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Certification of the Mound 1 KW Package for Shipping of Plutonium Dioxide Source Material

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DISCLAIMER

CERTIFICATION OF THE MOUND 1 KW PACKAGE FOR SHIPPING OF PLUTONIUM DIOXIDE SOURCE MATERIAL*

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ABSTRACT

The Department of Energy (DOE) has established procedures for obtaining certification of packagings used by DOE and its contractors for the transport of radioactive materials. Specifically, DOE Orders 5480.3[1] and 1540.2[2] provide references for other DOE Orders which must be followed when an applicant submits a Safety Analysis Report for Packaging (SARP). From the orders, Department EH of DOE, has internal oversight responsibility for transportation and packaging safety; package certification falls under EH responsibility; transportation and packaging safety division in EH certifies packages for DOE; and use of DOE-certified packages is authorized by DOT. An independent review of the SARP must confirm that the packaging designs and operations meet safety criteria at least equivalent to these standards.

This paper will discuss the independent review process of the shielding section of the Mound 1 kW SARP; describe the geometry of the packaging and the load configurations; discuss the analysis of the various neutron and photon source terms that were used for the load configuration under analysis; and provide illustrations of the use of the monte-carlo code, COG[3], which was utilized to perform the shielding analysis.

I. INTRODUCTION

EG&G Mound Technologies submitted a SARP[4] to DOE requesting certification for the transport of PuO_2 powder heat source material in the Mound 1 kW package as type B(U) Fissile Class I in support of the Office of Special Applications (NE-53), Space and Defense Power Systems. U. S. Department of Energy. Lawrence Livermore National Laboratory was asked to provide an independent analysis of the SARP to confirm that it meets the conditions set forth above.

The Mound 1kW package consists of a cask that is designed to carry three different loads. Of the three possible load configurations, independent review of the shielding will be presented in this paper for only the third configuration, threaded or welded product cans. Mound has requested certification for land and sea transport in an 8 x 8 x 20 ft cargo container[5] and land transport in a Safe and Secure Trailer. Transport is to be as exclusive use shipment.

The shielding section of the SARP was reviewed to determine that the Mound 1kW package shielding was designed in a manner that will assure compliance with the performance requirements of 10CFR Part 71,[6] paragraph 71.47 and 49CFR Part 173,[7] paragraph 173.441 for an exclusive use shipment under normal conditions of transport and 10CFR Part 71, paragraph 71.51 for hypothetical accident conditions.

II. MOUND 1KW PACKAGE DESCRIPTION

The Mound package was designed for transportation of up to one kilowatt of plutonium dioxide source material. A Type 304 stainless steel frame constructed of 2 x 2 x 3/8 inch angle and 1 1/2 x 1 1/2 x 1/4 inch bracing is 36 inches high with a 30.5 inch square base. Rectangular hollow structural tubes of Type A-500 carbon steel, bolted to the bottom of the framework, form the base of the shield and allow forklift access. The shield is completely enclosed with a stainless steel wire mesh. Figure 1.0 shows the Mound 1 kW package with the personnel shield attached.

The cask is a 1.5 inch thick, welded stainless steel vessel 19.5 inches high with an outside diameter of 9.5 inches. A base plate welded to the bottom of the cask is bolted to the personnel shield during transport. The cask contains both primary and secondary containment vessels constructed of Type 304L stainless steel tubing with .12

inch wall thickness. The secondary containment vessel (SCV) is 6.38 inch outside diameter by 16.25 inches tall. Two different primary containment vessel (PCV) sizes can be used: one is 6 inches outside diameter by 5 inches tall, the other is 6 inches outside diameter by 5.75 inches tall. The base plates and cover plates are .5 inch thick Type 304L stainless steel and are welded to the vessels after loading. Three primary containment vessels can be loaded into the secondary containment vessel. The three different loads that the cask is designed to carry are as follows:

1. Three general purpose heat source (GPHS) modules (four fuel pellets per module, twelve pellets per shipping package). The GPHS is a component of the radioisotope thermoelectric generator that will provide power for a number of space missions. It is a 250 Watt module containing four PuO_2 pellets encased in an iridium capsule. The capsule is protected by a graphite impact shell which fits inside a thermal insulator that is surrounded by a reentry member. This entire assembly is supported by a graphite block which fits snugly into the 5 inch tall primary containment vessel
2. Nine multihundred-watt (MHW) source spheres. The Multihundred Watt Isotope Heat Source modules are shipped in the form of fuel sphere assemblies. The fuel spheres are 100 watts of 80 to 84 wt% ^{238}Pu inside a welded .025 inch thick iridium impact shell assembly containing vents to allow helium escape. The iridium sphere is placed into a .46 inch thick wound graphite impact-energy-absorbing shell. Three spheres can fit into one primary containment vessel; a graphite spacer is added to limit motion within the containment vessel.
3. Eight threaded or welded product cans containing the GPHS fuel pellets, or powder fuel (two fuel pellets per product can; or a maximum of 130 g of ^{238}Pu as plutonia powder per product can at 89.21% enrichment). Threaded or Welded Product Cans can hold one of these three:

