Contract No. and Disclaimer:

A Methodology for Determining the Dose Rate for Bounding Mass Limits in a 9977 Packaging

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ABSTRACT

The Small Gram Quantity (SGQ) concept is based on the understanding that the hazards associated with the shipment of a radioactive material are directly proportional to its mass. This study describes a methodology that estimates the acceptable masses for several neutron and gamma emitting isotopes that can be shipped in a 9977 Package compliant with the Title 10 of the Code of Federal Regulations, Part 71 (10CFR71) external radiation level limits. 10CFR71.33 states that a shipping application identifies the radioactive and fissile materials at their maximum quantity and provides an evaluation demonstrating compliance with the external radiation standards. Since rather small amounts of some isotopes emit sufficiently strong radiation to produce a large external dose rate, quantifying of the dose rate for a proposed content is a challenging issue for the SGQ approach. It is essential to quantify external radiation levels from several common gamma and neutron sources that can be safely placed in a specific packaging, to ensure compliance with federal regulations. A methodology was established for determining the dose rate for bounding mass limits for a set of isotopes in the Model 9977 Shipping Package. Calculations were performed to estimate external radiation levels using the MCNP radiation transport code to develop a set of response multipliers (Green's functions) for "dose per source particle" for each neutron and photon spectral group. The source spectrum from one gram of each isotope was folded with the response multipliers to generate the dose rate per gram of each isotope in the 9977 shipping package and its associated shielded containers. The maximum amount of a single isotope that could be shipped within the regulatory limits for dose rate at the surface was determined. For a package containing a mixture of isotopes, the acceptability for shipment can be determined by a sum of fractions approach. Furthermore, the results of this analysis can be easily extended to additional radioisotopes by simply evaluating the neutron and/or photon spectra of those isotopes and folding the spectral data with the Green's functions provided.

Background

Radioactive Material (RAM) packages are required to fulfill three basic functions; provide containment of the contents, provide a minimally acceptable dose rate to the workers and members of the public, and assure subcriticality of the contents under normal conditions of transport and hypothetical accident conditions. These packages are required to meet these standards as single packages and/or arrays of packages. To meet these requirements, packages typically consist of content containers, packing materials, a containment vessel, shielding components, an overpack, an overpack lid, and closure, lifting and/or tie-down hardware. The packaging configuration is defined in the Safety Analysis Report for Packaging (SARP) [Ref. 1] and the Certificate of Compliance (CoC) documents how the package meets the safety requirements and conditions specified in Title 10 of the Federal Code of Regulations. [Ref. 2] The SARP identifies safety functions of each of these components and specifies their condition and characteristics in performing those functions.

10CFR71.33 states that a shipping application; must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package, and identifies the radioactive and fissile materials at their maximum quantity and *provides an evaluation demonstrating compliance with the external radiation standards*.

The Package must be demonstrated to be in compliance with the performance requirements specified in 10CFR71.47, 10CFR71.51, 49CFR173.403, [Ref. 3] and 49CFR173.441. These regulations specify that "each package of radioactive materials offered for transportation must be *designed and prepared* for shipment so that under conditions normally incident to transportation (NCT) the radiation level does not exceed 2 mSv/h (200 mrem/h) at any point on the external surface of the package, and the transport index (the dose rate 1 meter from the accessible surface of the package) does not exceed 10." and that the dose rate limits are "1000 mrem/h at 1 meter from the surface of a damaged package after a hypothetical accident (HAC)."

Typically an Applicant will perform a Shielding analysis based on the bounding isotope masses in their content envelope which demonstrates that their specific contents in the specific package comply with the federal regulations. The overall results are shown in their certification application. This application must demonstrate that, for the Content, the requirements of 10 CFR 71 for radiation dose rate limits are met under both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). As the number of radioisotopes increases, the number of combinations and permutations (looking at the maximum allowed mass limits) of calculations which are needed to be performed increases dramatically and beyond fiscal reasonability. To greatly simplify this process, a methodology of calculating the dose rate for the 9977 Packaging based for a specific population of radioisotopes was devised. [Ref. 4] The does rates outside the 9977 were calculated for a unit mass of each isotope and a process developed for combining the doses from each isotope on a per energy band basis.

