiting authorized contents or their shipping configurations in the SARP. SARP Section 1.2.2.7 describes PFS Targets.

The targets are normal form solids of Np-237 oxide which are irradiated in a nuclear reactor to produce Pu-238 heat source material. Two different PFS Targets will be offered for transport: the HFIR Gen II target and the ATR target. Both targets are of similar design and are approximately 0.4 inches in diameter and consist of a stack of NpO_2 cermet pellets clad in 0.035 inch (nominal) thick aluminum (NpO_2/Al pellets). The end structures of the targets include a plenum made from aluminum or stainless steel. The HFIR Gen II target is 33.6 inches long with a pellet stack length of 19.7 inches, and the ATR target length is bounded by 33.6 inches with a bounding pellet stack length of 23 inches.

The NpO_2/Al pellet material starts as approximately 47.6 wt. % Np-237, 45.7 wt. % aluminum, and 6 wt. % of other stable isotopes, and with microgram quantities of uranium and plutonium as described in Appendix E and SARP Reference 1.3.1.3. Since the PFS Target material will be used to produce Pu-238 under an extensive irradiation and separation regime, the radionuclide distribution of both the unirradiated and irradiated targets are complex; however, the specific radionuclide distribution and activity for both the unirradiated and irradiated targets are included in Tables 6 and 7 of SARP Reference 1.3.1.3.

The PFS Target loading configuration per package requires use of six Target Racks and Spacer Bars (Drawing 3022948-A6), and one Square Fuel Basket Assembly (Drawing 3032948-A5) as shown in SARP Figure 1.2- 8a. The Target Rack is an aluminum fixture that holds an array of 16 PFS Targets per cavity position in the Square Fuel Basket Assembly. The Target Rack lateral dimensions are 2.8 inches square and a maximum overall length of 39.75 inches. The Spacer Bar is an aluminum angle shape which acts as dunnage between the Square Fuel Basket Assembly cavity wall and the Target Rack. The Spacer Bar lateral dimensions are 3.2 inches square and a maximum overall length of 39.75 inches, and it is 3/8 inch thick. The Square Fuel Basket Assembly is described in SARP Section 1.2.1.4.5 and has eight cavities for loading fuel: six outer and two inner cavities as shown in SARP Figure 1.2- 8. The cavity sizes are approximately 3.4 inches square and 40 inches in depth. For the PFS Target loading configuration, only the six outer cavities are used and may be loaded with up to six Target Racks with a maximum of 96 total PFS Targets.

Both PFS Targets (HFIR and ATR) will be irradiated at INL but may be unirradiated or irradiated when offered for shipment.

The bounding weight of a single PFS Target is 1 lb. The Target Rack and its Spacer Bar with an array of 16 targets weighs approximately 28.3 lb., so the maximum weight of the PFS Target Configuration with six loaded Target Racks (96 targets) is approximately 170 lb., which is bounded by the 384 lb. weight limit for Square Fuel Basket payloads (SARP Table 2.1-3 – *BRR Package Basket and Payload Weights*).

The maximum decay heat load for the PFS Target Configuration is 511 watts per package based on 5.32 watts per target. This configuration is bounded by the maximum package decay heat of 1,264 watts for MURR Fuel, but exceeds the 240 watts limit for Square Fuel Basket payloads (SARP Table 3.1-3 – *Summary of Permissible BRR Package Fuel Basket*). The applicant performed a thermal evaluation of the PFS Target Configuration in SARP Section 3.7 to demonstrate safe use of the Square Fuel Basket Assembly for shipment of this content.

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 NCT and HAC, is complete and meets the requirements of 10 CFR Part 71.

There were no changes to the structural performance features of the package design. The Pu-238 Target Rack is credited as a Quality Category B (Q-Cat B) item (major impact on safety) for with supporting the targets within the packaging. The PFS Target design is not credited for safety in the SARP.

Since the PFS Target Configuration is bounded by existing authorized package content payloads in terms of both weight and heat load, DOE PCP staff's structural review and evaluation focused primarily on the effect of the PFS Target Configuration on the structural response of the packaging, and secondarily the structural response of the PFS Targets and Target Racks.

The maximum gross weight of the package is 32,000 lb. with MURR fuel contents. The maximum gross package weight with the Square Fuel Basket payload configuration is 31,864 lb., with the maximum payload weight of 384 lb. (SARP Table 2.1-3). Each Pu-238 Target Rack is conservatively estimated to weigh approximately 3.5 lb. (SARP Section 3.7.3.2.) with each rack holding 16, Pu-238 Production Targets estimated at 1 lb. each (SAR Section 2.7.1.5.3). Adding the estimated weight of 8.75 lb. of the Pu-238 Target Rack Spacer bar (2.259 in^2 x 39.75 in. x .0.0975 lb./in^3) gives a total weight of 28.3 lb. per loaded rack. This weight is bounded by the weight of a PULSTAR element is 48 lb., which bounds the weight of all other fuels used in the Square Fuel Basket Assembly (SARP 2.12.8.5 *Square Fuel Basket*). Assuming six loaded positions in the Square Fuel Basket, the maximum weight of the payload for Pu-238 Production Targets is approximately 170 lb., which is less than half the bounding payload of 384 lb.

