Department of Energy
Germantown, MD 20874-1290

SAFETY EVALUATION REPORT (SER)
Rev. 14, Certificate of Compliance USA/5467/AF-85 (DOE) for the N Reactor Ingots in the Rev. L SARP for the Steel Banded Wooden Shipping Containers (SBWSC) Docket No. 00-24-5467

INTRODUCTION

The staff has evaluated the shielding and criticality results presented in Chapters 5 and 6 of the latest revision, L, of the SARP (Safety Analysis Report for Packaging) for the Steel Banded Wooden Shipping Containers (SBWSC). The latest revision of SARP is necessary due to the increase in the maximum ^{235}U enrichment (from 0.95-1.25 to 0.956-1.256 wt%) and inclusion of radioactive impurities in the payloads that affect both criticality and shielding (radiation source terms and dose rates) evaluation. This SER contains the staff's confirmatory evaluation of shielding for all types of payloads in the SBWSC, and criticality safety only for the four types of N-Reactor Ingots described in the SARP, i.e., Mark I Outer, Mark I Inner, Mark IV Outer, and Mark IV Inner Ingots.

The staff's independent confirmatory evaluation finds the SBWSC in compliance with the 10 CFR Part 71 and 49 CFR Part 173 dose rate limits for all the payloads requested in Rev. L of the SARP under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The staff's independent confirmatory evaluation also finds the SBWSC in compliance with the 10 CFR Part 71 criticality safety requirements for the N-Reactor Ingots with the maximum ^{235}U content $\leq$ 0.956 and 1.256 wt%. Specifically, the staff has confirmed that the Transport Index (TI), and the maximum number of packages proposed in the SARP for the N-Reactor Ingots in an exclusive use shipment, meet the 10 CFR Part 71 criticality safety requirements under NCT and HAC. Other payloads previously authorized can still be shipped if the payloads have the maximum ^{235}U contents $\leq$ 0.95-1.25 wt.% and meet all other conditions of approval in the Certificate of Compliance (CoC).

Other safety aspects (i.e., general information, structural, thermal, containment, operating procedures, acceptance tests and maintenance, and quality assurance) of the SBWSC have been reviewed for similar types of payloads in the Rev. G and Rev. J SARP and documented in the SERs for Rev. 11 and Rev. 12 of the CoC dated July 15, 1999 and May 2, 2000, respectively. The conclusions reached in the earlier evaluation and SERs for the other safety aspects of the SBWSC remain valid and applicable to the N-Reactor Ingots with the isotopic specifications in the Rev. L SARP and will not be repeated here.

CHAPTER 5, SHIELDING EVALUATION

The payloads to be shipped in the SBWSC include N Reactor ingots, RMI forged billets, Hanford RMI billets, and FERMCO material consisting of derbies, ingots, ingot sections, and scrap. All of these materials are unirradiated, slightly enriched uranium containing 0.956-1.256 wt% ^{235}U, trace amounts of ^{241}Pu, ^{99}Tc, ^{90}Sr, ^{234}U, and ^{236}U, and a balance of ^{238}U as shown in Table 5.2 of the SARP (Rev. L). The increase in the ^{235}U enrichment (from 0.95-1.25 to 0.956-1.256 wt%)

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and inclusion of trace impurities in the payloads necessitated a re-evaluation of the radiation source terms and dose rates for all the payloads in the SBWSCs.

Source Terms and Payload Configuration

The ORIGEN-2 code was used in the calculation of the photon and neutron source terms for the three uranium isotopic compositions listed in Table 5.2 of the SARP (Rev. L). For each uranium isotopic composition, the maximum source strength per gram of material was calculated as a function of radiation energy at a decay time of one year. The source terms for the individual pieces of ingots, billets, derbies and scrap were obtained by multiplying the source strengths per gram with the mass of the individual pieces calculated from their geometrical volumes and the density of uranium (18.96 g/cc). The geometrical volumes of the individual pieces were calculated from the physical dimensions listed in Table 1.2.3-1 of the SARP.