Discussion

The goal was to establish the maximum masses of various radioisotopes within a specified shipping package that would meet the regulation limits for dose rate, both at the package surface and at one meter, both as single isotopes and as combinations of isotopes. The package analyzed was the SRNL Model 9977 Type B(M)F-96. The radioisotopes chosen are listed in Table 1. Because of their (α, n) reactions with light element impurities, some of the actinide isotopes were analyzed in conjunction with beryllium (which bounds other light elements), as indicated in Table 1. Several possible packaging configurations were evaluated for each of the sources within the 9977 package:

- The source directly within the containment vessel (no additional shielding),
- The source in a container which provides 2-inches of lead as gamma shielding,
- The source in a container with 2⅛-inches of high density polyethylene as neutron shielding, and
- The source in a container with 2.075-inches of tungsten as gamma shielding.

The dose rate outside the shipping package was calculated for a unit source in each neutron and photon group. The allowable mass for shipment of a single isotope under NCT (dose rate at the surface of the package < 2 mSv/hr) is established for:

- isotopes without impurities, and
- actinide isotopes with impurities.

The allowable mass for shipment of a single isotope under Exclusive Use (dose rate at the surface of the package < 10 mSv/hr) is established for

- isotopes without impurities, and
- actinide isotopes with impurities.

The results of these calculations were tabulated, and the Normal Condition of Transport limits for pure individual isotopes (i.e. with impurities) are presented in Table 2.

Table 1 –Isotopes Evaluated in the 9977

Ac-227	Am-241	Am-241 & Be	Am-243
Am-243 & Be	Cd-109	Cf-252	Cm-244
Cm-244 & Be	Cm-248	Co-60	Cs-137
Eu-152	Fe-59	Gd-153	Hf-181
Ho-166m	Ir-192	Mn-54	Np-237
Np-237 & Be	Pb-210	Pm-147	Po-210
Pu-238	Pu-238 & Be	Pu-239	Pu-239 & Be
Pu-240	Pu-240 & Be	Pu-241	Pu-241 & Be
Pu-242	Pu-242 & Be	Ra-226	Ru-106
Sc-46	Se-75	Sm-145	Sr-90
Tm-170	Yb-169	Zn-65	Zr-95

Table 2 – NCT Mass Limits by Isotope and Packing Configuration for 9977

Isotope	Allowed Mass of Isotope (g)			
	No Shielding	Lead Shielding	Polyethylene Shielding	Tungsten Shielding
Ac-227	4.1E-04	5.3E-01	1.4E-03	2.7E+00
Am-241	2.2E+01		1.2E+02	
Am-243	3.2E-01		1.2E+00	
Cd-109	5.7E-03	Unlimited	2.8E-02	Unlimited
Cf-252	1.9E-06		8.6E-06	
Cm-244	3.9E-01		1.8E+00	
Cm-248	1.1E-01		5.3E-01	
Co-60	3.3E-06	1.2E-04	9.6E-06	4.5E-04
Cs-137	1.6E-04	1.1E-01	5.0E-04	6.6E-01
Eu-152	4.4E-05	2.7E-03	1.3E-04	1.0E-02
Fe-59	1.6E-07	6.0E-06	4.6E-07	2.2E-05
Gd-153	1.4E-04	Unlimited	6.4E-04	Unlimited
Hf-181	9.1E-07	1.5E-02	3.0E-06	3.7E-02
Ho-166m	2.6E-03	7.2E-01	8.3E-03	3.7E+00
Ir-192	1.0E-06	6.8E-03	3.4E-06	4.1E-02
Mn-54	1.3E-06	2.0E-04	3.9E-06	1.1E-03
Np-237	3.2E+01		2.0E+02	
Pb-210	2.8E-02	3.0E+02	1.0E-01	1.7E+03
Pm-147	2.7E-01	Unlimited	1.2E+00	Unlimited
Po-210	2.2E-01	4.0E+01	6.5E-01	2.1E+02
Pu-238	1.1E+02		4.7E+02	
Pu-239	3.5E+03		1.2E+04	
Pu-240	3.0E+03		1.4E+04	
Pu-241	2.3E+01		1.2E+02	
Pu-242	2.5E+03		1.2E+04	
Ra-226	5.3E-03	2.3E-01	1.6E-02	7.3E-01
Ru-106	9.3E-06	2.3E-03	2.9E-05	8.5E-03
Sc-46	1.3E-07	8.7E-06	3.8E-07	3.7E-05
Se-75	1.5E-06	1.6E+00	5.6E-06	2.5E+01
Sm-145	1.4E-02	2.3E+03	7.6E-02	5.5E+03
Sr-90	2.9E-03	1.4E+00	1.0E-02	5.8E+00
Tm-170	2.7E-04	7.3E+00	1.0E-03	4.4E+01
Yb-169	2.1E-06	9.8E+00	8.1E-06	6.3E+01
Zn-65	1.9E-06	9.5E-05	5.5E-06	3.9E-04
Zr-95	4.6E-07	1.3E-04	1.4E-06	7.7E-04

