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DOE Packaging Certification Program

Safety Evaluation Report of NA-23 Request to Authorize Two Fast Burst Reactor Safety Blocks for Shipment in an ES-3100 Packaging

Docket No. 18-20-9315

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Summary

By letter [1] dated December 20, 2017, as supplemented [2] February 27, 2018, the National Nuclear Security Administration (NNSA) Office of Material Management and Minimization (NA-23) requested the U.S. Department of Energy (DOE) Packaging Certification Program (PCP) to amend DOE CoC Number 9315 to authorize use of a Model ES-3100 packaging for shipment of two Fast Burst Reactor (FBR) Safety Blocks. This request to amend the CoC is for shipment by ground transport and is not a permanent change to the CoC; therefore, a Letter of Authorization (a.k.a., Letter Amendment) will be issued by the DOE Headquarters Certifying Official (HCO) to amend the CoC based on this Safety Evaluation Report (SER).

The FBR Safety Block, hereinafter referred to as "Safety Block," is a single piece of highly enriched uranium (HEU) in the form of uranium/molybdenum (U-Mo) alloy. The Safety Block is defined as *Safety Block No 2* in the White Sand Missile Range Drawing #1023 [3] and fabricated in accordance with *FBRU Final Safety Block Machining*, Y-12 Drawing DD-T802365-0006. The Safety Block shape is an annular cylinder with approximate dimensions of 5.74 inches in length, outer diameter of 3.85 inches, and inner diameter of 1.40 inches.

The mass limits for the Safety Block and package evaluated in this SER are: total mass 16.31 kg each and 32.62 kg per package; maximum fissile mass is 13.88 kg of U-235 each and 27.76 kg per package based on an enrichment of 93.5 percent (%). The Criticality Safety Index (CSI) is 0.0.

A single Safety Block (13.88 kg U-235) meets the CoC Table 1.3 content description for "Broken HEU metal or alloy" with enrichments greater than 90 % and less than or equal to 95 %, but a package configuration of two Safety Blocks and the required 277-4 Heavy Can Spacers for nuclear criticality safety control would exceed Condition 5(d)(3) of the CoC: "the quantity of fissile materials located in any vacancy between or adjacent to can spacers shall not exceed one-third of the mass loading limit in Table 1.3." Therefore, an amendment to the CoC is necessary to authorize the Safety Block content configuration (i.e., two Safety Blocks per package).

There are no changes to the packaging design or operations for the Safety Block content configuration, but to demonstrate compliance with 10 CFR Part 71, *Packaging and Transportation of Radioactive Material*, the applicant performed a supplemental nuclear criticality safety evaluation (NCSE) [4] of the ES-3100 package configured with two Safety Blocks, a maximum of 500 grams of polyethylene, and approved neutron absorber and can spacer materials. PCP staff performed an independent technical review and confirmatory analysis of application to verify that the applicant's maximum $k_{eff} \pm 2\sigma$ of 0.849 is adequately below the upper subcritical limit (USL) of 0.925 calculated for the package in the Safety Analysis Report for Packaging (SARP) [5], and to verify the applicant's CSI of 0.0 for the proposed content configuration.

Based on the statements and representations in the application, as supplemented, the SARP, PCP staff's confirmatory evaluation, and the conditions listed in this SER, staff finds that the NA-23

request to authorize use of the packaging acceptable for shipment of the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

Evaluation

1.0 General Information

The application submitted by NA-23 to DOE PCP in support of this request consists of the letter dated December 20, 2017, a supplemental NCSE to the ES-3100 Safety Analysis Report for Packaging (SARP), and White Sands' drawing of the Safety Block. The application was supplemented February 27, 2018 with the Y-12's fabrication drawing. This new shipping configuration for two Safety Blocks does not affect the safety features of the packaging design or operational features.

