SAFETY EVALUATION REPORT

T-3 Safety Analysis Report Addendum
for the
IPNS Enriched Uranium Booster Target Assembly

Docket No. 92-16-9132

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Transportation and Packaging Safety Division, EH-33.2
U.S. Department of Energy

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1.0 GENERAL

1.1 Area of Review

The Addendum to the T-3 Spent Fuel Shipping Cask Safety Analysis Report for Packaging (SARP) for the shipment of the Intense Pulsed Neutron Source (IPNS) Enriched Uranium Booster Target Assembly (BTA) in the T-3 cask (Ref. 1) seeks authorization to ship a single BTA in the T-3 as exclusive use, Fissile Class III. The BTA will be installed with support spacers similar in function to the already approved FTR Driver Fuel Assembly support fixtures for Type 4 Contents shipments. The BTA contains 25.3 kg of 77.5 weight % enriched uranium metal (19.7 kg of U-235). The BTA has 19 grams of U-235 burnup and will have a decay heat load of less than 12 watts when shipped after May 31, 1992. Composition of the IPNS BTA payload is defined in Section 1.2.3 (Contents of Packaging) of the Addendum. The BTA contains 13 Zircaloy-2 clad, nominal four-inch diameter enriched uranium discs (77.5 weight % U-235), 11 of which are nominally 1/2-inch thick and two are one inch thick. A 1/2-inch thick disc contains 1.7 kg of uranium metal (1.3 kg of U-235), a one-inch thick disc contains 3.5 kg of uranium metal (2.7 kg of U-235), and the entire BTA contains 25.3 kg of uranium metal (19.7 kg of U-235). The payload weight and decay heat are lower in comparison to currently licensed payloads.

1.2 Findings and Conclusions

The staff has reviewed the T-3 SARP Addendum (Ref. 1) and concludes that it contains the information required to demonstrate compliance with 10 CFR 71 (Ref. 3) and DOE 5480.3 (Ref. 4). This conclusion is based in part on prior reviews of the T-3 SARP (Ref. 2) and its acceptance for certification.

2.0 STRUCTURAL EVALUATION

2.1 Area of Review

The structural analysis presented in the T-3 SARP addendum (Ref. 1) was reviewed for the proposed alternative payload. The proposed payload is the Intense Pulsed Neutron Source (IPNS) Enriched Uranium Booster Target Assembly (BTA). The payload is supported within the T-3 cask cavity with a spacer tube and an upper insert at one end, a lower insert at the other end, and a circular cylindrical protective liner around its outer circumference. The inserts and spacer tube are made of 6061-T6511 aluminum alloy and the liner is made of 1100-0 aluminum.

JAN 1 9 1992

The support fixture weighs approximately 64 lb. according to ANL Drawing #N4620-0003-DD, Rev. 6. Hence the payload (the BTA assembly) weighs approximately 552 lb. (616 less 64 lb.), of which 55.7 lb. (25.3 kg) is 77.5 weight % enriched uranium metal. The uranium metal is located in the target assembly of the BTA. The metal consists of 13 Zircaloy-2 clad, nominal four-inch diameter discs. Two of the discs are one inch thick and the remaining 11 are 1/2-inch. Each of the one-inch thick discs contains 7.7 lb. (3.5 kg) of uranium metal, and the 1/2-inch disc contains 3.7 lb. (1.7 kg).

The BTA assembly has two major components, the target assembly at one end of the BTA and the linkage/hose assembly at the other end. The target assembly of the BTA is a circular cylindrical vessel made of 304 stainless steel containing the uranium metal discs and their separator discs. A 304 stainless steel separator disc is placed between two adjacent uranium discs to provide flow channels for the cooling water needed during the BTA operation. The linkage/hose assembly is used during the BTA operation to lift and insert the BTA into a bore tube of the IPNS and to supply cooling water to the target. The assembly will also be used to lift and insert the BTA into the T-3 cask cavity.

The SARP concludes that the proposed contents is acceptable structurally based on the following observations: (1) the total weight of the proposed contents is less than the contents weight limit and is only a small fraction of the total weight of the T-3 cask; (2) the total decay heat generated by the proposed contents is much lower than the limit of the cask; (3) the support fixture provides adequate clearance for thermal expansion, and (4) the BTA assembly will be dry for shipment, and there will be no liquid or gaseous product to cause high internal pressure of the cask.

2.2 Acceptance Criteria

The payload is deemed acceptable if it does not cause adverse structural effects on the containment, shielding, and criticality functions of the T-3 cask which can result in the noncompliance of the T-3 with federal regulatory requirements (10 CFR 71).