For the payload configuration used in the shielding calculations, the SARP assumed that no radiation shielding is provided by the SBWSCs under NCT and HAC. Dose rates were calculated for each piece at the surface, and at 1 m, 2 m, and 6 m from the end and the side of the piece, using the MCNP code with the photon and neutron source terms determined from the ORIGEN-2 calculations. The neutron source terms were multiplied by a factor of 2, assuming a spontaneous fission neutron contribution equivalent to that of an effective neutron multiplication factor (k-eff) of 0.5 for all payloads. The total dose rates for the various payload types were calculated by one of two methods: (1) multiplying the dose rates calculated for a single piece by the maximum number of pieces allowed in a shipment; or (2) calculating the dose rates at specified distances from a square array that contains the maximum number of pieces determined by the total weight limit, i.e., 40,000 lb. (18,144 kg) in a shipment.

The staff finds the first method to be highly conservative because it neglects the shielding provided by the uranium pieces. Therefore, the resulting dose rate should give the absolute maximum dose rate for any configuration containing such a number of payload pieces. The staff finds the second method of square array is also conservative to distances of 6 m; the dose rates in Table 1 are generated by the second method because the dose rates obtained by the first method exceed the regulatory limits. Skin dose rates from beta particles were included in the evaluation of each payload only for HAC, but not for NCT because of the limited range of beta particles which would be easily stopped by the SBWSCs. The staff finds the flux-to-dose rate conversion factors for gamma dose and the flux-to-dose rate conversion factors for neutron dose used in the SARP from ANSI/ANS-6.1.1-1991 and ANSI/ANS-6.1.1-1977, respectively, to be appropriate.

The staff finds the decay time of one year applied to the source term in the SARP acceptable and conservative for the shielding analysis because the decay photon source strength reaches its peak at approximately one year.

Results of Confirmatory Analysis

The staff examined the ORIGEN-2 and the MCNP input files and found the models acceptable for use in the shielding evaluation of the SBWSCs. However, the staff has made two adjustments in the confirmatory evaluation to ensure that the dose calculations are conservative for all the payloads specified in the SARP. The first adjustment is made to account for the increase of the maximum weight limit of the payload in a shipment from 40,000 lb (18,144 kg) to 42,000 lb (19,051 kg) in the SARP. This adjustment requires an increase in the calculated dose rates by a factor of 1.05 (42,000/40,000). The second adjustment is made to increase the spontaneous fission neutron contribution to the neutron source terms from a factor of 2 to 10.

These spontaneous fission neutrons factors are equivalent to those systems with a k-eff of 0.5 and 0.95, respectively. As the criticality analysis in the SARP shows, the majority of the payloads in the proposed shipment configuration are limited by criticality safety consideration and the k-eff values of the finite arrays of these payloads are close to and less than 0.95, not 0.5.

Table 1 lists the maximum dose rates for the limiting payloads from the Rev. L SARP and the corresponding values after adjustments in the staff confirmatory evaluation. Among the various types of payloads, the limiting results were obtained for 64 Mark 15 ingots and FERMCO Ingot Scrap of 13" OD x 6" L. Although the dose rates from the staff confirmatory evaluation are higher than those in Rev. L SARP, they are far below the regulatory limits for an exclusive use shipment.

Table 1. Maximum Dose Rates for the Limiting Materials in the Rev. L SARP and Corresponding Dose Rates after Adjustments in the Staff Confirmatory Evaluation

