Department of Energy
Germantown, MD 20874-1290

SAFETY EVALUATION REPORT

for the Hanford RMI Billets in the Rev. J SARP of the Steel Banded Wooden Shipping Containers (SBWSC)

Authorized as Contents by Revision 13 of Certificate of Compliance USA/5467/AF-85 (DOE) Docket No. 00-07-5467

The criticality confirmatory evaluation in this Safety Evaluation Report (SER) addresses the Hanford RMI Billets described in the Rev. J Safety Analysis Report for Packaging (SARP) for the Steel Banded Wooden Shipping Containers (SBWSC). The Hanford RMI Billets (Mark I Outer) are unirradiated, low enrichment (1.25 wt.% U-235) annular cylindrical billets with the following outer and inner diameters (OD and ID) and lengths (L): (6.98 in. OD and 2.8 in. ID) x (18 to 19 in. L). The applicant proposes to ship the Hanford RMI Billets in the SBWSC Model G-4255 in three configurations: three billets per package, two billets per package, or one billet per package, each with its own Transport Index (TI) for criticality control and maximum allowable package limit.

The staff reviewed the criticality analyses presented in the SARP and performed independent confirmatory evaluation of criticality safety for the Hanford RMI Billets. The staff confirmed that the TI, and the number of packages proposed in the Rev. J SARP for the Hanford RMI Billets in an exclusive use shipment, meet the 10 CFR Part 71 criticality safety requirements under normal conditions of transport (NCT) and hypothetical accident conditions (HAC).

Other non-criticality safety aspects (i.e., General Information - Chapter 1, Structural - Chapter 2, Thermal - Chapter 3, Containment - Chapter 4, Shielding - Chapter 5, Operating Procedures - Chapter 7, Acceptance Tests and Maintenance - Chapter 8, and Quality Assurance - Chapter 9) of the SBWSC have been reviewed for similar types of contents in the Rev. G and Rev. J SARPs and documented in the SER for Rev. 11 of the Certificate of Compliance (CoC) dated July 15, 1999. The conclusions reached in the earlier evaluation and SERs for the non-criticality safety aspects of the SBWSC remain valid and applicable to the Hanford RMI Billets and will not be repeated here.

<u>Chapter 6 - Criticality</u>

6.1 Safety Evaluation

No special feature is incorporated in the design of the SBWSC for criticality control. According to 10 CFR Part 71, criticality safety must be demonstrated for a fissile material package under NCT and HAC. HAC consist of a sequence of events (e.g., vertical drops, fire, and immersion in water) that would damage the package and thus often represent a more limiting condition for criticality safety analysis, i.e., 2xN damaged array analysis where N is the number of packages in the array according to 10 CFR 71.59. In the criticality analysis for the SBWSC, the applicant conservatively assumed that all SBWSC in a shipment are burned during the 30-minute HAC fire (even though the wooden boxes are most likely only charred), and that the billets are "scattered and arranged" in the most reactive configuration with interspersed hydrogenous moderation and total water (30 cm) reflection, as required by 10 CFR 71.55 and 10 CFR 71.59. The staff confirmed that the applicant has indeed established the most reactive configuration for the number of billets (and packages) allowed in a shipment that would remain subcritical with an adequate safety margin. Once the allowable number of billets is obtained, the number of packages per shipment, N, can be determined based on the number of billets per package, and the minimum TI for criticality control in a shipment is calculated as TI = 50/N. For an exclusive-use shipment as requested for the SBWSC, the sum of TI must be limited to 100 per 10 CFR 71.59.

6.2 Determination of Optimal Lattice Parameters and the Most Reactive Configuration

Determination of the maximum allowable number of billets under the most reactive configuration begins with a search for the optimal ~~lattice~~ parameters, i.e., pitch, axial gap, and moderator density, that would maximize the reactivity, i.e., neutron multiplication factor (k_∞) for an infinite array of billets in a close-packed, hexagonal lattice. The search is non-trivial and in earlier confirmatory evaluation for similar types of payloads, the staff routinely performed a large number (e.g., 6x5x8 or 240) of MCNP calculations during the search of optimal lattice parameters for an infinite array of ingots. The staff found that for a given uranium ingot composition and geometry, the k_∞ is mainly influenced by the amount of water in the unit cell for the hexagonal lattice configuration. Consequently, a loosely packed array with a relatively large pitch and axial gap and low moderator density can have a mass ratio of fissile to moderator materials similar to that of a tightly packed array with a smaller pitch and axial gap, but higher moderator density. Infinite arrays of ingots (or billets) having these two types of lattice parameters will have comparable k_∞ values, and thus can be regarded as equally reactive configurations. Determination of the most reactive configuration, therefore, must consider the effect of neutron leakage, which exists only for a finite array of billets.