   a) A maximum of two GPHS fueled cladded assemblies segregated by 1.868 inch diameter graphite separators that fit over each end of the assembly. A maximum of sixteen GPHS fueled clad assemblies in welded cans can go into the secondary containment vessel.

   b) Two GPHS fueled cladded assemblies inside a graphite impact shell. A maximum of eight GPHS graphite impact shell assemblies in threaded product cans can go into the secondary containment vessel.

   c) A plutonium dioxide powder can (SRS configuration) is a 3.38 inch tall stainless steel tube with a 1.75 inch outside diameter, with a wall thickness of 0.1875 inches. The lid and base are 0.1 and 0.2 inches thick, respectively. The can is designed to hold 130 g of PuO_2 powder. A .02 inch thick copper gasket seals the powder can. A maximum of eight plutonium dioxide powder product cans can go into a secondary containment vessel.

In addition to these three configurations, the Mound 1kW package will also transport eight Russian-designed product cans containing 130 g of ^{238}Pu as plutonia powder per product can at 89.21% enrichment. In the Russian configuration, the PuO_2 powder heat source material is to be retained within eight welded stainless steel product cans, each of which holds a single threaded stainless steel ampule inside a welded stainless steel capsule.

In both the SRS and Russian shipping configurations, four product cans are positioned within a graphite support block and contained within each of two completely welded cylindrical stainless steel primary containment vessels (PCVs). The two PCVs are stacked on top of each other, with a graphite filler block in between, and contained within a completely welded cylindrical stainless steel secondary containment vessel (SCV). The SCV, with two PCVs , is confined by the stainless steel cask, which is surrounded by the stainless steel cage and wire mesh personnel shield described above. Figure 2.0 shows the product can containment assembly.

This work describes the review of the SRS-configured product cans.

III. REVIEW PROCESS

Each of the different sections of the SARP are reviewed by individuals with expertise in the corresponding area, except that the introductory section which contains the general information, and the quality assurance section are usually reviewed by all, in addition to their own sections. The general information is reviewed to determine if the packaging and its contents are described in sufficient detail to identify the package accurately and to provide a sufficient basis for evaluation of the package. The scope of the review covers the use of the packaging, the packaging description, the operational features, the contents of the packaging , the packaging evaluation, the quality assurance program and supportive information and documentation. The review must insure that the SARP contains all information required to demonstrate compliance with DOE Orders as described above.

