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CERTIFICATION OF DOT 7A TYPE A PACKAGING IN TYPE AF CONFIGURATIONS*

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ABSTRACT

Based on the U.S. Department of Transportation (DOT) regulations in 49 CFR 173.7(d), the U.S. Department of Energy (DOE) Order 460.1B (DOE 2003) codifies the authority of certification of Type-B and fissile material transportation packaging to the Office of Environmental Management (EM), except for materials of interest to national security, naval propulsion systems, and civilian radioactive waste management. DOE Order 460.1B also stipulates that the EM certification of Type B and fissile materials transportation packaging shall be in accordance with the U.S. Nuclear Regulatory Commission (NRC) safety standards in 10 CFR Part 71. The Packaging Certification Program (PCP) of the Office of Safety Management and Operations (EM-60) is supported by technical review teams at Argonne National Laboratory and Lawrence Livermore National Laboratory.

In recent years EM-60 has received requests for certification of fissile material packages for the shipment of low-enrichment uranium oxides in DOT 7A Type A drums in Type AF configurations. One request originally sought for DOT exemption (i.e., special permit) per 49 CFR 107, Subpart B that underwent reviews by DOE, NRC, and DOT. DOT eventually advised DOE that the packaging should be certified as a DOT 7A Type A drums in a Type AF configuration. Historically EM-60 has also issued Certificate of Compliances (CoC) for low-enrichment fissile uranium metals in wooden boxes as Type B packages for shipment, even though the wooden boxes do not meet the structural and thermal requirements in 10 CFR 71 under hypothetical accident conditions. There are also provisions in 10 CFR 71.15 for exemption from classification as fissile material, and in 10 CFR 71.22 General license: Fissile material that specifically references the DOT requirements in 49 CFR 173.417(a) for Type A package. The myriad of NRC and DOT regulations applicable to fissile materials and Type A packages availed alternative approaches in the requests for packaging certification; however, in all cases the primary concern for fissile material packages is the assurance of criticality safety in the shipment under both normal conditions of transport and hypothetical accidents.

This paper will present a case in the certification of DOT 7A Type A packaging in Type AF configurations, drawing highlights from a recent certification review of packagings for shipment of low-enrichment uranium oxides in Type A drums. Various regulatory requirements are also discussed.

INTRODUCTION

The Savannah River Operations Office of the Department of Energy (DOE) has submitted a request for change to the Certificate of Compliance (CoC) USA/9976/AF (DOE), Rev. 0, in order to meet the Nevada Test Site (NTS) Waste Acceptance Criteria for the shipment of 227 drums containing low-enrichment uranium oxide (LEUO) [DOE 2006]. Steel shots, up to 50 lbs, will be added

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to each of approximately two-thirds of the 227 Industrial Packaging (IP)-1 drums shown in Figure 1 below.

Fig. 1. Type A drums containing LEUO material

The original approval for CoC USA/9976/AF (DOE), Rev. 0 was documented in the Packaging Certification Approval Record under Docket 04-10-0000. The DOE had originally requested the Department of Transportation (DOT) to issue an exemption from certain fissile regulations in order to permit the one-time, one-way shipment of uranium oxide powder with U^{235} enrichment up to 1.098 wt.% in 227 IP-1 drums meeting DOT Specification 7A Type A performance requirements. The exemption demonstrated the criticality safety of proposed shipping campaign with specified exclusive use shipment controls. There are no containment or shielding issues associated with the contents.

At the request of DOT, the Nuclear Regulatory Commission reviewed DOE's exemption application and confirmed the criticality safety of the proposed shipments. However, DOT subsequently advised DOE that an exemption was not required, insofar as sufficient documentation has been provided to justify DOE certifying the drums as Type AF containers. The contents approved for USA/9976/AF (DOE), Rev. 0 do not include steel in any of the 227 drums.