Dose Rate Location	Package Description	SARP Max Dose Rate mSv/h			Confirmatory[(1)] Max Dose Rate mSv/h			Regulatory Limits mSv/h
		n	γ	n+γ	n	γ	n+γ	Total
Normal Conditions of Transport (NCT)								
SBWSC Surface	64 Mark 15 Inner Ingots	0.090	1.600	1.700	0.945	1.680	2.625	10.0
1m from SBWSC Surface	64 Mark 15 Inner Ingots	0.0028	0.042	0.0448	0.0294	0.0441	0.0735	Not Specified
2m from Vehicle Surface	294 FERMCO 13in OD x 6 in L Scrap	0.0018	0.021	0.023	0.0189	0.0220	0.0410	0.100
6m from Vehicle Surface	294 FERMCO 13in OD x 6 in L Scrap	0.0004	0.0048	0.0053	0.0044	0.0050	0.0092	0.020
Hypothetical Accident Conditions (HAC)								
1m from SBWSC Surface	64 Mark 15 Inner Ingots	0.0028	0.0042	0.140[(2)]	0.0294	0.044	0.171[(2)]	10.0

(1) Neutron and gamma dose rates (n and γ) are adjusted by a factor of 1.05 to account for the increase in the maximum weight limit from 40,000 to 42,000 lb. Neutron dose rates (n) are further adjusted by a factor of 10 for the increase in k-eff from 0.5 to 0.95 (from 1/0.5 to 1/0.05).

(2) Includes the maximum beta effective dose equivalent of 0.093 mSv/h in the SARP and 0.098 mSv/h (after adjustment) in the staff confirmatory evaluation.

10 CFR 71.47 and 49 CFR 173.441 require that when the radiation limits for exclusive use are used, the shipper must provide “specific written instructions to the carrier for maintenance of exclusive use shipment controls.” Chapter 7, Operating Procedures, of the SARP does not provide for these written instructions. The staff finds the lack of provision for written instructions acceptable because although the exclusive use radiation limits are used, the analysis is so conservative that the 2.0 mSv/h radiation limit at the surface of the SBWSC for non-exclusive use will not be exceeded. To ensure that the exclusive use radiation limits are not mistakenly applied, the CoC starting with Rev. 14 is conditioned on the radiation at the surface of the SBWSC not exceeding 2 mSv/h, the limit for non-exclusive use shipments, as measured by the radiation survey required of every radioactive materials package by 10 CFR 71.87(j) and 49 CFR 713.475(i).

Further, the staff notes the TI for radiation, based on the calculated NCT dose rate at 1 m from the external surface of the payload, is 7.4 calculated as 0.0735x100. However, because of the highly conservative nature of the shielding evaluation, the dose rate measured during the radiation survey of the package after loading is expected to be far lower than the calculated 0.0735 mSv/h (7.35 mRem/h) at 1 m from the package surface.

In summary, the staff's confirmatory shielding evaluation finds the SBWSC in compliance with the 10 CFR Part 71 dose rate limits for NCT and HAC. Pre-shipment radiological survey of the containers with payload will ensure that the regulatory dose rate requirements are satisfied for radiation safety.

CHAPTER 6, CRITICALITY EVALUATION

The criticality confirmatory evaluation in this SER addresses only the four N-Reactor Ingots (Mark I Outer, Mark I Inner, Mark IV Outer, and Mark IV Inner) in the Rev. L SARP.

No special feature is incorporated in the design of the SBWSC for criticality control. The containers have not been tested under HAC and cannot be credited to maintain package integrity under all conditions of transport. For conservative criticality safety analysis, the SARP generally assumed that all SBWSCs in a shipment are burned during HAC and the ingots are "scattered and arranged" in the most reactive configuration as required by 10 CFR 71.55 and 10 CFR 71.59. Consequently, the most limiting criticality safety configuration is determined by the 2xN damaged array analysis as defined in 10 CFR 71.59. Close and full water reflection (12 inches) is assumed on all sides of the 2xN damaged array in the Monte Carlo MCNP calculations.

The SARP presented results of calculations for an infinite array of ingots to determine if a 2xN finite array analysis is necessary. For the N-Reactor Ingots listed in Table 2, the Mark I Inner, Mark IV Outer, and Mark IV Inner Ingots (all with 0.956 wt.% U-235) have their k_∞+2s+bias less than the subcriticality safety criterion of 0.95. These ingots thus have no criticality safety concern and no need for finite array analysis. However, these N-Reactor Ingots are limited by the maximum allowable weight (42,000 lb) in a shipment and a TI can be calculated based on the maximum weight limit as shown later.