A single Safety Block (13.88 kg U-235) meets the CoC Table 1.3 content description for "Broken HEU metal or alloy" with enrichments greater than 90 % and less than or equal to 95 %, but a package configuration of two Safety Blocks and the required 277-4 Heavy Can Spacers for nuclear criticality safety control would exceed Condition 5(d)(3) of the CoC: "the quantity of fissile materials located in any vacancy between or adjacent to can spacers shall not exceed one-third of the mass loading limit in Table 1.3." Therefore, an amendment to the CoC is necessary to authorize the Safety Block content configuration (i.e., two Safety Blocks per package).

1.1 Packaging Description

Detailed packaging descriptions, drawings, and content packing materials can be found in the SARP. The components of the packaging include a drum enhanced by impact-limiting and thermal-insulating materials, neutron-absorbing materials, and a containment vessel (CV) inside the drum.

The Safety Blocks are prepared for loading in the CV with packing materials evaluated in the SARP. Prior to loading in the CV, each Safety Block will be placed in a polyethylene bag and then carbon steel caps will be placed over each end of the Safety Block which may then be secured to the bag with metal tape, as necessary. This configuration is limited to a maximum of 500 grams of polyethylene to comply with Conditions 5(d)(7) and 5(d)(9) of the CoC.

The Spacer Blocks and packing materials will be loaded in the CV in the following order and arrangement as shown in Figure 3 of the NCSE and is defined in this SER as the Safety Block content configuration:

1. Safety Block in the bottom of the CV,
2. 277-4 Heavy Can Spacer Assembly (CoC Drawing M2E801580A043),
3. an empty convenience can, 10-inches in length and with minimum vent hole size of 0.125-inch diameter hole through the can lid per CoC Condition 5(d)(8),
4. Safety Block,

5. 277-4 Heavy Can Spacer Assembly, and
6. the remaining void space, approximately 4-inches, near the top of the CV will be filled with stainless steel scrubbers per CoC Condition 5(d)(8).

1.2 Contents

The Safety Block is a single piece of highly enriched uranium (HEU) in the form of uranium/molybdenum (Material $U_{10}Mo$) alloy less than or equal to 90 weight % uranium and U-235 enrichment less than or equal to 93.15%. The calculated mass of a Safety Block is 16.21 kg. The Safety Block shape is an annular cylinder with approximate dimensions of 5.74 inches in length, outer diameter of 3.85 inches, and inner diameter of 1.40 inches. The entire Safety Block is plated with aluminum to a thickness of approximately 0.01 inch. The Safety Block design was evaluated in the NCSE based on *Safety Block No 2* (Drawing #1023), but fabricated in accordance with *FBRU Final Safety Block Machining* (Drawing DD-T802365-0006). The overall dimensions from the drawings and NCSE model for an aluminum-plated Safety Block are listed below.

Aluminum Plated Safety Block - Overall Finished Dimensions			
Reference	**Length (inches)**	**Outer diameter (inches)**	**Inner diameter (inches)**
Drawing # 1023	5.750 ± .001	3.850 ± .001	1.400 +.001/-.000
Drawing DD-T802365-0006	5.738 ± .002	3.850 ± .002	1.4005 ± .0020
NCSE Model, Section 4.1	5.751	3.851	1.4

The applicant rounded up the calculated mass of the Safety Block, uranium/molybdenum alloy ratio, and U-235 enrichment for conservatism in the supplemental NCSE as follows: maximum mass of the Safety Block not to exceed 16.31 kg, alloy ratio not to exceed 91 % uranium, and U-235 enrichment not to exceed 93.5%. The resulting maximum fissile content mass limits are based on U-235 enrichment of 93.5%: 13.88 kg of U-235 per Safety Block and 27.76 kg of U-235 per package.

This content configuration is limited to 500 grams of polyethylene per package and must comply with CoC Conditions 5(d)(7) and 5(d)(9).

The maximum content mass content for two Safety Blocks is 32.62 kg, which is less than the CoC limit (for radioactive contents) of 35.2 kg. The total mass of two Safety Blocks and all packing materials loaded in the CV shall not exceed the CoC limit of 40.82 kg.

1.3 Criticality Safety Index

The CSI of the package for Safety Block content configuration is 0.0. PCP staff confirmed the applicant's results, using the procedure in 10 CFR 71.59(b).

