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DOE Packaging Certification Program

Safety Evaluation Report for Request to Remove Carbon Limit for Ground Transport of HEU Oxide in the ES-3100 Packaging

Docket No. 15-01-9315

Prepared by: ______________________ Date: ____________

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This Safety Evaluation Report (SER) documents the U.S. Department of Energy (DOE) Packaging Certification Program (PCP) technical review of the Application submitted by the National Nuclear Security Administration (NNSA) Office of Defense Nuclear Nonproliferation (NA-26) requesting special authorization to ship highly enriched uranium (HEU) in the form of U_3O_8 oxide by ground transport mode, with no limit on the carbon concentration, in the ES-3100 package.

Summary

By Application [1] dated October 20, 2014, supplemented [2] October 27, 2014, NA-26 submitted a request to DOE for special authorization to remove the carbon concentration limit for highly enriched uranium (HEU) oxide in the form of U_3O_8, for ground transport in the ES-3100 package. The current Safety Analysis Report for Packaging (SARP) [3] and DOE Certificate of Compliance (Revision 8) were analyzed with a carbon limit of 921 grams in a package loaded with 15.13 kg of HEU Oxide. The Applicant evaluated the nuclear criticality safety of the U_3O_8 content in the ES-3100 package with varying amounts of water in the containment vessel (CV) and varying concentrations of carbon in a fully loaded package, for both normal conditions of transport (NCT) and hypothetical accident conditions (HAC). The Applicant demonstrated that the reactivity for all cases evaluated were below the upper subcriticality limit, and their analyses showed, for carbon concentration, that as the percentage of carbon in the oxide increases (and thus replaces uranium), reactivity decreases.

PCP staff reviewed the Application and performed a confirmatory evaluation of the proposed change. Based on the statements and representation in the Application, as supplemented, PCP staff concludes that this content amendment to DOE CoC 9315 does not affect the ability of the package to meet the requirements of 10 CFR Part 71, *Packaging and Transportation of Radioactive Material*.

Evaluation

The authorized contents of the ES-3100 package include various forms of uranium metal, uranium alloys, uranium oxides, uranyl nitrate hydrate, uranium compounds, and unirradiated TRIGA fuel elements (See Tables 1.3, 1.3a and 1.3b of the SARP for loading limits). The Application only addresses a loading limit change for skull oxide, which is a mixture of U_3O_8 and carbon. The existing mass limits for HEU oxide in Table 1.3 of the SARP are 15.13 kg oxide, 9.682 kg ^{235}U and 921 g carbon. The Application requests removal of the carbon limit for U_3O_8 ground shipments.

The ^{235}U enrichment limit varies with uranium form and payload mass and can range up to 100% for some payload configurations. Neutron absorber can spacers are required to meet criticality safety requirements for some payload configurations; however, these can spacers are not required for ground transport of U_3O_8.

The proposed U_3O_8 content change is evaluated with respect to nuclear criticality safety in Reference 2. Descriptions of the ES-3100 package design features in the SARP include identification of packaging materials, densities and compositions of packaging materials, and the fissile/fissionable material forms, masses and isotopic compositions of the payloads. PCP staff confirmed that criticality-related information in the SARP is complete and representative of the actual materials specified for the ES-3100 package. Staff also confirmed that the models used in the criticality evaluation in Reference 2 are consistent with the drawings and the detailed package description given in the SARP.

Criticality Models

The contents and the neutronically significant components of the ES-3100 package were included in the KENO V.a models for ground transport of U_3O_8. Separate models were developed for single package, NCT, and HAC analyses. Two single package models, one consisting of a full ES-3100 package and the other of only the containment vessel, were used to calculate the neutron multiplication factors for U_3O_8 under fully flooded and reflected conditions. The NCT and HAC array calculations for U_3O_8 were based on detailed models of the ES-3100 package and on infinite arrays.