Table 2. Comparison of Infinite Array Criticality Evaluation Results for N-Reactor Ingots Between Previous Revisions and the Rev. L SARP.

Payload	Description	Previous Revisions[1]		Rev. L[1]	
		^{235}U, wt%	$k_\infty+2\sigma+bias$	^{235}U, wt%	$k_\infty+2\sigma+bias$
N-Reactor Ingots	Mark I Outer	1.250	0.9555	1.256	0.9555
	Mark I Inner	0.950	0.9094	0.956	0.9116
	Mark IV Outer	0.950	0.8871	0.956	0.8874
	Mark IV Inner	0.950	0.9094	0.956	0.9116

(1) σ is the uncertainty obtained in the MCNP calculations. The code bias (0.00258) is obtained from benchmark calculations against the critical experiments.

For the Mark I Outer Ingots with 1.256 wt.% U-235 enrichment, the SARP shows $k_\infty+2\sigma+bias > 0.95$ and thus only a finite number of packages can be transported in a shipment to meet the 10 CFR Part 71 criticality safety requirements.

The finite array analysis in the Rev. L SARP included a systematic search of the optimal lattice parameters (axial moderator gap, moderator density, and lattice pitch) and a re-optimization to obtain the minimum leakage surface for the most reactive configuration. The result is a finite array of 43.5 Mark I Outer Ingots (29,247 kg total uranium mass) with a $k_{eff}+2\sigma+bias$ of 0.9362. The staff performed independent calculations and confirmed that the most reactive configuration has indeed been established in the SARP for the N-Reactor Mark I Outer Ingots and the staff obtained a $k_{eff}+2\sigma+bias$ of 0.93743. Based on the number of ingots per package, two, for the Mark I Outer Ingots in the SBWSC, the TI for criticality control is 4.6 for a maximum of 21= 100/4.6 packages in an exclusive use shipment. However, 21 packages containing 42 Mark I Outer Ingots (62,244 lb) would have exceeded the 42,000 lb weight limit, since each N-Reactor Ingot weighs 1,482 lb.

Transport Index for Maximum Number of Packages

The staff evaluation of criticality analysis results in the Rev. L SARP found that all four N-Reactor Ingots have no criticality safety concern if they meet the maximum weight limit (42,000 lb) for the SBWSC. A simple calculation using the weight of a single N-Reactor Ingot and the tare weight of the SBWSC gives the maximum number of the SBWSCs (N) that is allowed under the maximum weight limit of 42,000 lb in an exclusive use shipment. The Transport Index can then be derived from $TI = 50/N$ and the sum of $TI \leq 100$. Table 3 summarizes the results and show a minimum TI of 7.6 for up to 13 SBWSCs containing the N-Reactor Ingots (two per package) in an exclusive use shipment.

Table 3. Minimum TI and Maximum Number of Packages for Exclusive Use Shipment for N-Reactor Ingots in the SBWSCs

Payload	Description	SBWSC Model	Ingots per SBWSC	Min. TI	Max. SBWSC per Shipment
N-Reactor Ingots	Mark I Outer	G-4273-6	2	7.6	13
	Mark I Inner	G-4273-6	2	7.6	13
	Mark IV Outer	G-4273-6	2	7.6	13
	Mark IV Inner	G-4273-6	2	7.6	13

<u>Summary</u>

The staff's independent confirmatory evaluation finds the SBWSC in compliance with the 10 CFR Part 71 dose rate limits for all the payloads (including the N-Reactor Ingots) under NCT and HAC. The staff's independent confirmatory evaluation also finds the SBWSC in compliance with the 10 CFR Part 71 criticality safety requirements for the N-Reactor Ingots, and the TIs and the maximum number of packages in Table 3 are conservative with adequate criticality safety margin. All four types of the N-Reactor Ingots described in the Rev. L SARP can be safely packaged and transported in the designated model of the SBWSC.

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