The applicant revised SARP Rev. 1, Section 2.7.1.5.3, SARP Drawing 3022948, and its supporting calculations to address DOE PCP staff's concern (Q 2-1) about the possible failure of the top cap retention threads on the Target Rack. Staff confirmed in SARP Rev. 2 that the top cap will be retained through all regulatory impact tests. Given that the PFS Targets are bounded by the package contents identified in the existing SARP, no further structural evaluation of payload's impact on the cask structure is necessary.

DOE PCP staff review determined (Q3-1) that the PFS Targets were supported in such a way that they were vulnerable to failure in an HAC side drop. Specifically, in a side drop the upper portion of the target has a large, cantilevered portion resulting in a large moment at the edge of the cantilever support. The applicant confirmed that failure of the target could not be easily discounted and submitted a revised thermal and shielding analyses in SARP Rev. 2 that assumed target failure and rearrangement of the target rods in the Square Fuel Basket.

Figure 1 below shows a simplified representation how a single target is supported, with the center rod and upper plate of the Target Rack omitted in the figure. The upper plate restricts longitudinal movement only and does not provide lateral support to the PFS

Targets. As can be seen from the figure, the cantilevered portion of the target exceeds the length of the simple supported portion of the target.

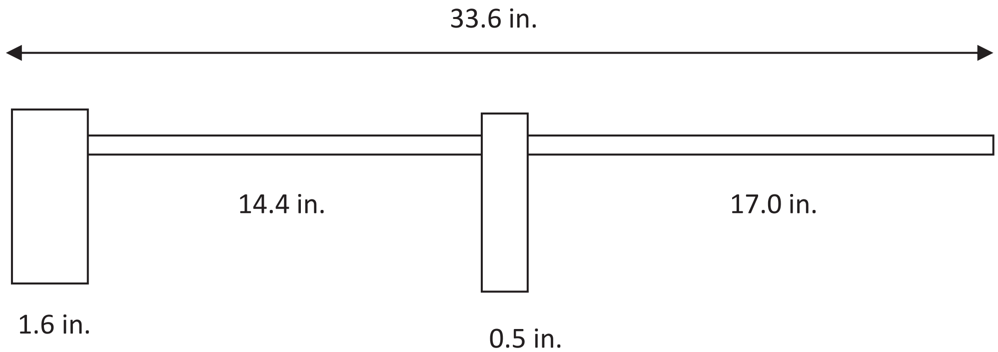

Figure 1. Simplified Representation of Pu-238 Production Target Support

Given a cantilevered free length of "a" and a distributed constant weight "w" across the entire length of the target, the moment at the cantilever edge is:

$$M_{2max} = \frac{w \cdot g \cdot a^2}{2}$$

Assuming a 120 g side loading (g = 120, w =0.0299 lb./in., a =17.25 in), the moment at the cantilever edge M_{2max} is 533.827 in-lb.

The applicant concurred that this moment was potentially sufficient to completely fracture the fuel cladding by bending at the cantilever support. To address this issue, the applicant revised SARP Rev. 1, to assume target failure and rearrangement in both the thermal and shielding analyses. The target rearrangement shown in Figure 2 below assumes the targets form a rectangular slab at the lower portion of each of the six occupied Square Fuel Basket positions. Crucially, the length of the slab is still assumed to be the original 33.6-inch length of an undamaged target. In this configuration, the applicant assumes that the individual NpO_2/Al pellets remain locked in the target debris with the same axial distribution. The applicant bases this assertion on the hydrostatic compression of 30,000 psi during fabrication as well as experience with removal of fuel pellets from irradiated targets (SARP Reference Section 1.3.1.4, *Irradiation Testing of NpO_2-Al Cermet Pellet Targets in Support of Pu-238 Production at the High Flux Isotope Reactor*, ORNL/TM-2017/9).