Since neutron leakage from a system reduces reactivity, the most reactive configuration for a finite array of billets must be one with a minimum surface-to-volume ratio that gives the smallest total surface area for neutron leakage. A tightly packed array within a spherical enclosure and with total water reflection, therefore, should minimize neutron leakage. The staff has developed the necessary framework for determining the radius of the spherical enclosure for the finite array using iterative MCNP calculations (See "Criticality Control in Shipments of Fissile Material," J. R. Liaw and Y. Y. Liu, to be published in Proc., ANS Topical Meeting on Spent Fuel and Fissile Material Management, San Diego, CA., June 5-8, 2000.) The most reactive configuration of the finite array (and the maximum number of ingots allowed in a shipment) is determined when the adjusted effective neutron multiplication factor (k_{adj}) for the 2xN damaged array satisfies the following criterion,

$$k_{adj} = k_{eff} + 0.00258 + 2 \times (0.006^2 + s^2)^{0.5} \leq 0.95,$$

where k_{eff} and s are the effective neutron multiplication factor and uncertainty, respectively, obtained in the MCNP calculations. The other constants in the equation are the code bias (0.00258) and uncertainty (0.006) obtained from benchmark calculations against the critical experiments. This is the same formula used by the applicant, and the formula is consistent with that recommended in NUREG/CR-5661, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages," April 1997.

6.3 Determination of Transport Index and Maximum Number of Packages per Shipment

The Hanford RMI Billets are similar to the RMI Forged Billets (Mark I Outer) for which the staff has completed criticality confirmatory evaluation for the 16-inch long Billets (approved for shipment in Rev. 11 and Rev. 12 CoC). The Hanford RMI Billets were added as a content for the SBWSC in the Rev. H SARP, and the applicant performed the criticality analysis taking credit for certain impurities (iron, aluminum, copper, nickel, silicon, cadmium, boron, etc.) in the Billets as neutron poisons to maximize the number of Billets in a shipment. Due to the relatively small margin of safety in the criticality analysis, the staff raised the concern on the determination and uncertainty in the concentrations of impurities in the Hanford RMI Billets. In response to the staff concern, the applicant changed the approach in the Rev. I SARP by requesting that the criticality analysis for the Hanford RMI Billets be covered by the previous analysis performed for the 16-inch long RMI Forged Billets, using a "maximum mass rule" described in the Rev. G SARP and summarized in the corresponding SER for the Rev. 11 CoC.

The maximum mass rule based on the 16-inch long RMI Forged Billets is a conservative approach that can be used to establish a conservative TI for billets of the same diameters but longer lengths. The rule is conservative because fissile material of the same composition and total mass is generally more reactive in smaller physical dimensions. For example, the subcriticality mass limit for the 16-inch long RMI Forged Billets is 2,933 kg, which has been shown to meet the subcriticality requirement in the Rev. G SARP and confirmed in the SER for the Rev. 11 CoC. For the Hanford RMI Billets that have the same outer and inner diameters as the RMI Forged Billets, the applicant determined the allowable number of Billets in a shipment by dividing the above maximum mass (2,933 kg) for the 16-inch long RMI Forged Billets by the mass (189.5 kg) of the 19-inch long Hanford RMI Billets, i.e.,

Number of Hanford RMI Billets = 2,933/189.5 = 15.47,

or 15 after round off. Depending on the number of billets per package (I = 3, 2, or 1) as indicated in Table 1.2.3-2 of the Rev. J SARP, the corresponding TI for criticality control can be calculated from TI = 50/N, where the number of packages N is determined from 2xNxI = 15.47. The staff has confirmed the TI values listed in the Rev. J SARP and shown in Table 1 below. From a criticality safety point of view, the three package configurations behave identically because the total number of billets in each configuration is $\leq$15.

Table 1. Transport Index (TI) for the Hanford RMI Billets (18-19 inch long) derived based on the "Maximum Mass (2,933 kg)" of the 16-inch Long RMI Forged Billets

(OD/ID) x L, (inches)	SBWSC Model	I, Billets/ Package	Package/ Shipment	TI
(6.98/2.8) x 18-19	G-4255	3	5	19.5
(6.98/2.8) x 18-19	G-4255	2	7	13.0
(6.98/2.8) x 18-19	G-4255	1	15	6.5

6.4 Summary

The staff has evaluated the criticality safety analysis presented in the SARP (Rev. G to Rev. J) for the Hanford RMI Billets. The staff has performed independent calculations and confirmed that the TI values (and the corresponding maximum number of packages) for the Hanford RMI Billets listed in the Rev. J SARP and Table 1 of this SER are conservative and meet the 10 CFR Part 71 requirements under NCT and HAC. The Hanford RMI Billets addressed in this SER can thus be safely packaged and transported in the designated models of the SBWSC.

Approved:

Michael E. Wangler

Michael E. Wangler, Director
Package Approval and Safety Program
Office of Safety, Health and Security, EM-5

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