The technical basis for the material change of adding steel to drums is provided in the *Savannah River Site Request for Department of Transportation Exemption (U),* WSRC Document No. OBU-TRA-2004-00022, Rev. 2, June 8, 2006 (SRS 2006). The Revision 2 changes involved mainly Attachment 6 of OBU-TRA-2004-00022, Rev. 1 that included additional calculations showing no adverse effects to criticality safety during transportation due to the addition of steel to drums. The certification review and confirmatory evaluation of the technical basis document is given in the following sections.

REGULATORY REVIEW

1. Spherical safe mass for the LEUO material

For a given amount of fissile material, the most reactive configuration is one that achieves optimal moderation, minimizes leakage, and attains full reflection of neutrons emitted from the fissile material, e.g., U^{235}, for sustaining chain reactions. A UO_3/H_2O mixture in spherical geometry with water surrounding the sphere is generally considered as the most reactive configuration that can be achieved at a certain intermediate ratio (H/U) of the moderator content in the mixture.

Monte Carlo calculations were performed using the MCNP-4C code (MCNP 1992) to obtain the safe spherical mass of LEUO and the results are given in Attachment 4 of the technical basis document (SRS 2006). MCNP-4C is a general-purpose Monte Carlo radiation transport code developed and maintained by the Los Alamos National Laboratory and used widely by members of the criticality safety community. UO_3/H_2O mixtures in a spherical geometry surrounded by 30-cm water were modeled in the MCNP-4C calculations with the water content in the mixtures varying from 0 to 40 wt.% (to determine the optimum moderation), and with U^{235} enrichments of 1.098, 1.084, 1.05, and 1.033 wt%. The criticality safety criterion used is a k_{safe} value of 0.934 such that the calculated $k_{eff} + 2\sigma \leq k_{safe}$, where k_{eff} is the effective neutron multiplication factor and σ is the standard deviation associated with the statistical uncertainty of the MCNP-4C calculations. Table 1 below lists the values of the spherical safe mass thus obtained for configurations with optimum moderation and full reflection. No neutron poison, e.g., boron, or absorber material,

Table 1. Spherical safe mass for UO_3/H_2O mixtures with optimum moderation and full reflection by water

U^{235} enrichment (wt. %)	1.033	1.050	1.084	1.098
Spherical safe mass (metric tons, MT)	4.50	4.06	3.07	2.81

e.g., steel, were included in these MCNP-4C calculations.

An equation has been derived to fit the MCNP-4C calculated spherical safe mass as follows:

UO_3 Mass (MT) = -26.698 (wt.% U^{235}) + 32.076

This equation was used to calculate the values of the safe mass for the 20 shipping groups listed in Attachment 1 of the technical basis document (SRS 2006). Each shipping group consists of multiple number of drums, each containing LEUO with maximum U^{235} enrichments between 1.033 and 1.098 wt.%.

EM-60 Evaluation - The spherical safe mass values listed in Table 1 for UO_3/H_2O mixtures are bounded by results of independent calculations documented for UO_2-H_2O homogeneous mixtures (NRC 1978); the extra oxygen atom in UO_3 is not expected to have any significant effect on the criticality calculations. The use of a criticality safety criterion, k_{safe} = 0.934, is more conservative than the usual k_{safe} value of 0.95 with a safety margin of 5%. The assumption of a UO_3/H_2O mixture in spherical geometry with optimum moderation and full reflection is the most conservative case, and, therefore, the limits placed on the number of LEUO drums in the shipment plan, to be discussed later under criticality safety index determination, should increase the margin on criticality safety even for the worst-case hypothetical accident.

2. Criticality analysis for arrays of UO_3 drums

10 CFR 71.59 defines standards for arrays of fissile material packages that are applicable to the LEUO drums. Part (a) of 71.59 states "... the designer of a fissile material package shall derive a number N based on all of the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water:

(1) Five times N undamaged packages with nothing between the packages would be subcritical;

(2) Two times N damaged packages, if each package were subjected to the tests specified in 71.73 (Hypothetical accident conditions) would be subcritical with optimum interspersed hydrogenous moderation; and

(3) The value of N cannot be less than 0.5."