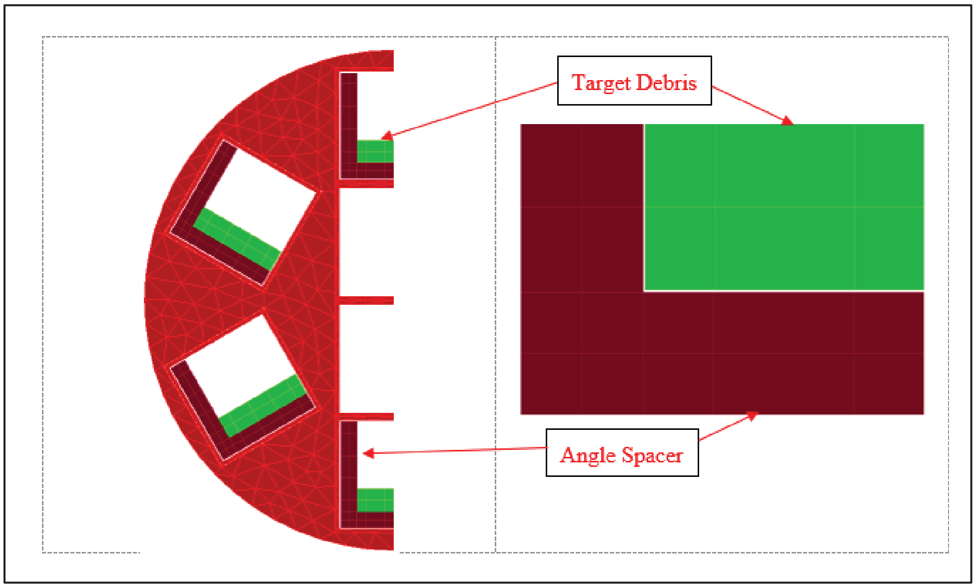

Figure 2. Pu-238 Target Reconfiguration in Square Fuel Basket

Although the applicant could not provide test data for the bending failure of PFS Targets, DOE PCP staff noted in the side drop scenario that the moment calculated above (M_{2max}) only applies until deflection of the target is stopped by the walls of the Square Fuel Basket cavity or support from another target. Staff investigated the deflection of a single PFS Target in a side drop scenario by applying an instantaneous distributed inertial load of 120 g using ABAQUS explicit finite element (FE) analysis. Staff assumed for the FE Model, that the PFS Target cladding is manufactured from 6061-T4 aluminum (ORNL/TM-2017/9) and filled with NpO_2/Al pellets along the entire target length.

ORNL/TM-2017/9 indicates that the aluminum cladding would experience radiation induced embrittlement from the Np that reduces fracture strain from 19% to 12%. Because the material properties of irradiation embrittled 6061-T4 aluminum are considered unknown, DOE PCP staff considered two model cases of 6061-T4 aluminum without (Case 1) and with (Case 2) radiation induced embrittlement. Case 2 simulated the embrittled material by including the 12% fracture strain and arbitrarily increasing the yield strength to 221 MPa, to increase the elastic region of the stress-strain curve and decrease the plastic region, as is typical in embrittle materials. The material properties for both cases are given in Table 1, below. The cladding was modeled as a bilinear material to capture plastic deformation during impact. The model has the capability of detecting material damage if it is strained past its ultimate tensile strength.

Table 1. Estimated Mechanical Properties of Cladding Material

Case	Density (kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Fracture Strain (%)
1	2700	68.9	0.33	145	241	19
2	2700	68.9	0.33	221	241	12

The NpO_2/Al cermet pellets in the model were assumed to run the length of the PFS Target. The pellets do not lend strength to the PFS Target in tension, and can be reasonably approximated in FE simulations using a foam material plasticity model, which is much weaker in tension than compression. The exact mechanical properties of the cermet were not known, so the pellet material properties were assumed to be similar to the aluminum cladding. Due to the weakness of the cermet in tension, its specific mechanical properties were expected to be inconsequential. A simple check varying the Young's modulus from 50 to 150% of the 6061-T4 aluminum for the cermet foam material showed it had a negligible effect on the stress in the cladding; therefore, these material properties assumed by the applicant are acceptable to DOE PCP staff. The distributed weight of the target used in staff's analysis is approximated by dividing bounding target weight of 1 lb. by the target overall length of 33.6 inches.

DOE PCP staff results of the side drop FE analysis, assuming deceleration of 120g at the time frame of maximum deflection, are shown in Figure 3, below. The FE embrittled model predicted a maximum stress in the cladding of 234 MPa. This value is above the assumed 221 MPa yield strength, but below the typical 6061-T4 ultimate tensile strength of 241 MPa where damage and crack initiation will occur. The stress at the PFS Target tip was lower. The maximum plastic equivalent strain in the target, of approximately 5%, was well below the failure plastic equivalent strain of 12%. This case bounded the ductile case.