2.3 Findings and Conclusions

The staff concurs with the applicant that the proposed payload has insignificant structural effects on the safety performance of the T-3 cask and is, therefore, acceptable as an alternative payload. The reasons are as follows:

(1) The payload and support fixture have a total weight (616 lb.) less than the approved maximum contents weight of the cask (700 lb.);

(2) The contents weight is a very small percentage of the total cask weight (38200 lb.) and, therefore, the precise distribution of the contents is immaterial;

(3) The heat generation of the payload (12 watts total, or 1.66 watts per inch of the axial length of the heat source) is significantly lower

than the approved maximum limit for the T-3 cask (1400 watts total or 9.55 watts per inch of cask cavity length);

(4) The design of the payload support fixture has provided sufficient clearance for free thermal expansion;

(5) The payload is not expected to produce a significant amount of gas since the SARP addendum indicates that the BTA is dry before loading and the target assembly does not produce an appreciable amount of gas fission products. Thus, the rise of the internal pressure is due only to the heating up of the dry air in the cask cavity. It should be lower than the maximum internal pressure predicted in the T-3 SARP, which also included the effect of the complete leakage of pressurized gas in fuel pins.

3.0 THERMAL EVALUATION

3.1 Area of Review

The thermal evaluation presented in the T-3 SARP Addendum (Ref. 1) was reviewed for the proposed payload. The thermal performance of the T-3 package when transporting the proposed payload has been reviewed to assure that the critical components of the package and its contents would not be impaired to the extent that contents would be released during the normal transport and hypothetical accident conditions defined in 10 CFR 71.

The BTA contains 25.3 kg of 77.5 weight % enriched uranium metal (19.7 kg of U- 235). The BTA has 19 grams of U-235 burnup and will have a decay heat load of less than 12 watts when shipped after May 31, 1992. The BTA contains 13 Zircaloy-2 clad, nominal four-inch diameter enriched uranium discs (77.5 weight % U-235), 11 of which are nominally 1/2-inch thick and two are one inch thick. A 1/2-inch thick disc contains 1.7 kg of uranium metal (1.3 kg of U-235), a one-inch thick disc contains 3.5 kg of uranium metal (2.7 kg of U-235), and the entire BTA contains 25.3 kg of uranium metal (19.7 kg of U-235). The payload weight and decay heat are lower in comparison to currently approved payloads.

3.2 Acceptance Criteria

The requirements of 10 CFR 71.51 can be satisfied if temperatures and pressures in the containment system do not exceed those allowed for containment as defined in the T-3 SARP (Ref. 2).

3.3 Review Procedure

The package design, including containment and shield, has been approved for a content decay heat load of 1400 W. Thus, since the contents of this package produce a decay heat load of less than 12 W (which is less than for the approved package), the impact of the thermal loads on the containment and lead shielding should be less than that of the approved package. Therefore, the containment and lead shielding conform to the requirements of 10 CFR 71 (Ref. 3).

3.4 Findings and Conclusions

Based on the review described above, temperatures, pressures, and stresses in the T-3 package are within allowed limits.

The staff concludes that the thermal design features described in Section 3 (Thermal Evaluation) of the T-3 SARP Addendum (Ref. 1) will assure compliance with the performance requirements of 10 CFR 71.

4.0 CONTAINMENT EVALUATION

The containment features associated with shipments of the Intense Pulsed Neutron Source (IPNS) Enriched Uranium Booster Target Assembly (BTA) payload remain the same as those presented in the T-3 SARP (Ref. 2) with the cask providing containment under both normal and hypothetical accident conditions. Thus, the staff's conclusion of a review of Section 4 (Containment) of the Addendum is that the containment design features will assure compliance with the containment requirements of 10 CFR 71.

5.0 SHIELDING EVALUATION

5.1 Area of Review

The shielding analysis presented in the T-3 SARP Addendum (Ref. 1) was reviewed for the proposed additional payload for the T-3 package. The proposed payload is the Intense Pulsed Neutron Source (IPNS) Booster Target Assembly (BTA), containing 25.3 kg of 77.5 weight % enriched uranium metal, which produced neutrons by spallation reactions resulting from an impinging high- energy proton beam and subsequent fissions. The BTA is assumed to have operated at 450 MeV and 20 A (70 kW) with a 100% duty cycle for 270.5 days before shutdown on August 9, 1991. (Actual operation was over a long period of time with a duty cycle.) The burnup of U-235 is approximately 19 g (~0.75 MWd/kgHM), and the decay heat will be less than 12 W when shipped after May 31, 1992. The T-3 cask will be shipped as exclusive use, Fissile Class III.