1.4 Radiation Level and Transport Index

PCP staff confirmed that the radiation transport indices (TIs) are less than 10, which is the TI limit in 10 CFR 71.47(a) for non-exclusive use shipment. The actual TI of the package will be determined by measurement prior to shipment.

1.5 Conclusion

Based on a review of the statements and representations in the application, SARP, and PCP staff's confirmatory evaluation, staff concludes that the information provided by the applicant is adequate to evaluate the package for the Safety Block content configuration to the requirements of 10 CFR Part 71 for each technical discipline addressed in the subsequent sections of this SER.

2.0 Structural Evaluation

Based on the review of the statements and representations in the application, the SARP, and PCP staff's confirmatory evaluation, staff finds that there are no structural issues related to the request to authorize use of the packaging to ship the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

3.0 Thermal Evaluation

Based on the review of the statements and representations in the application, the SARP, and PCP staff's confirmatory evaluation, staff finds that there are no thermal issues related to the request to authorize use of the packaging to ship the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

4.0 Containment

Based on the review of the statements and representations in the application, the SARP, and PCP staff's confirmatory evaluation, staff finds that there are no containment issues related to the request to authorize use of the packaging to ship the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

5.0 Shielding Evaluation

Based on the review of the statements and representations in the application, the SARP, and PCP staff's confirmatory evaluation, staff finds that there are no shielding issues related to the request to authorize use of the packaging to ship the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

6.0 Criticality Evaluation

PCP staff reviewed the SARP and the applicant's supplemental NCSE of the package for the proposed Safety Block content configuration and performed a confirmatory nuclear criticality safety analysis using the Monte Carlo N-Particle Transport Code (MCNP6) to independently evaluate the nuclear criticality safety of the package under the most reactive conditions.

6.1 Criticality Safety Design

The criticality safety design features of the packaging are addressed in Section 6.1.1 of the SARP and have not changed for Safety Block content configuration. The applicant used the same package performance assumptions in the supplemental NCSE as SARP Section 6.1.2, for consistency in the methodology for demonstrating maximum reactivity.

The Safety Block content configuration requires the use two 277-4 Heavy Can Spacer Assemblies (CoC Drawing M2E801580A043) in the CV for nuclear criticality safety. These cans provide spacing and absorb neutrons.

An empty convenience can approximately 10-inches in length and with a minimum vent hole size of 0.125 inch in diameter in the can lid, and stainless steel scrubbers are used for spacing and dunnage in the CV. SARP Table 2-7 lists the material specifications for the packaging components.

The package content loading restrictions stated in SARP Sect. 6.2.4 are modified below in this SER for applicability to the Safety Block content configuration, based on the supplemental NCSE:

1. Each Safety Block (i.e., HEU fissile material) to be shipped in the packaging must be placed in polyethylene bagging, and then carbon steel caps will be placed over each end of a Safety Block which may then be secured to the bag with metal tape, as necessary. 277-4 Heavy Can Spacers shall be used as indicated for criticality control.
2. Each Safety Block shall not exceed 13.88 kg of U-235 and each package shall not exceed 27.76 kg of U-235.
3. Not applicable for this content based on the supplemental NCSE.
4. Only the Safety Block content configuration shown in Fig. 3 of the NCSE may be shipped in the packaging. The empty 10-inch convenience can must have a minimum vent hole size of 0.125 inch in diameter in the can lid.
5. The Safety Block U-Mo maximum uranium content is 91 weight % and maximum U enrichment of 93.5%.
6. Safety Blocks must conform to the Drawing DD-T802365-0006.
7. The content loaded in the CV is defined as: two Safety Blocks (HEU fissile material) prepared in accordance with Step 1 (above); two 277-4 Heavy Can Spacers; one empty 10-inch convenience can; and stainless steel scrubbers. The maximum amount of hydrogenous packing material inside the CV shall not exceed an equivalent mass of 500 g polyethylene.
8. Not applicable for this content. The content configuration is to specific Safety Blocks and unidentified HEU constituents are prohibited.
9. Not applicable for this content. HEU oxide and air transport prohibited.
10. Not applicable for this content. Only ground transport is authorized for use of the package to ship the Safety Block content configuration.