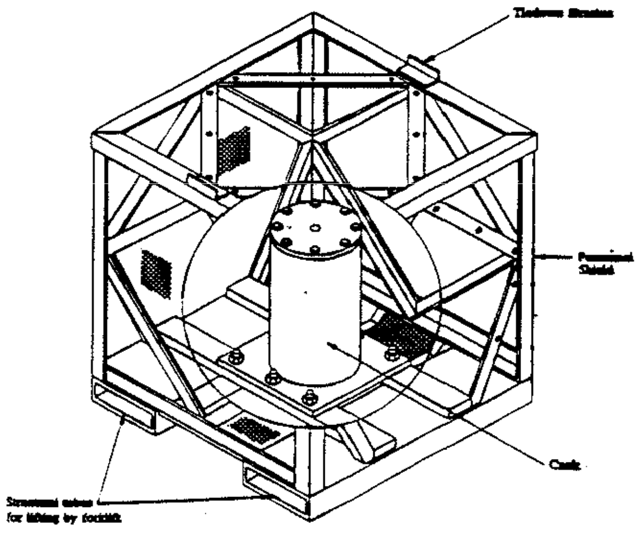

Figure 1.0 Mound 1kW Package Showing Cask Bolted Inside the Personnel Shield

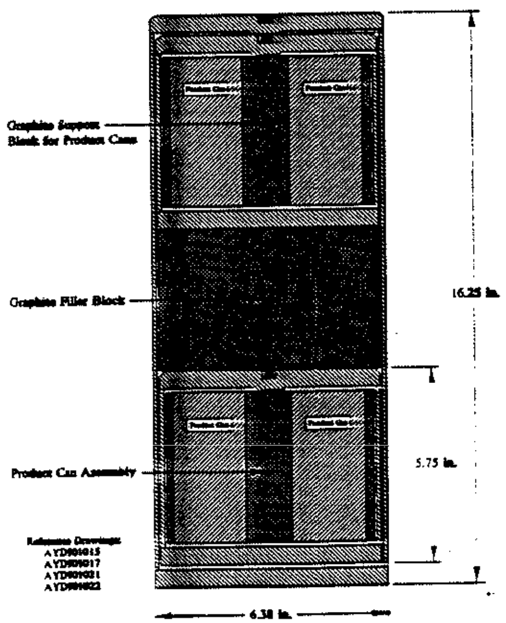

Figure 2.0 The Mound 1kW Cask Loaded with the Product Can Containment Assembly

IV. SHIELDING ANALYSIS

A. Radiation Limits

DOE Order 5480.3 defines the limits for the various classes of fissile materials, establishes responsibilities and authorities, states requirements for adherence to federal regulations, defines package standards, and outlines the minimum quality assurance procedures and operating procedures required.

10CFR71 requires that a package be designed and prepared for shipment so that the radiation level does not exceed 200 mrem/h at any point on the external surface of the package and the transport index (TI) does not exceed 10. Radiation levels external to the package may exceed those limits for a package transported as *exclusive use* by rail, highway, or water, but must not exceed any of the following:

a) 200 mrem/h on the accessible external surface of the package unless the following conditions are met, in which case the limit is 1000 mrem/h:
   1) the shipment is made in a closed transport vehicle;
   2) provisions are made to secure the package so that its positions within the vehicle remains fixed during transportation, and
   3) there are no loading or unloading operations between the beginning and end of the transportation;
b) 200 mrem/h at any point on the outer surface of the vehicle, including the upper and lower surfaces, or, in the case of an open vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load, and on the lower external surface of the vehicle;
c) 10 mrem/h at any point 2 meters from the vertical planes represented by the outer lateral surfaces of the vehicle, or, in the case of an open vehicle, at any point 2 meters from the vertical planes projected from the outer edges of the conveyance; and
d) 2 mrem/h in any normally occupied positions of the vehicle, except that this provision does not apply to private motor carriers when persons occupying these positions are provided with special health supervision, personnel radiation exposure monitoring devices and training in accordance with 10CFR19.[8]

10CFR71 requires, in part, that under tests specified (Hypothetical Accident Conditions) there be no external radiation dose equivalent rate exceeding 1000 mrem/h at 1 meter from the external surface of the package.

The threaded and welded product cans of the Mound 1kW package have been reviewed by LLNL for exclusive use and have been recommended for approval for certification for exclusive use only. Therefore, package shielding was deemed acceptable by LLNL independent verification that:

1) the expected dose equivalent rates (mrem/h) at the external surface of the personnel shield, the bottom of the trailer bed, 2 meters from the external surface of the trailer side wall, and the normally occupied position in the truck tractor were not in excess of the applicable limits set forth above for exclusive use shipments; and
2) the expected dose equivalent rates (mrem/h) at 1 meter from the external surface of the cask were not in excess of the applicable limits set forth above for hypothetical accident conditions.

B. Source Specification

1. Gamma Source

The constituents to the source of photons are:

1) direct decay of the plutonium isotopes present;
2) direct decay of fuel impurities;
3) photons due to fissions and the decay of fission products; and
4) neutron activation of the stainless steel containers and graphite.

The source material can be Russian or SRS. The source specification for the foreign source differs slightly from the SRS source material. By evaluation, the design basis fuel is identified as the Russian PuO_2 powder enriched to 89.21 wt% in ^{238}Pu. For the ^{236}Pu, the composition is the maximum allowed in the Russian PuO_2 powder: 2 ppm of the ^{238}Pu. Since no isotopic breakdown for U and Th was specified for the Russian fuel, the compositions for ^{234}U and ^{232}Th for the SRS powder are used to supplement the Russian data. This should have no effect on the source because the photon source is primarily from the ^{236}Pu and the neutron source is primarily from the ^{238}Pu.

Gamma source strengths and source spectra for the PuO_2 powder were calculated by ORIGEN-S[9] as a function of 18 energy groups for decay periods covering the interval from 10 days to 18.5 years. Evaluation of the resultant gamma source strengths (photons/s) and source spectra (photons/s) shows fuel decayed for 17.5 years to have the greatest impact on gamma dose equivalent rate (mrem/h). The most significant contributors to the gamma spectra were from the decay of the ^{236}Pu family. Photons from the decay of fuel impurities and from fissions and the decay of fission products were not found to be significant; and neutron activation of the shipping package was determined to have less than 0.4% effect on the dose equivalent rate (mrem/h) over a 17.5 year interval.