5.2 Acceptance Criteria

Cask shielding is deemed acceptable if it can be shown that the expected dose rates do not exceed the limits specified in 10 CFR 71.47 and 71.51. For a more restrictive criteria, cask shielding is also deemed acceptable if it can be shown that the expected dose rates will not exceed those of payloads previously approved for the T-3, which are significantly below the allowable limits of 10 CFR 71. (In the context of this review, the dose rates associated with the transport of materials in the approved payload configurations of the SARP are assumed to have been calculated correctly.)

5.3 Review Procedure

The neutron and gamma source terms for the BTA were compared with those of the original design-basis sources for which the T-3 was initially approved.

Source terms for the BTA were calculated in Section 5.2 of the Addendum using ORIGEN-S, assuming the operating power level presented above. Shutdown activity is stated to be dominated by the fission products of the U-235 fission.

The original gamma source for the approved SARP is addressed in Sections 5.2 and 5.2.1 of Ref. 2. It consists of 21 carbide/nitride pins with a 90-day cooling period following an irradiation to a maximum fuel burnup of 80 MWd/kg. The source contains 9.5 kg of fuel material with a composition of 20% PuC or PuN and 80% UC or UN. Although the fuel mass is smaller than other payloads (including the 38-kg payload used for the bounding neutron source), it was selected as the design-basis gamma source because of its short cooling time.

The original neutron source for the approved SARP is addressed in Sections 5.2 and 5.2.2 of Ref. 2. It consists of 217 mixed oxide pins with a 360-day cooling period following an irradiation to a maximum fuel burnup of 80 MWd/kg. The source contains 38 kg of fuel material with a composition of 25% PuO and 75% UO_2. The primary source of the spontaneous fission neutrons is Cm-242.

The burnup of the fuel in the BTA is significantly less than that of the design-basis payloads previously approved for the T-3. Primarily because of this very low burnup (and activation), as well as a longer cooling time, both the neutron and gamma source terms for the BTA are significantly less than those of the other design-basis sources, even for the conservative 100% duty cycle assumed for the irradiation time.

Calculations summarized in Section 5.1 of the Addendum indicate that the total dose rate on the surface of the T-3 will be less than 1 mrem/h during shipment of the BTA.

5.4 Findings and Conclusions

Arguments presented are sufficient to conclude that the expected dose rates from the BTA are significantly less than those previously approved for the T-3 and well below the limits of 10 CFR 71, when subject to the limitations specified:

(1) The BTA shall have been irradiated with a 450-MeV, 20- A proton beam (~19 g burnup of U-235) for no more than 270.5 days prior to a shutdown date of August 9, 1992;

(2) Decay heat shall be less than 12 W, which shall be primarily due to fission-product activity.

The staff concludes that the T-3 revisions defined in Section 5 of the SARP Addendum for the BTA are in compliance with the requirements of 10 CFR 71.

6.0 CRITICALITY EVALUATION

6.1 Area of Review

Approval is requested to ship a single Intense Pulsed Neutron Source (IPNS) Enriched Uranium Booster Target Assembly (BTA) in the T-3 Cask (Ref. 1) as exclusive use, Fissile Class III. The BTA will be installed with support spacers similar in function to the already approved FTR Driver Fuel Assembly support fixtures for Type 4 Contents shipments. The BTA contains 25.3 kg of 77.5 weight % enriched uranium metal (19.7 kg of U-235). The BTA has 19 grams of U-235 burnup.

The criticality design features of the package and the adequacy of the criticality evaluation are reviewed for a package transported under normal conditions of transport and hypothetical accident conditions. Included in this review are (1) the package fuel loading; (2) the model specification: description of the calculational model and the package regional densities; (3) the criticality calculation: calculational or experimental method, fuel loading or other contents loading optimization, and criticality results; (4) the critical benchmark experiments: benchmark experiments and applicability, details of benchmark calculations, and results of benchmark calculations; and (5) any supportive information or documentation.

6.2 Acceptance Criteria

The requirements of 10 CFR 71.61 can be met if it is demonstrated that the T-3 cask remains subcritical for all conceivable configurations and environments. This is based upon a single cask in each shipment.

6.3 Review Procedure

The criticality evaluation of the Addendum for Fissile Class III included in the SARP Addendum is based on calculations made with stand-alone KENO V.a and the 16-group Hansen-Roach neutron cross section set. An array of two packages was considered for Normal Conditions of Transport and a single package for Hypothetical Accident Conditions.