The criticality analysis for U_3O_8 in Reference 2 did not take credit for watertight containment either in the single package or array analyses. Water was modeled as the moderator and reflector for the single package and array calculations. Reference 2 determined the configurations of maximum reactivity with respect to moisture content within the containment vessel and moisture contents of the neutron absorber and impact absorbing insulation.

The Standard Composition Library and the 238GROUPNDF5 nuclear data library in the SCALE code package were used for all KENO V.a calculations in Reference 2 and in the confirmatory analyses. Reference 4 summarizes the determination of the minimum k_{safe} value. The lowest k_{safe} value determined from the validation for the proposed content change is 0.957. Therefore, any configurations of ES-3100 packages with $k_{eff} + 2\sigma < k_{safe}$ are deemed subcritical. All calculations incorporated sufficient neutron histories to ensure statistical uncertainty (σ) less than 0.002 and adequate convergence. PCP staff concurs that the benchmark experiments and corresponding bias value are applicable and conservative as applied to the ES-3100 package.

Summary of SARP Criticality Analysis and PCP Staff's Confirmatory Evaluation

The analysis in Reference 2 examined, a) the full range of U_3O_8-carbon mixtures from 15,487g U_3O_8/0 g carbon to 1,000 g U_3O_8/14,487 g carbon, b) the full range of the specific gravity of water inside the CV from 0 to 1.0, c) the full range of the specific gravity of water outside the CV from 0 to 1.0, and d) densities of skull oxide (i.e., mixtures of U_3O_8 and carbon) ranging from 3.054 g/cm^3 to 2.0 g/cm^3.

Reference 2 shows that, a) the maximum reactivity occurs for configurations with no carbon mixed with the oxide, b) k_{eff} decreases monotonically as oxide is replaced by carbon, and c) maximum reactivity occurs for flooded CV configurations. For array configurations, Reference 2 shows that the maximum reactivity occurs for configurations with the minimum specific gravity of water outside the CV.

Evaluation of a CV or single package under NCT and HAC

Table 1 of the SER shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Reference 2 and PCP staff's confirmatory analyses for the skull oxide content in the CV and single package configurations. All CV and single package configurations resulted in acceptable $k_{eff} + 2\sigma$ values that are below the k_{safe} limit of 0.957. Therefore, the ES-3100 CV and single package with the proposed skull oxide content, the oxide and ^{235}U loading limits listed in Table 1.3 of the SARP and removal of the 921 g carbon limit in Table 1.3 of the SARP are subcritical and satisfy the requirements of 10 CFR 71.55(b) related to a flooded CV or single package.

Table 1 Summary of SARP Criticality Analysis and PCP Staff's Confirmatory Analysis for the Package

Case	SARP Case	Content	U/C, g	Density, g/cm³	MOCFR[a]	MOIFR[b]	Maximum $k_{eff} + 2\sigma$[c]	
							Reference 2	PCP Staff
CV								
CV-1	cvcrskx3cc_1_1_15	U_3O_8/C	15487/0	3.054	1.0	-	0.83560	0.83696
CV-2	cvcrskx3cc_1_3_15	U_3O_8/C	15487/0	2.5	1.0	-	0.85740	0.85318
CV-3	cvcrskx3cc_1_5_15	U_3O_8/C	15487/0	2.0	1.0	-	0.87210	0.87031
CV-4	cvcrskx3cc_10_5_15	U_3O_8/C	1000/ 14487	2.0	1.0	-	0.67670	0.67378
NCT Single Package								
NS-1	ncsrskx_1_5_15	U_3O_8/C	15487/0	2.0	1.0	-	0.76230	0.76108
HAC Single Package								
HS-1	hcsrskx_1_5_15	U_3O_8/C	15487/0	2.0	1.0	-	0.76340	0.76367
NCT Array								
NA-1	nciaskx_1_5_15_2	U_3O_8/C	15487/0	2.0	1.0	1.0E-05	0.93740	0.93290
HAC Array								
HA-1	hciaskx_1_5_15_2	U_3O_8/C	15487/0	2.0	1.0	1.0E-05	0.93500	0.93400

a) Specific gravity of water inside CV.
b) Specific gravity of water outside CV.
c) Upper subcritical limit (USL) k_{safe} is 0.957.