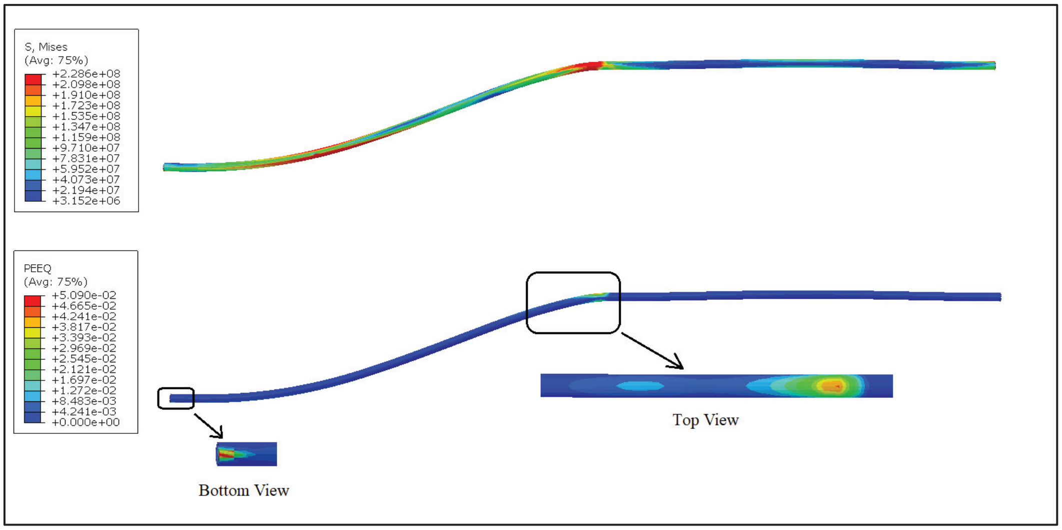

Figure 3. Staff Estimate of Target Stress and Strain in 120g Side Drop

While these results, which were obtained with unconfirmed material properties, do not prove that the PFS Targets will not fracture, they do provide reasonable assurance to the applicant's position that the NpO_2/Al pellets are unlikely to separate from the cladding and consolidate in a manner that would significantly affect the revised thermal and shielding analyses detailed in SARP Sections 3.7.4.3.3 and 5.7.4.5.

Furthermore, when evaluating the axial consolidation scenario, DOE PCP staff noted that there are large margins between the peak closure/vent port seal temperatures and the allowable temperature limit of 265°F vs 400°F limit in SARP Table 3.7-5. Dose rates at the cask side walls are also very low so that axial consolidation of severed target halves is unlikely to exceed the allowable dose rates. Although the drain port seal temperature has the lowest margin to failure, 342°F vs 400°F limit in SARP Table 3.7-5, there is insufficient clearance for a severed upper target to slide past the mid plate into the lower portion of the package. This scenario is addressed in Section 3 of this SER.

In SARP Section 3.7.4.3.3, the applicant postulated that a bending failure of the PFS Target could occur under NCT or HAC from the free-drop test with the package in a side-drop (horizonal) orientation. DOE PCP staff did not analyze PFS Target response under the NCT side drop orientation, because the stresses and strains to the targets under NCT are unlikely to cause the release of fuel pellets, since it occurs at much lower stresses and strains than under HAC.

2.1 Evaluation Findings

A design change to the Pu-238 Target Rack would provide greater lateral support of the PFS Targets and increase the margin-to-failure in a package side drop orientation; however, 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 1264 Watts for the package thermal design. This limit is based on Irradiated MURR Fuel Elements and remains the bounding loading configuration for the SARP structural, thermal, and containment evaluations.

A summary of the maximum component temperatures and pressures for the PFS Target Configuration under NCT and HAC are shown SARP Tables 3.7-1 – *Maximum Temperatures (°F) for NCT and HAC when Transporting Pu-238 Production Targets* and Table 3.7-2 – *Summary of Maximum Pressures when Transporting Pu-238 Production Targets*.
Although the maximum heat load of the PFS Target Configuration is 511 watts, it exceeds the maximum decay heat limit of 240 watts in the SARP and CoC for fuel loaded in the Square Fuel Basket and limit of 30 watts per basket cavity (based on PULSTAR Fuel.) The structural design of the basket was previously evaluated at 400°F in SARP Section 2.12.8.5 under NCT and HAC, based on the SARP Table 2.12.8-1 – *Material Properties and Allowable Stress*. The PFS Target Configuration is 511 watts with 85 watts per basket cavity (5.32 watts/element x 16 elements/cavity = 85 watts/cavity); therefore, the applicant provided a new thermal evaluation in SARP Section 3.7 for the PFS Target Configuration to demonstrate this configuration is bounded by the previous evaluation of the thermal design.

DOE PCP staff's review focused on the new thermal evaluation of the package in SARP Section 3.7 for the PFS Target Configuration, the effects of PFS Target failure on the package thermal design, and a review of gas generation of the PFS Target material.

3.1 Normal Conditions of Transport (NCT)

The maximum calculated temperatures of the packaging components under NCT with a decay heat load of 511 watts, for the PFS Target Configuration, and their allowable temperature limits are shown in SARP Table 3.7-4 – *NCT Temperatures (°F) for BRR Packaging with Pu-238 Production Target Payload*. Staff confirmed by document review that all the calculated maximum component temperatures are within their allowable material limits and are also bounded by the maximum component temperatures in SARP Table 3.1-1 – *Maximum Temperatures for NCT and HAC Conditions when Transporting Irradiated Fuel*.

3.2 MNOP and Gas Generation

Pressure within the package cavity is caused by thermal expansion of air, helium fill-gas, and the decay-heat generated gases. The package design pressure and maximum normal operating pressure (MNOP) are summarized in SARP Section 3.1.4. The package design pressure is 25 psig (39.7 psia) and the MNOP is 15 psig (29.7 psia). For all other previous contents, the contribution to pressure from the release of fission gases is negligible under NCT.

The applicant evaluated the MNOP for the PFS Target Configuration in SARP Section 3.7.3.2. Since these targets have unique fission gas production characteristics and the package has a low MNOP, DOE PCP staff requested (Q3-4) the applicant to calculate the bounding gas source term and resulting pressure. The applicant's subsequent calculations in SARP Section 3.7.3.2 assumed fission product gasses (Xe and Kr) and helium generated from the alpha decay of Pu-238 were available for release in the package cavity and were not bound in the pellet matrix. Staff concurred that the applicant's assumption is conservative, in that some gasses would be bound in the pellet matrix. The quantity of fission product gas was estimated at the minimum decay time of 180 days and assumed to remain constant thereafter, while the helium quantity was based on ten years of alpha decay, which bounds any reasonable storage period of the targets. The resulting calculated MNOP for the PFS Target Configuration under NCT is 4.1 psig (18.8 psia), which is well below the package design pressure of 25 psig and the MNOP of 15 psig (29.7 psia).