6.2 Contents

The Safety Block is a single piece of highly enriched uranium (HEU) in the form of uranium/molybdenum (Material is $U_{10}Mo$) alloy with a nominal 90 weight % of uranium and nominal U-235 enrichment of 93.15%. The calculated mass of a Safety Block is 16.21 kg. The Safety Block shape is an annular cylinder with approximate dimensions of 5.74 inches in length, outer diameter of 3.85 inches, and inner diameter of 1.40 inches. The entire Safety Block is plated with aluminum to a thickness of approximately 0.01 inch.

The applicant's supplemental NCSE modeled the Safety Block as simple annulus with a length of 5.751 inches. The diameters used are the maximum drawing values with an outer diameter of 3.851 inches and an inner diameter of 1.4 inches. The differences in the NCSE model dimensions and the actual maximum dimensions of a fabricated Safety Block (5.740 inches in length, 3.853 inches outer diameter, and 1.4025 inches inner diameter) are inconsequential to safety and the NCSE. The composition of the Safety Block is modeled as U-Mo having the maximum uranium content of 91 weight % and a maximum U-235 enrichment of 93.5%, so the mass of the U-Mo alloy is 16,313.3 grams alloy, 14,845.1 grams uranium, of which 13,880.2 grams are U-235. Any impurities in the uranium are bounded by the additional U-235 due to modeling the Safety Block at a higher enrichment. The Safety Block is plated with 0.005 inch thick aluminum so the applicant calculated 51.3 grams as the corresponding mass of aluminum. The Safety Block is modeled in 500 grams of polyethylene bagging material. The model assumes the bagging material has a uniform thickness of 0.785 cm.

6.3 Model Configuration and Material Properties

The applicant evaluated the two Safety Block loading configurations shown in Figures 3 and 4 of the NCSE, but with modifications in the NCSE models to increase reactivity by substituting water for non-safety (non-Q items) packing materials used for dunnage or by decreasing the distance between Spacer Blocks by eliminating the 10-inch convenience can. Figure 3 is the actual proposed loading configuration, but the Figure 4 loading configuration was included in the NCSE to evaluate the package with only important to safety (Q-Item) packaging components.

The first loading configuration corresponds to Figure 3. In Figure 3, the order of items stacked in the CV (starting from the bottom of the CV) are:

1. Safety Block,
2. 277-4 Heavy Spacer Can,
3. empty 10-inch convenience can,
4. Safety Block,
5. 277-4 Heavy Spacer Can, and
6. stainless steel scrubbers filling the remaining void space above the spacer can.

The model for this loading configuration is modified to increase reactivity by substituting water for the space normally occupied by the 10-inch convenience can and stainless steel scrubbers. The distance between Spacer Blocks is approximately 10 inches in the model.

The second loading configuration corresponds to Figure 4. In Figure 4, the order of items stacked in the CV (starting from the bottom of the CV) are:

1. Safety Block,
2. 277-4 Heavy Spacer Can,
3. Safety Block,
4. 277-4 Heavy Spacer Can,
5. and stainless steel scrubbers filling the remaining void space above the spacer can.

The model for this loading configuration is modified for reactivity by substituting water in the space normally occupied by the stainless steel scrubbers. The distance between the Spacer Blocks is approximately 1.4 inches in the model.

The material properties for the Safety Block (U-Mo, Aluminum, and polyethylene) are listed in NCSE Table 3. The material properties used in the NCSE for all other packaging components are from SARP Table 6.4

6.4 Summary of NCSE Results and PCP Staff's Criticality Safety Analyses

Table 6-1 of this SER summarizes and compares the applicant's NCSE results and PCP staff's nuclear criticality safety analyses results for the Safety Block content configuration for a single package and an infinite array of packages under normal conditions of transport (NCT) and hypothetical accident conditions (HAC) in accordance with §§71.55 and 71.59.