Evaluation of undamaged package arrays for NCT

The NCT undamaged package array model for the proposed U_3O_8 content with no carbon limit consisted of an infinite array of packages. The analysis in Reference 2 shows that maximum reactivity occurs in an array of ES-3100 packages when the containment vessel is flooded and the packaging is dry, referring to a configuration in which: (a) the neutron poison of the body weldment liner inner cavity and the impact absorbing insulation are dry, (b) recesses of the package external to the containment vessel do not contain any residual moisture, and (c) the interstitial space between packages in the array does not contain any residual moisture.

Table 1 of the SER shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Reference 2 and PCP staff's confirmatory analysis for the skull oxide content under NCT. All NCT arrays resulted in acceptable $k_{eff} + 2\sigma$ values that are below the k_{safe} limit of 0.957. Therefore, the ES-3100 package with the proposed skull oxide content, the oxide and ^{235}U loading limits listed in Table 1.3 of the SARP and removal of the 921 g carbon limit in Table 1.3 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(d) and 10 CFR 71.59(a)(1).

Evaluation of damaged package arrays for HAC

The HAC damaged package array model consisted of an infinite array of packages, each with a flooded containment vessel and dry packaging to maximize the k_{eff} of the array. Table 1 of the SER shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Reference 2 and PCP staff's confirmatory analyses for the skull oxide content under HAC. All HAC arrays resulted in acceptable $k_{eff} + 2\sigma$ values that are below the k_{safe} limit of 0.957. Therefore, the ES-3100 package with the proposed skull oxide content, the oxide and ^{235}U loading limits listed in Table 1.3 of the SARP and removal of the 921 g carbon limit in Table 1.3 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(e) and the HAC-related requirements of 10 CFR 71.59(a)(2).

Criticality Safety Index (CSI) for Nuclear Criticality Control

Based on the NCT/HAC infinite array analyses of the proposed removal of the carbon limit for skull oxide, a minimum CSI of 0.0 was determined. PCP staff concurs that this CSI value is appropriate for the ES-3100 package with the proposed skull oxide content, the oxide and ^{235}U loading limits listed in Table 1.3 of the SARP, and removal of the 921 g carbon limit in Table 1.3 of the SARP.

Conditions

Add additional parameter to Table Note "j" to Table 1.3, as follows, "The carbon limit of 921 g does not apply to HEU Oxide in the form of U_3O_8 for ground transport."

Revise Condition 13 to allow the use of Revision 7 and 8 of the DOE Certificate of Compliance until September 30, 2015.

Conclusion

Based on the statements and representations in the Application, as supplemented, and the condition listed above, PCP staff has reviewed the proposed content change for the Model ES-3100 package and concludes that the change does not affect the ability of the package to meet the requirements of 10 CFR Part 71.

References

[1] *Request for Letter Amendment to Ship HEU Oxide in the ES-3100 Package with no carbon limit*, Docket 15-01-9315, CoC USA/9315/B(U)F-96 (DOE), submitted to US Department of Energy Packaging Certification Program, by the National Nuclear Security Administration (NNSA), Office of Defense Nuclear Nonproliferation (NA-26), October 20, 2014.

[2] *Analysis of HEU oxide (U_3O_8) with carbon concentrations for shipment in the ES-3100*, Performed by Y-12 National Security Complex, September 15, 2014.

[3] *Safety Analysis Report for Packaging for Model ES-3100 Package with Bulk HEU Contents*, SP-PKG-801940-A001, Rev. 0, Page Change 6, Babcock & Wilcox Technical Services Y-12, LLC, Y-12 National Security Complex, February 27, 2014.

[4] Joshua Schwartz, *Critical Experiment Benchmark Calculations with CSAS5 from SCALE6.1 for Interim Criticality Safety Analyses on the HP Integrity Series rx3600 (CMODH)*, RP_02-F-0014_000_00, Rev. 0, February 2012.