The PFS Target Configuration does not include packing materials (e.g., plastics) that would decompose and generate hydrogen or other flammable gases within the package cavity. The package is drained and vacuum dried prior backfilling the package cavity with helium gas. There are no chemical or galvanic reactions or other reactions between the materials of the package and packaging (see SARP Section 2.2.2).

DOE PCP staff confirmed by document review that the applicant's pressure calculations in SARP Section 3.7.3.2 for the PFS Target Configuration are accurate and all calculated pressure results are bounded by the package design pressure and MNOP in the SARP for previously authorized content configurations. Staff also confirmed by document review that no flammable gas mixture will form within the cask cavity during transport.

3.3 HAC

The PFS Target Configuration used in the applicant's thermal evaluation under HAC are the same as those used for NCT. The applicant assumed the PFS Targets, Target Racks, and Square Fuel Basket Assembly are modeled as intact, without significant re-positioning in the package as a result of the free-drop test. The applicant subsequently addressed the consequences of a structural failure of targets in SARP Section 3.7.4.3.3, in response to a question (Q3-2) from DOE PCP staff.

The initial conditions of the package prior to the HAC thermal test are listed in SARP Section 3.4.1.

The calculated HAC peak temperatures of the package components for the intact PFS Target Configuration are shown in SARP Table 3.7-5 – *HAC Temperatures (°F) for BRR Packaging with Pu-238*, and in SARP Table 3.7-6: *HAC Temperatures (°F) for Failed Targets Case* for damaged targets. The results in these tables demonstrate that the PFS Targets and all packaging components are below their allowable temperature limits for either the undamaged or damaged case.

As noted in SER Section 2.0, the applicant considered the potential that bending failure of the target may occur during NCT, and rather than revise the NCT thermal evaluation to account for target failure, addressed it by demonstrating the HAC thermal evaluation of post transient steady state component temperatures (with insolation) are bounding for NCT. The steady-state peak temperatures listed in SARP Table 3.7-5 for most packaging components are within 3°F of their peak temperatures for the failed target case in SARP Table 3.7-6, which are a reasonable approximation of the component temperatures under NCT with failed targets. The only exceptions were the temperatures of the PFS Targets and the Square Fuel Basket. For these components the peak temperatures with target failure were 17°F (targets) and 16°F (basket) higher than without target failure, but still within their maximum allowable temperature limits listed in SARP Tables 3.7-1.

DOE PCP staff confirmed by document review that all the calculated maximum component temperatures under HAC for both the intact and failed target cases are within their allowable material limits and are also bounded by the maximum component temperatures in SARP Table 3.1-1.

3.4 Maximum Pressure

For irradiated fuel payloads under HAC, including a small contribution from the release of fission gases in the PULSTAR fuel, the maximum package pressure is 11.7 psig (26.4 psia) and is summarized in SARP Section 3.1.4 and Table 3.1-2. Under HAC, including the gas contribution from the potential release of water vapor from five (5) older design aluminum targets, the maximum package pressure is 17.6 psig (32.3 psia) as determined in SARP Section 3.6.4.3.2, *Maximum HAC Pressures* and Table 3.6-2 – *Summary of Maximum Pressures when Transporting Isotope Production Targets*.

The maximum HAC pressure for the PFS Target Configuration, accounting for gas generation from SARP Section 3.7.4.3.2, is 8.3 psig (23 psia) which is bounded by the existing maximum HAC pressure of 17.6 psig (32.3 psia) in SARP Section 3.6.4.3.2. Although the applicant did not recalculate the package cavity gas bulk average temperature for the failed target case in SARP Table 3.7-6 using the increased target temperature from 336°F to 353°F, a 5% rise in temperature will not increase pressure beyond 17.6 psig.

DOE PCP staff confirmed by document review that the maximum pressure in the package cavity under HAC for both the intact and failed target cases are bounded by the maximum pressure for previously approved contents in SARP Table 3.6-2 and package design pressure of 25 psig (39.7 psia) in SARP Section 3.1.4.

3.6 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 to the containment performance features of the package design for shipment of PFS Targets. The package containment boundary is designated and evaluated as Category I with respect to fracture toughness criteria and test methods for Type B packaging with contents greater than 3,000 A_1 or A_2.

The package containment boundary is "leaktight" in accordance ANSI N14.5, Section 2.1, *Definitions* (ANSI N14.5–2014, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*).

The results of the NCT and HAC structural and thermal evaluations in SARP Sections 2.6, 3.3, 2.7, and 3.4 respectively, demonstrate that the package containment meets the requirements for Type B packages in accordance with §71.51(a)(1) and (2).

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 shielding performance features of the package design to use the package for shipment of PFS Targets. The applicant added SARP Section 5.7 to evaluate the PFS Target Configuration.

