Department of Energy
Germantown, MD 20874-1290

SAFETY EVALUATION REPORT

for the
FERMCO Ingot Sections in the Revision J SARP of the Steel Banded Wooden Shipping Containers (SBWSC)

Authorized as Contents by
Revision 12 of Certificate of Compliance USA/5467/AF-85 (DOE)
Docket No. 99-23-5467

The criticality confirmatory evaluation in this Safety Evaluation Report (SER) addresses the three FERMCO Ingot Sections described in the Rev. J Safety Analysis Report for Packaging (SARP) for the Steel Banded Wooden Shipping Containers (SBWSC). The three types of FERMCO Ingot Sections are unirradiated, low enrichment (≤ 1.25 wt.% U-235) cylindrical ingots with the following diameters (D) and lengths (L): 13" D x 3" L; 13" D x 6" L; and 10" D x 6" L.

The staff reviewed the criticality analyses presented in the SARP and performed independent confirmatory evaluation of criticality safety for each of the FERMCO Ingot Sections. The staff confirmed that the Transport Index (TI), and the number of packages proposed in the Rev. J SARP for each FERMCO Ingot Section 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 SARP. This review is documented in the SER for Rev. 11 of the Certificate of Compliance (CoC) dated July 15, 1999 and filed in Dockets 96-39-5467, 98-20-5467, and 98-26-5467. The conclusions reached in the earlier evaluation and SER for the non-criticality safety aspects of the SBWSC remain valid and applicable to the FERMCO Ingot Sections and will not be repeated here.

Chapter 6 - Criticality

6.1 Safety Evaluation

No special feature is incorporated in the design of the SBWSCs for criticality control. According to 10 CFR Part 71, criticality safety must be demonstrated for a fissile material package under NCT and HAC. HAC consists 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 hypothetical accident fire (even though the wooden boxes are most likely only charred), and that the ingots 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 ingots (and packages) allowed in a shipment that would remain subcritical with an adequate safety margin. Once the allowable number of ingots is obtained, the number of packages per shipment, N, can be determined based on the number of ingots 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 ingots 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 ingots 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 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 ingots.

Because neutron leakage from a system reduces reactivity, the most reactive configuration for a finite array of ingots 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.

Table 1 summarizes the results of the confirmatory criticality evaluation for each of the FERMCO Ingot Sections described in the Rev. J SARP. For each FERMCO Ingot Section and using the previous experience as a guide, the staff performed a minimum of eight MCNP calculations by systematically varying the lattice parameters to verify that the applicant has considered the optimal lattice parameters and the most reactive configuration in the 2xN damaged array calculations. When a slightly more reactive configuration was found with a set of staff's parameters, additional MCNP calculations were performed with incremental changes of parameter values to ensure that the calculated k_{adj} was still bounded by 0.95 with an adequate safety margin. Case files for these confirmatory calculations are archived as appropriate.

Table 1.
Transport Index (TI) and Confirmatory k_{adj}
for the FERMCO Ingot Sections

D x L (in.)	SBWSC Model	Ingots/ Package	Packages/ Shipment	TI	k_{adj}
13 x 3	G-4214 or G-4292	4	8	11.5	0.93958
13 x 6	G-4214 or G-4292	2	24	4.1	0.93888
10 x 6	G-4214 or G-4292	2	24	4.1	0.93938

6.3 Summary

The staff has evaluated the criticality safety analysis presented in the SARP for the FERMCO Ingot Sections. The staff has performed independent calculations and confirmed that the minimum TI values (and the corresponding maximum number of packages) for the FERMCO Ingot Sections 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 FERMCO Ingot Sections addressed in this SER can thus be safely packaged and transported in the designated models of the SBWSC.

Approved:

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Date: MAY 18 2000