The USL for the calculations performed in the NCSE (which are intermediate energy HEU systems per the results from KENO V.a outputs) would be 0.9352.

Based on the NCSE results, the Safety Block content configuration is well below the USL when each block is wrapped with 500 grams of polyethylene or with no polyethylene. Cases with 500 grams of polyethylene are slightly more reactive until the distance between Safety Blocks is decreased from approximately 10 inches to 1.4 inches. NCSE cases under NCT of an infinite array of undamaged packages shows a small difference in reactivity when aluminum plating thickness on the Safety Block is varied from 0, 0.01, and 0.1 inch: reactivity slightly decreases with increased plating thickness (i.e., mass of aluminum). The NCSE also demonstrates that amount of aluminum plating on the Safety Block, in cases with or without up to 500 grams of polyethylene, is not a nuclear criticality safety concern. PCP staff confirmed the NCSE results by independent confirmatory analyses.

Table 6-1 – NCSE and Staff's Criticality Analysis Results for Safety Block Content Configuration

Single Package Evaluation (NCT and HAC)		
Conditions	**NCSE (SCALE 6.1.3)**	**PCP Staff (MCNP6)**
• Two Safety Blocks (each wrapped in 500g of poly) per package, • Credit taken for the 277-4 Heavy Can Spacers and the spacing the 10-inch convenience can provides, • Flooding of the CV, and • 30.48 cm H_2O surrounding the CV.	$k_{eff} + 2\sigma \leq 0.816$	$k_{eff} + 2\sigma \leq 0.820$
• Two Safety Blocks (each wrapped in 500g of poly) per package, • Credit taken for the 277-4 Heavy Can Spacers and the spacing the 10-inch convenience can provides, • Flooding of the CV, and • 30.48 cm H_2O surrounding the CV.	NCT: $k_{eff} + 2\sigma \leq 0.788$ HAC: $k_{eff} + 2\sigma \leq 0.789$	NCT: $k_{eff} + 2\sigma \leq 0.792$ HAC: $k_{eff} + 2\sigma \leq 0.794$
Infinite Array Evaluation (NCT and HAC)		
• Two Safety Blocks (each wrapped in 500g of poly) per package, and • Credit taken for the 277-4 Heavy Can Spacers and the spacing the 10-inch convenience can provides	NCT: $k_{eff} + 2\sigma \leq 0.849$ HAC: $k_{eff} + 2\sigma \leq 0.849$	NCT: $k_{eff} + 2\sigma \leq 0.858$ HAC: $k_{eff} + 2\sigma \leq 0.858$
CSI	**0.0**	**0.0**

Note - Upper subcritical limit (USL) k_{safe} value is 0.9352 (NCSE Section 8)

6.5 Single Package Evaluation (NCT and HAC)

The applicant's analyses in SARP Sect. 6.4 demonstrates that the calculated $k_{eff} \pm 2\sigma$ values increase as a function of increasing moisture fraction of the package external to the containment vessel (MOIFR). The applicant used a fully flooded, reflected package to calculate the neutron multiplication factors for the single package evaluation. For both of the two loading configurations in the NCSE, the applicant modeled the Safety Blocks, with and without polyethylene wrapping, inside a flooded containment vessel that is reflected on all sides by 30.48 cm of water. The applicant substituted water for polyethylene in the Safety Block calculations without polyethylene wrapping. Full water reflection around the flooded CV was a more effective moderator and reflector than the flooded CV.

6.6 Package Array Evaluation (NCT and HAC)

The applicant's analyses in SARP Sections 6.5 through 6.6 demonstrates that maximum reactivity occurs in an array of packages when the moisture fraction inside the containment vessel (MOCFR) equals 1.0 (i.e., CV is flooded) and the MOIFR in 1E-04 (i.e., package is dry). A MOIFR of 1E-04 pertains specifically to NCT or HAC, where the neutron poison of the body weldment liner inner cavity and the Kaolite are dry and where the recesses of the packaging outside of the CV and the interstitial space between packages in the array do not contain any residual moisture. There is an insignificant difference between the applicant's calculated $k_{eff} \pm 2\sigma$ values for undamaged packages under NCT and for damaged packages under HAC.