DOE PCP staff review and evaluation focused on the applicant's shielding evaluation of the PFS Target Configuration.

5.1 Shielding Design

A detailed description of the package shielding design is provided in SARP Section 5.1.1. Irradiated fuel is positioned within one of five custom-designed fuel baskets. The safety function of the baskets is to maintain their geometry under NCT and HAC, as demonstrated in SARP Section 2.7.1.5, *Fuel Basket Stress Analysis*, thereby maintaining the a fixed location of the source. The PFS Targets Configuration consists of 96 intact targets, in six Target Racks , which are located in the outer cavity positions in the Square Fuel Basket Assembly. SARP Section 5.7.4.5, *Dose Rates with Failed Targets* was added, based on a comment from DOE PCP staff (Q3-2) to evaluate failed targets.

5.2 Source Specification

The applicant's modeling of the PFS Target source term is performed using unit quantities of target material and maximum target flux. A 180-day minimum cooling time was selected. Isotope activities (per inch of NpO_2/Al pellet) are converted into gamma and neutron source terms using the ORIGEN module of the SCALE 6.2.1 code package with ENDF/B-VII.1 decay data. The per-inch source strengths are multiplied to calculated payload source strengths (23.0 inches of pellets per target, 96 targets in payload).

Unirradiated PFS Targets were not evaluated because their dose rates are bounded by irradiated targets.

The gamma source spectrum is shown in SARP Table 5.7-2. An ENDF/B-VII.1 19-group energy distribution is used. The source term includes modeling of Bremsstrahlung but does not include secondary gamma radiation, which is instead modeled within MCNP (Monte Carlo N-Particle code). The total payload source strength is 1.1734×10^{15} gammas/sec.

The neutron source spectrum is shown in SARP Table 5.7-3. An ENDF/B-VII.1 28-group energy distribution is used. Neutrons from subcritical multiplication are not accounted for due to the low reactivity of the payload (see SARP Section 6.10, *Fissile Material Assessment of Pu-238 Production Targets*). The total payload source strength is 1.6486×10^{6} neutrons/sec.

Due to the low dose rates of the PFS Targets, DOE PCP staff performed a document review of the source specification instead of a confirmatory analysis.

5.3 Shielding Model

The applicant used MCNP to model the PFS Target Configuration for their shielding evaluation. The model is described in SARP Section 5.7.3, and is based on their previous shielding model of the package and Square Fuel Basket used to analyze other package payloads. The applicant omitted the aluminum from the PFS Target and Target Rack from the MCNP model and replaced the aluminum thicknesses with air or void. The key dimensions relevant to the PFS Targets and Target Racks are shown in SARP Table 5.7-6.

For the PFS Target Configuration analysis, the applicant reduced the package steel inner shell wall thickness is from 1 inch to 0.94 inches to model the minimum thickness allowed by the fabrication tolerance. The PFS Target Configuration is modeled in the maximum load configuration of 16 targets in each of the outer six square tube cavity positions of the Square Fuel Basket Assembly. The target source regions, corresponding to the locations of the NpO_2/Al pellet stacks, are modeled as void space as shown in SARP Figure 5.7-2. The source regions are oriented so that the package side dose rate is maximized at a single location as shown in SARP Figure 5.7-3.

DOE PCP staff confirmed by document review that the applicant's model of the PFS Target Configuration is consistent with the applicable drawing dimensions, source configuration and location, shielding, and material properties to perform the shielding evaluation.

5.4 Shielding Results

The package is shipped vertically-oriented under exclusive use requirements using an open (flatbed) transport vehicle. Although the package offered for shipment meets the radiation and transport index requirements of §71.47(a), the basis for exclusive use shipment of the package is "sole use" as defined in §71.4, and not radiation protection.

DOE PCP staff reviewed the applicant's package dose rates for NCT and HAC (for intact targets), summarized in SARP Table 5.7-1, and its supporting computer analysis. Based on the applicant's results, the radiation level does not exceed 2 mSv/h (200 mrem/h) at any point on the external surface of the package, and even under HAC the transport index does not exceed 10.

The applicant 's maximum calculated dose rates under NCT are: 8.4 mrem/hr. at the package surface; 2.0 mrem/hr. at the vehicle surface; 0.2 mrem/hr. at 2 meters from the vehicle surface; and 0.03 mrem/hr. in the normally occupied space in the transport vehicle. These dose rates are well within the limits of §71.47(b). The maximum calculated dose rate under HAC, at 1 meter from the package surface is 1.1 mrem/hr., which is well within the limit of §71.51(a)(2).