6.3.1 Package Fuel Loading

Section 6.2 (Fuel Package Loading) of the Addendum contains fuel loading information for the BTA. The BTA contains 13 Zircaloy-2 clad, nominal four-inch diameter enriched uranium discs (77 weight % U-235, 11 of which discs are nominally 1/2-inch and two are nominally one-inch thick. A 1/2-inch thick disc contains 1.7 kg of uranium metal (1.3 kg of U-235), a one-inch thick disc

contains 3.5 kg of uranium metal (2.7 kg of U-235), and the entire BTA contains 25.3 kg of uranium metal (19.7 kg of U-235). The uranium metal density is 18.75 g/cm^3. The first seven of the 1/2-inch thick discs at the bottom of the BTA and the next-to-last one-inch thick disc at the top of the BTA contain a Zircaloy-2 thermowell into which single thermocouples are placed to monitor disc temperatures during operation. The Zircaloy-2 clad on the disc faces, circumference, and thermowell is greater than 0.017 inches thick.

JAN 19 '92

6.3.2 Criticality Calculations

Table 6.1 in Section 6.1 (Discussion and Results) of the Addendum presents k-effective calculations for single packages under accident conditions. The calculations were performed with the KENO V.a Monte Carlo code using the standard 16-group Hansen-Roach neutron cross section set. The applicant homogenized the BTA fuel resulting in a fuel cylinder containing uranium at a density of 14.1 g/cm^3 plus diluents of iron, chromium, nickel, zirconium, and manganese.

Configuration	K-effective	+/- sigma
BTA in cask, submerged and flooded	0.883	0.005
BTA in cask flooded with 10% density water	0.791	0.003
BTA in cask, submerged, internally dry	0.776	0.004
BTA in cask, submerged and flooded; no credit for Boron and Copper in back plate	0.881	0.004

Table 6.2 in Section 6.1 (Discussion and Results) of the Addendum presents k-effective calculations for two T-3 casks with the BTA payload under a number of conditions.

Configuration	K-effective	+/- sigma
Flooded casks in water; 0.0 cm separation	0.888	0.004
Flooded casks in water; 2.5 cm separation	0.879	0.004
Flooded casks in water; 5.0 cm separation	0.891	0.005
Flooded casks in water; 7.5 cm separation	0.884	0.004
Flooded casks in water; 10.0 cm separation	0.885	0.004
Flooded casks in water; 20.0 cm separation	0.883	0.004
Flooded casks in water; 200.0 cm separation	0.882	0.005
Unflooded casks in water; 5.0 cm separation	0.777	0.004

The staff reviewed KENO models in Section 6.3, Model Specification of the Addendum used by the applicant for dimensions and number densities. The staff performed an independent bounding calculation discussed below.

The Nuclear Safety Guide TID-7016, Revision 2 (Ref. 5) contains the following information. Table 2.2 gives the single-parameter subcritical limit for 100 weight % metallic U-235 as 20.1 kg. Figure 3.3 gives factors by which U-235 metal subcritical mass limits may be increased for reduced uranium enrichment.

At 80 weight % the factor is at least 1.4 resulting in a subcritical limit of 28.1 kg total uranium, which is greater than the 25.3 kg total mass of uranium in the BTA. In fact, the U-235 content of the BTA, which is 19.7 kg U-235, is slightly less than the subcritical limit of 20.1 kg for 100 weight % metallic U- 235. This information from the Nuclear Safety Guide TID-7016, Revision 2 shows that a single package cannot be made critical in the Hypothetical Accident Conditions and supports the results of Table 6.1. The results of the calculations made by the applicant and the bounding calculations discussed below show that the casks are isolated neutronically. Hence the subcritical limit from the Nuclear Safety Guide TID-7016, Revision 2 also applies to the two-cask situations.

6.3.3 Critical Benchmark Experiments

The applicant asserted that there are no benchmark experiments involving fissionable material which would closely resemble the 77.5 weight % enriched uranium discs making up the BTA. The applicant performed no calculations of benchmark experiments. The applicant asserts that there is an error of 0.015 associated with the Hansen-Roach cross section set and assumes a modeling error of 0.010. The staff has no basis to judge the accuracy of the values for these errors.

6.3.4 Bounding Confirmatory Calculation

The staff performed a number of bounding confirmatory calculations using the SCALE/KENO V.a computer package with the 27-group cross section set. This combination of code sequences and cross section set has been validated by Jordan et al. (Ref. 6). The bounding confirmatory model consisted of a cylinder of 77.5 weight % uranium metal at a density of 18.75 g/cm^3 with a radius of 5.08 cm and length of 16.64 cm. The uranium cylinder in this model contains no diluents. The fuel was surrounded by a space that could fill with water and the lead shield and stainless steel outer wall of the cask. Single units and two units side-by-side were considered.