Criticality calculations were performed for arrays of UO_3 drums using the MCNP-4C code and the details of the models and results are given in Attachment 6 of the technical basis document (SRS 2006). Two 3-D array configurations were modeled, one with five rows of 24 drums in each row and arranged with a triangular pitch (4-5-6-5-4), for a total of 120 drums; and the other a 5 x 5 x 5 square-pitch array for a total of 125 drums. The total number of drums in either configuration bounds the "5N" undamaged packages that vary from 40 to 65, i.e., 8 to 13 drums, in each of the twenty LEUO shipment groups described in Attachment 1 of the technical basis document (SRS 2006).

In all of the array calculations, each drum was modeled as a cylinder (55.88-cm ID x 83.82-cm internal height) with wall, top and bottom treated as 16-gauge (0.1519-cm thickness) carbon steel. Each drum was assumed to contain 803 lb of UO_3 with a maximum U^{235} enrichment of 1.098 wt.%, and with 3 to 24 wt.% H_2O. No neutron poison, e.g., boron, or absorber material, e.g., additional steel shots, were included in the MCNP-4C calculations. The fissile solution in each drum was modeled as a cylinder filled with LEUO material inside the internal radius of the drum; other parameters considered in the 3-D array models included the gap, i.e., surface-to-surface separation (0, 2, 4 cm) between drums, interstitial water density (0, 10, 20, and 100 wt.%), and full reflection on all sides of the arrays by water. The criticality safety criterion, $k_{eff} + 2\sigma \leq k_{safe}$, where k_{safe} = 0.934 and k_{eff} and σ are from the MCNP-4C calculations for the arrays, is the same as that used for the determination of the spherical safe mass in Attachment 4 of the technical basis document (SRS 2006).

The calculated k_{eff} values for the two most reactive configurations are 0.931 (σ = 0.0005) for the triangular-pitch array of 120 drums, and 0.923 (σ = 0.0005) for the square-pitch array of 125 drums. The triangular-pitch configuration has 15 wt.% H_2O in the UO_3/H_2O mixture inside each drum and 10% interstitial moderation between drums. The square-pitch configuration has 18 wt.% H_2O in the UO_3/H_2O mixture inside each drum and no interstitial moderation

between drums. In both configurations, the calculated values of $k_{eff} + 2\sigma$ are less than the conservative $k_{safe} = 0.934$.

EM-60 Evaluation – MCNP-X, a more current version of MCNP than MCNP-4C, was used to perform confirmatory calculations of the two most reactive configurations of arrays identified in Attachment 6 of the technical basis document. Table 2 shows the comparison of the MCNP calculations. The k_{eff} values obtained by EM-60 differ slightly from those of the technical basis document. The values of $k_{eff} + 2\sigma$ are, however, all lower than k_{safe} of 0.934, with an adequate margin on criticality safety.

Table 2. Comparison of MCNP calculations for the most reactive configurations of arrays of drums

	Wt.% H_2O (mixture / interstitial)	k_{eff} (σ)	$k_{eff} + 2\sigma$
SRS	(15 / 10)[1]	0.931 (0.0005)	0.932
EM-60	(15 / 10)[1]	0.93266 (0.00018)	0.93335
SRS	(18 / 0)[2]	0.923 (0.0005)	0.924
EM-60	(18 / 0)[2]	0.91720 (0.00067)	0.91788

[1]Triangular pitch; [2]square pitch

3. Criticality Safety Index determination

The critical safety index (CSI) for each of the 20 groups of shipments was calculated based on the mass limit, i.e., spherical safe mass, and 10 CFR 71.59(a)(2). For example, the CSI of Shipping Group 1 in Attachment 1 of the technical basis document (SRS 2006) is determined as follows: The 2N damaged drums is calculated by dividing the spherical safe mass (6,089 lbs), which depends on the U^{235} enrichment, by the average drum weight (757 lbs) of the eight drums in this shipping group. This gives N = 4.02, and CSI = 50/N = 12.44 (rounded up to 12.5). For exclusive use shipment and according to 10 CFR 71.59(c)(2), the sum of CSI shall be less than 100, hence the number of drums permitted is 100/CSI = 100/12.5 = 8.04 (rounded down to 8). The values of CSI and the permitted number of drums for the other shipping groups in Attachment 1 of the technical basis document (SRS 2006) were determined in a similar manner; they are tabulated in Table 3, along with the mass limits for each shipping group.