2. Neutron Source

The constituents to the source of neutrons are:

1. (α,n) reactions;
2. Spontaneous fissions; and
3. Neutron-induced fissions

The design basis fuel parameters are as described under section IV.B.1, Gamma Source. The largest contributor to the neutron source spectra from (α,n) reactions with the oxygen in the fuel is ^{238}Pu (99.96%). The largest contributors to the neutron source spectra from spontaneous fissions are ^{238}Pu (99%), ^{240}Pu (0.8%), and ^{242}Pu (0.1%). Neutron source strengths and source spectra for the PuO_2 powder were calculated by ORIGEN-S[10] as a function of 27 energy groups for decay periods covering the interval from 10 days to 18.5 years. Evaluation of the resultant neutron source strengths and source spectra shows fuel decayed for 10 days to have the greatest impact on neutron dose equivalent rate (mrem/h).

B. The Model

Two different product cans can be used: 1) a Russian-configured product can or 2) the SRS-configured product can. The Russian product can is narrower than the SRS product can. As such, the design basis Russian PuO_2 powder occupies more axial and less radial space in the Russian product can configuration than in the SRS product can configuration for the same amount of loading. The staff shielding model was prepared for the SRS product can configuration; the Russian product can configuration was not prepared. The staff shielding evaluation of the Russian product can configuration is limited to a review of the information provided and a judgment as to the validity of the arguments.

The staff radial and axial shielding configuration used for the SRS product can configuration in the Mound 1 kW package shielding was independently determined from the drawings in the Appendix of the SARP. With the exception of the nuts, bolts, lock washers, metallic o-ring, eyebolt, and personnel shield, all source and shield configurations are accurate representations of the design geometries and/or dimensions. The nuts, bolts, lock washers, metallic o-ring, and eyebolt were not modeled. Neither are the personnel shield components except the two base strip bars and hollow rectangular tubes. For added detail and to provide conservatism in the axial model, the bolt holes in the center of the PCV, SCV, and cask lids were included. With the exception of the detector location at the front wall of the trailer, the staff detector locations were those described in the section Description of Radial and Axial Shielding Configuration of the SARP for a single package. Detector locations for multiple package truck shipments were not addressed.

The staff regional densities for the (SRS) product can configuration used for the source and shield components in the Mound 1kW package shielding evaluation are independently determined from the information provided and most closely resemble the shield regional densities of the SARP. Differences between Mound analysis and staff analysis are associated with an effort by the staff to represent the various regional densities as accurately as possible. Major, minor, and trace element constituents of all materials have been included wherever known. No credit is taken for materials of the conveyance.

The staff shielding evaluation of a single package truck shipment of a Mound 1 kW package loaded in the SRS product can configuration and containing the design basis Russian PuO_2 powder is performed with COG. COG is a continuous-energy, generalized geometry, time-dependent, coupled neutron and gamma ray code which uses the monte-carlo method to transport both neutrons and gamma rays. We use three-dimensional finite cylinder analyses to determine the average gamma and neutron dose equivalent rates (mrem/h) at all detector locations appropriate to non-exclusive use and exclusive use shipments and hypothetical accident conditions. Dose rate conversion factors used in all COG calculations are those of ANSI/ANS-6.1.1.[11]

C. Results

The staff calculated average total dose equivalent rates for the top, side, and bottom external surfaces of the personnel shield for exclusive use truck shipments of a single Mound cask loaded with eight SRS configuration product cans containing Russian PuO_2 powder fuel are 41.6 + 10% mrem/h, 121.0 + 1.8% mrem/h, and 236.4 + 9.6% mrem/h, respectively. Total dose equivalent rates are less than the 200 mrem/h allowed under 10CFR 71 and 49CFR at all locations except the bottom surface of the package. *The necessity for exclusive use shipment is confirmed.* The total dose equivalent rates are less than the 1000 mrem/h allowed under 10CFR and 49CFR for exclusive use shipment.

The staff calculated total dose equivalent rate under normal conditions of transport at the *bottom of the trailer bed* for exclusive use truck shipments of a single Mound 1 kW package loaded with eight SRS configuration product cans containing Russian PuO_2 powder fuel is 149.1 + 5.9% mrem/h. The total dose equivalent is less that the 200 mrem/hr allowed under 10CFR and 49CFR.