SARP Section 5.7.4.5 *Dose Rates with Failed Targets*, was added in response to a comment (Q3-2) from DOE PCP staff. The applicant reran the shielding model with the PFS Targets separated from the Target Rack and collected in a bundle on one side of its cavity position in the Square Fuel Basket Assembly. The shielding evaluation of the failed target configuration assumes that the source remains axially distributed in the fuel debris in the same manner as intact targets. DOE PCP staff accepts this assumption based on the staff's fracture analysis Section 2.0 of this SER. The applicant modeled each bundle of 16 PFS Targets as a rectangular block, for simplicity. This model change concentrates and moves the radioactive material slightly closer to the package surface. SARP Table 5.7-11 lists and compares the maximum does rate under NCT and HAC for intact and failed targets at the same tally locations. The largest NCT dose rate increase from failed targets was 2.9%, from 8.44 mrem/hr. to 8.69 mrem/hr., at the side surface of the package. DOE PCP staff confirmed that dose rates for the PFS Target Configuration with intact or failed targets, are well below the maximum package dose rates for irradiated fuels as detailed in SARP Table 5.1-1 and meet the external radiation requirements of §§71.47(b) and 71.51(a)(2).

5.5 Evaluation Findings

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

The applicant demonstrated in SARP Section 6.10 *Fissile Material Assessment of Pu-238 Production Targets* and SARP Table 6.10-1 – *Isotope Masses for Pu-238 Production Target Fissile Material Assessment*, that the PFS Target Configuration, with unirradiated or irradiated targets, is exempt from classification as fissile material and the fissile material package standards in accordance with §71.15(b) or (f).

The unirradiated PFS Target Configuration has approximately 0.05 grams of fissile material and the package has at least 200 grams of solid nonfissile material (see SARP Table 2.1-2, excluding lead) for every gram of fissile material; therefore, this configuration meets §71.15(a).

The irradiated PFS Target Configuration has 697 grams of Pu, and the Pu fissile mass percent of 9.1% (63.6 grams) in the Pu; therefore, this configuration meets §71.15(f).

The applicant demonstrated that these shipping configurations are exempted from being classified as fissile material per §71.15(a) or (f) respectively and no criticality evaluation for these configurations is required.

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 of the package. SARP Section 7.1.2 was revised to add wet (SARP Section 7.1.2.1) and dry (SARP Section 7.1.2.2) loading steps for the PFS Target Configuration. DOE PCP staff verified that the loading configurations described in SARP Section 7.1.2 are consistent with the configurations evaluated in the SARP, that is, an array of 16 targets per Target Rack, six Target Racks per Square Fuel Basket Assembly and loaded in the six outer cavity positions in the Square Fuel Basket Assembly with Target Spacers used as dunnage and the two inner cavity positions left empty.

SARP Section 7.1.4, Step 17 was added to clarify labeling requirements for use of the package under the DOE or NRC certificate. The letters "DOE" must be added the package nameplate so that the package identification number is USA/9341/B(U)F-96 DOE when used under the DOE certificate, and must be removed or covered when the package is used under the NRC certificate (i.e., package ID# is USA/9341/B(U)F-96).

SARP Section 7.2.2 was revised to add the Targets Racks for wet (SARP Section 7.2.2.1) and dry (SARP Section 7.2.2.2) unloading steps.

SARP Section 7.3 was revised to clarify that "A leakage rate test is not required for empty shipments." DOE PCP staff agrees that a leak test is not required as long as the transport of the empty packaging complies with §173.428 *Empty Class 7 (radioactive) materials packaging*.

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 to the acceptance test and maintenance program described in the SARP for the primary packaging components. The only new component for the PFS Target Configuration is the Pu-238 Target Rack, which is listed and classified in SARP Table 9.1-1 as major impact on safety (Q-Category B component). The safety function of the Target Rack and its Space Bar is to support the targets in the Square Fuel Basket Assembly.

The Pu-238 Target Rack and Spacer Bar were added to Drawing 3022948 (A6). The acceptance criteria for the Target Rack consists of the visual and dimensional inspections, and material verification per the drawing.

SARP Section 8.1.2 *Weld Examinations*, was revised to add inspection and examination requirements for the Target Rack: AWS D1.2 for aluminum and ASME Code, Subsection NF, Article NF-5000, and Section V, Article 6, consistent with the drawing and requirements for other cask body welds and for the impact limiter shells and isotope basket. The applicant also added Reference 18, ANSI/AWS D1.2/D1.2M:2014, *Structural Welding Code–Aluminum*, American Welding Society (AWS) to the list of references in SARP Section 8.3.1.

There are no periodic maintenance or test requirements for the Target Rack and Spacer Bar.

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 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). SARP Section 9.0 *QUALITY ASSURANCE* clearly defines the organizational roles and responsibilities related to the package design, procurement, preparation of the SARP, and use of the package for shipment of the PFS Target Configuration. DOE PCP staff confirmed the roles and responsibilities are consistent with DOE Order 460.1D, *Hazardous Materials Packaging and Transportation Safety* and 10 CFR 71 Subpart H.