EM-60 Evaluation

The mass limits, CSI and the permitted number of drums in the 20 shipping groups in Table 3 are confirmed by the EM-60 review staff.

Table 3. Mass limits, CSI and number of drums permitted in shipment groups 1 to 20

Group	Max. U^{235} (wt.%)	Mass (lbs)	CSI	No. Drums[1]
1	1.098	6,089	12.5	8
2	1.066	7,973	9.6	10
3	1.063	8,150	9.4	10
4	1.062	8,209	9.3	10
5	1.060	8,326	8.9	11
6	1.059	8,385	9.1	11
7	1.055	8,621	8.8	11
8	1.053	8,738	8.7	11
9	1.089	6,089	12.5	8
10	1.050	8,915	8.5	11
11	1.048	9,033	8.2	12
12	1.046	9,151	8.3	12
13	1.043	9,327	8.2	12
14	1.037	9,680	8.0	12
15	1.034	9,857	7.7	13
16	1.031	9,916	7.7	13
17	1.026	9,916	7.7	13
18	1.017	9,916	7.7	13
19	1.010	9,916	7.7	13
20	1.003	9,916	7.7	13

[1]Exclusive use shipment

4. Reactivity change due to adding steel shots (up to 50 lbs) to drums

The MCNP calculations performed for the spherical safe mass determination and for the most reactive array configurations did not include neutron poison, e.g., boron, or absorber material, e.g., steel shots, as part of the contents in the drums. Adding steel shots to the drums is expected to decrease the reactivity of the system (individual drum and array of drums) due to parasitic neutron absorption. This was demonstrated in the MCNP calculations for which 42 and 50 lbs of steel were modeled as a fictitious lid and added to each drum of the two

most reactive configurations of arrays identified in Attachment 6 of the technical basis document (SRS 2006). The calculated values of $k_{eff} + 2\sigma$ are 0.91932 and 0.91746, respectively, which represent a reduction of 1.31% and 1.51% of the corresponding values of $k_{eff} + 2\sigma$, without the addition of steel.

5. Type A packaging shipping requirements

Item 4 Conditions in USA/9976/AF (DOE) states that "*This certificate is conditional upon the fulfilling of the applicable Operational and Quality Assurance requirements of 49 CFR parts 100-199 and 10 CFR Part 71, and the conditions specified in Item 5 below.*" The packaging requirements for fissile materials in 10 CFR 71.55 and 71.59 have been evaluated and shown satisfactory per previous sections (1 to 4) of the regulatory review and confirmatory evaluation. All other requirements for fissile material shipments in Type A packagings such as shipping papers, marking, labeling, and placarding in 49 CFR 172.203(d), 172.310, 172.403, and 172.500, respectively, must also be met. Attachment 5A of the technical basis document (SRS 2006) detailed the compliance of the LEUO 55-gallon IP-1 drums to the regulatory requirements in 49 CFR 173.24 *General Requirements for packagings and packages*; 173.24a *Additional general requirements for non-bulk packagings and packages*; and 173.411(b) for *Industrial packagings* (IP)-1 drums. The specific requirement in 49 CFR 173.24a(b)(2) for non-bulk packaging filling limits is met by the restriction that the gross mass shall not exceed the 900 lbs capacity of the IP-1 package.

Attachment 5B of the technical basis document (SRS 2006) contains closing instructions for the LEUO 55-gallon IP-1 drums after the previously closed drums are opened for addition of steel shots. Attachment 8B of the technical basis document (SRS 2006) establishes the acceptance criteria for drum integrity. Any drum that does not meet the acceptance criteria shall be overpacked in an 85-gallon drum meeting DOT 7A Type A requirements and shipped accordingly.