	Single Cask		Two Casks	
Configuration	k-eff	+/- sigma	k-eff	+/- sigma
Dry inside, no water reflector	0.7728	0.0020	0.7781	0.0021
Dry inside, water reflector	0.7767	0.0022	0.7794	0.0022
Flooded inside, water reflector	0.9524	0.0024	0.9565	0.0021

Jordan et al. (Ref. 6) list a number of appropriate critical benchmark calculations for highly enriched uranium metal which indicate that the SCALE/KENO V.a computer package with the 27-group cross section set does not have a negative bias for these systems. Hence the staff concludes that the bounding confirmatory calculations indicate subcritical systems under all conditions considered. The benchmark information from Jordan et al. is shown below.

JAN 19 1993

ID	Description	k-eff	+/- sigma
CAS01	93.8% U metal sphere, unreflected (GODIVA)	1.0004	0.0027
CAS07	93.5% U metal hemisphere shell, H_2O reflected	1.0042	0.0030
CAS08	93.2% U metal cylinder annulus, graphite reflected	1.0124	0.0031
CAS09	94% U metal cuboid, natural U reflector	1.0027	0.0025
CAS10	93.1% U metal hemispherical shell, oil reflected	1.0114	0.0034
CAS11	93.1% U metal hemispherical shell, steel center and oil reflector	0.9977	0.0035
CAS12	97.67% U metal sphere, H_2O reflected	0.9995	0.0031

6.4 Findings and Conclusions

On the basis of review of the applicant's calculations, the subcritical limit in the Nuclear Safety Guide TID-7016, Revision 2 (Ref. 5), and bounding confirmatory calculations, the staff concludes that the T-3 cask is designed to maintain its contents in a subcritical state when containing the proposed Intense Pulsed Neutron Source (IPNS) Enriched Uranium Booster Target Assembly (BTA) payload and only one cask in a shipment in compliance with 10 CFR 71.61 during transportation and storage.

7.0 OPERATING PROCEDURES

The operating procedures described in the T-3 SARP (Ref. 2) are applicable to the Intense Pulsed Neutron Source (IPNS) Enriched Uranium Booster Target Assembly (BTA) payload defined in the T-3 SARP Addendum (Ref. 1).

This section of the T-3 SARP Addendum has been reviewed and determined to contain operating procedures that have been defined in a manner that will assure compliance with requirements of 10 CFR 71 (Ref. 3) and DOE 5480.3 (Ref. 4).

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAMS

The acceptance tests and maintenance programs presented in the T-3 SARP (Ref. 2) are for the Type 9 payloads. The Intense Pulsed Neutron Source (IPNS)

Enriched Uranium Booster Target Assembly (BTA) payload described in the T-3 Addendum (Ref. 1) does not increase the containment pressure, package structure temperatures, or impact loads above allowed limits. Thus, no revision of the acceptance tests or maintenance programs is required.

This section of the T-3 SARP Addendum has been reviewed and the staff concludes that it contains acceptance tests and maintenance programs that have been defined in a manner that will assure compliance with the requirements of 10 CFR 71 (Ref. 3).

9.0 REFERENCES

1. Addendum to the Consolidated Safety Analysis Report for the T-3 Spent Fuel Shipping Cask, Revision 3, Document No. N0001-092-SA, Argonne National Laboratory, Argonne, IL, July, 1992.

2. NUPAC, 1986, Consolidated T-3 Spent Fuel Shipping Cask Safety Analysis Report, Rev. 4, Nuclear Packaging, Inc., Federal Way, WA (Revisions 5 & 6 added by Westinghouse Hanford Company, Richland, WA).

3. United States Nuclear Regulatory Commission, Packaging and Transportation of Radioactive Material, Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), Office of the Federal Register, National Archives and Records Administration, Washington, DC.

4. DOE Order 5480.3: Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes, U.S. Department of Energy, Washington, DC, August 9, 1985.

5. NRC Nuclear Safety Guide TID-7016, Revision 2, NUREG/CR-0095, U.S. Nuclear Regulatory Commission, Washington, DC, June 1978.

6. W. C. Jordan, N. F. Landers, and L. M. Petrie, Validation of KENO V.a Comparison with Critical Experiments, ORNL/CSD/TM-238, Oak Ridge National Laboratory, 1986.

APPROVED:

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