The applicant's infinite package array calculation models for the two loading configurations in the NCSE were based on the infinite package array model described in SARP Section 6.3.1.2.

6.7 Evaluation Findings

Based on the review of the statements and representations in the application and the SARP, and PCP staff's confirmatory evaluation, staff finds that there are no nuclear criticality safety issues related to the request to authorize use of the packaging to ship the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

7.0 Package Operations

Based on the review of the statements and representations in the application and the SARP, and PCP staff's confirmatory evaluation, staff finds that there are no package operations issues related to the request to authorize use of the packaging to ship the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

8.0 Acceptance Tests and Maintenance Program

Based on the review of the statements and representations in the application and the SARP, and PCP staff's confirmatory evaluation, staff finds that there are no acceptance tests and maintenance issues related to the request to authorize use of the packaging to ship the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

9.0 Quality Assurance

Based on the review of the statements and representations in the application and the SARP, and PCP staff's confirmatory evaluation, staff finds that there are no quality assurance issues related to the request to authorize use of the packaging to ship the Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

Conditions of Approval

PCP staff finds the requested change to authorize use of the Model ES-3100 packaging to ship two Safety Blocks is acceptable and does not affect the ability of the package to meet 10 CFR Part 71 subject to the following conditions to amend the CoC:

1. The FBR Safety Blocks must conform to FBRU Preplating Safety Block Machining, Y-12 Drawing # DD-T802365-0006, February 15, 2018,
2. The maximum mass for each FBR Safety Block is 16.31 kg,
3. The maximum fissile mass and enrichment for each FBR Safety Block is 13.88 kg of U-235 and 93.5% respectively,

4. The maximum fissile mass for the package is 27.76 kg of U 235,
5. The total mass of two Safety Blocks and all packing materials loaded in the Containment Vessel (CV) shall not exceed the CoC limit of 40.82 kg,
6. Prior to loading in the CV, each Safety Block will be placed in polyethylene bagging and then carbon steel caps will be placed over each end of the Safety Block which may then be secured to the bagging with metal tape, as necessary,
7. Only the Safety Block content configuration components and arrangement shown in Figure 3 of Criticality Evaluation of Two WSMR FBR Safety Blocks in the ES_3100 Package, RP 801940 0018 000 00, dated December 2017, may be shipped in the packaging,
8. Only one ES-3100 package per shipment is authorized,
9. Only ground transport is authorized; all other modes of transportation are prohibited,
10. DOE CoC 9315 Rev 14, Conditions 5(d)(1), (2), (7), (8), (9), (12), (15), (17), and (18) apply to this shipment, and
11. This authorization shall expire on February 28, 2019.

Conclusion

Based on the review of the statements and representations in the application and the SARP, and PCP staff's confirmatory evaluation as summarized in this SER and the conditions listed above, staff finds the use of the Model ES-3100 packaging acceptable for shipment of the FBR Safety Block content configuration. Therefore, staff has reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

References

[1] Request for Letter Amendment to Ship Two HEU Alloy Parts for the White Sands Missile Range in the ES-3100 Package, CoC USA/9315/B(U)F-96 (DOE), from W. E. Kilmartin to James M. Shuler, December 20, 2017.

[2] FBRU Final Safety Block Machining, Y-12 Drawing DD-T0802365-0006, Rev. 0, Consolidated Nuclear Security, LLC, February 15, 2018.

[3] Safety Block No 2, Drawing # 1023, White Sands Missile Range - Fast Burst Reactor Facility, June 2014.

[4] Criticality Evaluation of Two WSMR FBR Safety Blocks in the ES_3100 Package, RP 801940-0018 000 00, Consolidated Nuclear Security, LLC, December 2017.

[5] Safety Analysis Report for Packaging, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents, SP-PKG-801940-A001 Revision 2, Consolidated Nuclear Security, LLC, September 8, 2016.