It should be noted that Attachment 8A of the technical basis document (SRS 2006) Instructions for compliance with alternative packaging requirements of 49 CFR 107.105(c)(9) is related to an application for exemption (i.e., special permit), not for certification of a Type AF packaging. Attachment 8A, however, contains other relevant information for the IP-1 drums on quality assurance controls, package design, manufacture, performance test criteria, in-service performance, and service-life limitations. The in-service performance section of Attachment 8A of the safety basis document (SRS 2006) is where the NTS waste disposal criterion is mentioned, i.e., up to 50 pounds of steel shot be placed into approximately two-thirds of the drums (on top of the LEUO).

EM-60 Evaluation

The attachments in the technical basis document that are related to the Type A packaging shipping requirements and IP-1 drums are reviewed and found acceptable.

DISCUSSION

As mentioned earlier, the DOE originally requested the DOT to issue an exemption from certain fissile regulation in order to permit a one-time, one-way shipment of LEUO from the SRS to the NTS. The request for exemption (i.e., special permit) followed the DOT regulations in 49 CFR 107, Subpart B and included an evaluation of repackaging the LEUO into existing Type AF packaging for shipment. Among the 65 Type AF packagings identified from www.rampac.com, 53 are for fuel/ overpacks/pellets/liquids/import-export only; 12 are approved for compounds/powder; and 9 out of the 12 are unique designs. Re-packaging the LEUO material into each of these unique designs would cost anywhere from $670,000 to ≈$4M on containers alone, not to mention labor, exposure, and transportation.

Whereas DOT eventually advised DOE that the packaging should be certified as a DOT 7A Type A drums in Type AF configuration, the original CoC USA/9976/AF (DOE), Rev. 0 does not address a content modification, i.e., adding steel, up to 50 lbs per drum, to meet the NTS Waste Acceptance Criteria; hence requiring additional criticality safety calculations and revision of the technical basis document, followed by additional review and revision of the CoC. Had the specific NTS Waste Acceptance Criteria become known in advance of the shipment, nearly 6 months would have been saved by including steel in the criticality safety evaluation in the original CoC.

Accurate content description is, therefore, a key requirement in an application for packaging certification.

It is of interest to note that Title 10 of the Code of Federal Regulations, Part 71.4 (10 CFR 71.4) defines *fissile material* as the radionuclides uranium-233, uranium-235, plutonium-239, and plutonium-241, or any combination of these radionuclides. Also defined in 10 CFR 71.4 is *package* that means the packaging together with its radioactive contents as presented for transport, and includes fissile material packages [Type AF, Type BF(U), and Type BF(M)] and non-fissile, radioactive material packages (Type A and Type B). *Type A quantity* means a quantity of radioactive material, the aggregate radioactivity of which does not exceed A_1 for special form radioactive material, or A_2, for normal form radioactive material, where A_1 and A_2 are given in Table A–1 of 10 CFR 71, or may be determined by procedures described in Appendix A of 10 CFR 71. *Type B quantity* means a quantity of radioactive material greater than a Type A quantity.

For uranium-235, uranium-238, and both natural and depleted uranium, the A_1 and A_2 values listed in Table A-1 of 10 CFR 71 are unlimited; hence, a Type A or Type AF package is sufficient to meet the Federal regulations for the shipment of these fissile and radioactive contents. Historically EM-60 has also issued CoCs for low-enrichment fissile uranium (LEU) metal ingots in steel-banded wooden shipping containers (SBWSC) [Ferrell 2000] as Type BF packages for shipment. Another example of certified Type BF package is the ATR packaging for fresh, un-irradiated ATR fuel elements containing highly enriched U^{235}. Neither the SBWSC, nor the ATR, meets the structural and thermal requirements in 10 CFR 71.73 under hypothetical accident conditions; the assurance of criticality safety, however, remains the primary concern and must be demonstrated during shipment under both normal conditions of transport and hypothetical accidents. The EM-60's criticality safety evaluation performed for the various LEU metal ingots in the SBWSCs used in the Fernald shipping campaign between 1999 and 2001 can be found in the two references (Liaw and Liu 2000; Liaw et al. 2001). The ATR evaluation can be found in www.rampc.com under the NRC Certificate of Compliance for the package.