The addition of the PFS Target Configuration as authorized package contents does not affect the existing QA Program of the packaging or Quality Levels for the primary packaging components. The new packaging component for the PFS Target Configuration is the Pu-238 Target Rack which is classified as Quality Level B (Q-Cat B), as shown in SARP Table 9.1-1 *Quality Categories for BRR Packaging Components*. The QA level of effort for all packaging components is listed in SARP Table 9.1-2 - *Level of Quality Assurance Effort per QA Element*. DOE PCP staff reviewed Tables 9.1-1 and 9.1-2 for the function, failure effect and quality level, and QA level of effort for the Target Rack and found them appropriate and acceptable. The primary safety function of the Target Rack is “support targets” within the Square Fuel Basket Assembly. The Target Rack minimizes fracture failure damage to the targets under NCT and HAC. Complete fracture failure of targets would release NpO_2/Al pellets and may concentrate the pellets in the Square Fuel Basket Assembly to produce higher dose rates from the package. DOE PCP staff finds the shielding model assumptions consistent with the applicant’s Q-Cat B classification of the Target Rack.

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 SARP Revision 2 for the PFS Target Configuration evaluated in this SER and renewal of the CoC.

- Title and identification of report or application, 3.(2) and 3.(3): (2) Safety Analysis Report , BEA Research Reactor Package Safety Analysis Report, Docket No. 71-9341, Revision 2 DOE; (3) December 2020.
- Drawings 5(a)(3) replaced:

  The packaging is constructed in accordance with Orano Federal Services, LLC drawings:

Drawing Number	Revision	Title
3022946	0	BRR Package Assembly SARP Drawing, Sheets 1-5
3022947	0	BRR Package Impact Limiter SARP Drawing, Sheets 1-2
3022948	1	BRR Package Fuel Baskets SARP Drawing, Sheets 1-5
3022949	0	BRR Package Isotope Target Basket SARP Drawing, Sheets 1-2

- Contents 5(b)(1)(viii): Added description and Table 1.10

  Pu-238 Production Targets. Pu-238 production targets contain Np-237 which is irradiated in a nuclear reactor to produce Pu-238 heat source material. Two different targets will be transported: the HFIR Gen II target (a.k.a., HFIR) and the ATR target. Both targets are of similar design and both will be irradiated in the ATR located at the Idaho National Laboratory. Both unirradiated or irradiated targets can be shipped. The Both targets are approximately 0.4 inch in diameter and consist of a stack of NpO_2 cermet pellets clad in aluminum. The end structures include a plenum and may be made from aluminum or stainless steel. The HFIR target is 33.6 inches long with a pellet stack length of 19.7 inches, and the ATR target length is bounded by 33.6 inches with a bounding pellet stack length of 23 inches. Up to 16 targets can be placed into each target rack, and up to six target racks can be placed into the outer tubes of the square fuel basket (Drawing 3022948, Assembly A5) for a maximum payload quantity of 96 targets. When transporting Pu-238 targets, the center two square holes are not used. The personnel barrier does not need to be used with Pu-238 production targets.

  Table 1.10 below assumes full complement of 96 targets and maximum pellet stack length of 23.0 inches. The isotopic distribution and activity limits for unirradiated targets is Appendix E of SARP Section 1.3.1 Reference 3 and for irradiated targets Table 6 of SARP Section 1.3.1 Reference 3.

Table 1.10 Characteristics of Pu-238 Production Targets

Item	Characteristic/Limit
Unirradiated targets	3.5 kg (max) of Np-237
Irradiated targets (cooling and activity)	180 days (min) cooling prior to shipment and 50,122 Ci (max per package)
Irradiated targets (fissile mass)	64 g (max per package)
Irradiated targets (decay heat)	5.32 W (max target, 511 W per package)
Pellet cermet composition	65% aluminum (min), 10% void (approximately), and the balance NpO_2
Nominal Cladding thickness	Wall thickness is 0.035 inches (minimum between ribs)

- Contents 5(b)(2), Maximum Quantity of Material per Package revised:
  - Renumbered Table 1.10 to 1.11
  - Added limits for Pu-238 Production Targets to Table 1.11
  - Clarified the Pu limit of 6,500 Ci applies to all other fuel

Table 1.11 Radioactive Material Package Limits

Content Type & Form	Item	Package Limit	Loading Condition
Pu-238 Production Targets	Irradiated or unirradiated targets	96	Up to 16 targets can be placed into each target rack, and up to six target racks can be placed into the outer tubes of the square fuel basket, except the center two square holes are not used
Pu-238 Production Targets	Plutonium (Ci)	11,010	Package limit is based on SARP Table 6.10-1
All (others)	Plutonium (Ci)	6,500	Package limit is based on 4% ^{235}U enrichment of PULSTAR fuel

Conclusion

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

References

[1] *New Docket Request for BRR Cask*, Email Carl Friesen to Shuler, October 3, 2019.

[2] *Safety Analysis Report, BEA Research Reactor Package Safety Analysis Report,* Docket No. 71-9341, Revision 1 DOE; June 2020.

[3] Docket 21-02-9341, Q1 Comments from DOE PCP Staff's Review, Letter with attachment, Shuler to Noss, August 21, 2020.

[4] *Responses to DOE PCP on PFS SARP, ref. docket 20-02-9341*, Email with attachments, Noss to Shuler, November 12, 2020.

[5] Docket 20-02-9241 Technical Review Complete, Letter, Shuler to Noss, December 3, 2020.

[6] *Safety Analysis Report, BEA Research Reactor Package Safety Analysis Report,* Docket No. 71-9341, Revision 2 DOE; December 2020.