The staff calculated average total dose equivalent rate under normal conditions of transport at *2 meters from the external surface of the trailer side wall* for exclusive use truck shipments of a single Mound 1 kW package loaded with eight SRS configuration product cans containing Russian PuO_2 powder fuel is 2.06 + 5.2% mrem/h The total dose equivalent rate is less than the 10 mrem/hr (TI) allowed under 10CFR 71.47(c) and 49CFR173.441(b)(3).

The staff calculated average total dose equivalent rate under normal conditions of transport*at the normally occupied position in the truck tractor* for exclusive use truck shipments of a single Mound 1 kW package loaded with eight SRS configuration product cans containing Russian PuO_2 powder fuel is 2.81 + 4.8% mrem/h The total dose equivalent rate is greater than the 2 mrem/h allowed under 10CFR71.47(d) and 49CFR173.441(b)(4); therefore, the dose equivalent rate (mrem/h) to the driver must be monitored and the driver must be properly trained.

The staff calculated average total dose equivalent rate under hypothetical accident conditions at 1 meter from the top, side, and bottom surfaces of a single Mound 1 kW package loaded with eight SRS configuration product cans containing Russian PuO_2 powder fuel are 4.64 + 27%, 15.7 + 2.9%, and 9.46 + 23% mrem/h, respectively. The total dose equivalent rates are less than the 1000 mrem/hr allowed under 10CFR71.51(a)(2).

The staff shielding evaluation of several other configurations are limited to a review of the information provided and a judgment as to the validity of the arguments. These configurations include the following:

1. A multiple package truck shipment of six Mound 1 kW packages loaded in the SRS product can configuration and containing the design basis Russian PuO_2 powder ;
2. A single package truck shipment of a Mound 1 kW package loaded in the Russian product can configuration and containing the design basis Russian PuO_2 powder;
3. A multiple package truck shipment of six Mound 1 kW packages loaded in the Russian

product can configuration and containing the design basis Russian PuO_2 powder;

4. A Single package truck shipment of a Mound 1 kW package loaded in the Russian product can configuration and containing the package thermal limit design basis Russian PuO_2 powder;
5. A multiple package truck shipment of six Mound 1 kW packages loaded in the Russian product can configuration and containing the package thermal limit design basis Russian PuO_2 powder;
6. A multiple package cargo container sea shipment of three Mound 1 kW packages loaded in the Russian product can configuration and containing the package thermal limit design basis Russian PuO_2 powder; and
7. A multiple package cargo container truck shipment of three Mound 1 kW packages loaded in the Russian product can configuration and containing the package thermal limit design basis Russian PuO_2 powder

IV. SUMMARY

The shielding section of the SARP was reviewed to determine that the Mound 1 kW package shielding was designed in a manner that will assure compliance with the performance requirements of 10CFR71, paragraphs 71.47 and 49CFR173.441 for an exclusive use shipment under normal conditions of transport and 10CFR71.51 for hypothetical accident conditions. The scope of the review covers the shielding design features of the package configuration that carries eight product cans, the source and model specifications, the shielding evaluation, and supportive information or documentation. An independent evaluation was made for Russian source material using ORIGEN-S; the Russian source material in SRS product cans was modeled independently from drawings provided in the SARP; and the doserates at the required locations were calculated for the Russian source material in SRS product cans using the 3-D monte-carlo code, COG. Based on expert knowledge from these results and a review of the information provided and a judgment as to the validity of the arguments, the additional seven configurations of section IV.C were reviewed.

Basis for acceptance in the review has been conformance with established guidelines and criteria. The review of the Mound 1 kW package shielding for the product cans indicated that the total dose equivalent rates (mrem/h) are such that exclusive use shipment must be employed and that under normal conditions of transport and hypothetical accident conditions, exclusive use truck shipments of one and six Mound 1 kW packages loaded with eight product cans containing PuO_2 powder with total source strengths equivalent to the package thermal limits are in compliance with the performance requirements of 10CFR71.47 and 71.51 and 49CFR173.441 at all locations except the normally occupied position in the truck tractor. To assure compliance, any persons occupying this position must be provided with special health supervision, personnel radiation exposure monitoring devices, and training in accordance with 10CFR19.19. To ensure that the total dose equivalent rates (mrem/h) are in compliance with 10CFR71.47 and 49CFR173.441 for exclusive use cargo container shipment by sea, the external surface of the cargo container must be 2.44 m (8 ft) or more from any normally occupied position.

The remaining load configurations described in section II above; i.e., the GPHS and MHW loads are currently being evaluated, and a summary of their results will be presented at this meeting.

ACKNOWLEDGMENTS

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