There are other regulations for fissile material packages. 10 CFR 71.15 *Exemption from classification as fissile material* lists five paragraphs that exempt fissile material from classification as fissile material and from the fissile material package standards of 10 CFR 71.55 and 71.59, but are subject to all other requirements of 10 CFR 71, except as noted. For example, individual package containing 2 grams or less fissile material is exempt from classification as a fissile material package. Another exemption is the uranium enriched in uranium-235 to a maximum of 1 percent by weight, and with total plutonium and uranium-233 content of up to 1 percent of the mass of uranium-235, provided that the mass of any beryllium, graphite, and hydrogenous material enriched in deuterium constitutes less than 5 percent of the uranium mass.

10 CFR 71.22 *General license: Fissile material* states that a general license is issued to any licensee of the NRC to transport fissile material, or to deliver fissile material to a carrier for transport, if the material is shipped in accordance with this section. The fissile material need not be contained in a package which meets the standards of subparts E and F of 10 CFR 71; however, the material must be contained in a Type A package. The Type A package must also meet the DOT requirements of 49 CFR 173.417(a). The general license applies only to a licensee who has a quality assurance program approved by NRC as satisfying the provisions of subpart H of 10 CFR 71. These requirements, and those mass limits for general license packages containing mixed quantities of fissile material or U^{235} of unknown and known enrichment per 10 CFR 71.22(e) in Table 71-1 and Table 71-2, respectively, offer an alternative means to calculate the CSI for a shipment of multiple packages containing fissile material, such as the LEUO in Type A drums.

SUMMARY

A recent case of DOE certification of DOT 7A Type A packaging in Type AF configuration has been presented, drawing highlights from the certification review of packagings for shipment of the LEUO material in Type A drums. The technical basis document has been reviewed to determine the safety adequacy for the request for change to CoC USA/9976/AF (DOE), Rev. 0 to add steel to drums for the LEUO shipments. Based on EM-60's confirmatory evaluation,

there is an adequate margin and reasonable assurance of criticality safety during transportation for each of the 20 shipping groups identified in Table 3. The mass limits of LEUO and the number of drums permitted under exclusive use shipment for the shipping groups were determined very conservatively based on the spherical safe mass and 10 CFR 71.59(a)(2). The requirement in 10 CFR 71.59(a)(1) is also satisfied by the MCNP-4C criticality calculations shown in Table 2. These MCNP calculations assumed no neutron poison, e.g., boron, nor absorber material, e.g., steel shots inside the drums. Adding steel shots to the drums is expected to reduce the reactivity due to parasitic neutron absorption, which was confirmed for two of the most reactive array configurations identified in Attachment 6 of the technical basis document. Adding steel shots to drums, therefore, will further increase the criticality safety margin for the shipments.

The technical basis document has demonstrated that the drums would satisfy the requirements of 10 CFR 71.55(e). If the drums were subjected to the hypothetical accident conditions in 10 CFR 71.73 (drop and fire), it is anticipated that the drums would breach and the LEUO contents dispersed, rather than conglomerate, into a sphere with optimum moderation and full reflection. The technical basis document has also demonstrated that all other requirements for fissile material shipments in Type A packagings and IP-1 drums in 49 CFR 172 and 173 are met.

The CoC USA/9976/AF (DOE), Rev. 1 was issued by EM-60 on September 15, 2006, and cancelled on December 4, 2006 after the one-time, one-way shipment from the SRS to the NTS was completed. The CoC and its technical basis documented in the Safety Evaluation Report can be found in www.rampac.com.

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