But what if a package contains a mixture of isotopes? The cost of performing the number of calculations necessary to demonstrate the acceptability for shipment of all possible combinations of the isotopes can be prohibitive. The calculations would necessarily have to be repeated every time a new candidate isotope was added to the content pool. However, with the limiting dose methodology used, the allowable isotope masses can be determined by a sum of fractions approach. That is, the proposed contents within a specific configuration within the 9977 package would be acceptable if:

$$\Sigma_i \left(\underline{M_i}/Limit_i\right) \leq 1$$

Where:

M_i is the mass of isotope i in the package

$Limit_i$ is the allowed mass established in the calculation.

A spreadsheet has been developed which permits the Shipper to input the known masses of their isotopes and immediately establish the acceptability of their content for shipment in any of the approved configurations. This spreadsheet will be issued as a tool for the Users of the package for the evaluation of their contents against the Certificate of Compliance limitations. An example is shown in Table 3. For this example our proposed content consists of 75 grams of Pu-238 and 10 grams of Pu-241 and contains no light element impurities. The Shipper enters the masses for the two isotopes into the spreadsheet and the sum-of-the-fractions results are displayed and highlighted in the results columns for each configuration and for non-exclusive and exclusive use shipments. It is in the best interest for the shipper to use the most cost effective shipping configuration, but the spreadsheet lists results for all the conditions. Note that the spreadsheet also calculates the decay heat rate for the contents and since the 9977 is currently limited to 19-watts of decay heat, both the Pu-238 watts and the "Total" watts cells are highlighted in red to indicate that they exceed the authorized limit. Each of the isotopes would be shippable as an individual content in any configuration, but combined they are expected to exceed the non-exclusive dose limits if shipped without shielding. The spreadsheet does not provide a limit for these contents in either of the two gamma shielded configurations as the isotopes are neutron emitters.

Table 3 – "Sum of the Fractions" for Isotopes without Impurities by Packing Configuration in the 9977

				Sum of Fractions for 200 mrem/hr (non-exclusive use)				Sum of Fractions for 1000 mrem/hr (exclusive use)			
	Isotope	Grams	Watts	None	Lead	HDPE	Tungsten	None	Lead	HDPE	Tungsten
1	Ac-227	0.000	0.0	--	--	--	--	--	--	--	--
2	Am-241	0.000	0.0	--	--	--	--	--	--	--	--
3	Am-243	0.000	0.0	--	--	--	--	--	--	--	--
4	Cd-109	0.000	0.0	--	--	--	--	--	--	--	--
5	Cf-252	0.000	0.0	--	--	--	--	--	--	--	--
6	Cm-244	0.000	0.0	--	--	--	--	--	--	--	--
7	Cm-248	0.000	0.0	--	--	--	--	--	--	--	--
8	Co-60	0.000	0.0	--	--	--	--	--	--	--	--
9	Cs-137	0.000	0.0	--	--	--	--	--	--	--	--
10	Eu-152	0.000	0.0	--	--	--	--	--	--	--	--
11	Fe-59	0.000	0.0	--	--	--	--	--	--	--	--
12	Gd-153	0.000	0.0	--	--	--	--	--	--	--	--
13	Hf-181	0.000	0.0	--	--	--	--	--	--	--	--
14	Ho-166m	0.000	0.0	--	--	--	--	--	--	--	--
15	Ir-192	0.000	0.0	--	--	--	--	--	--	--	--
16	Mn-54	0.000	0.0	--	--	--	--	--	--	--	--
17	Np-237	0.000	0.0	--	--	--	--	--	--	--	--
18	Pb-210	0.000	0.0	--	--	--	--	--	--	--	--
19	Pm-147	0.000	0.0	--	--	--	--	--	--	--	--
20	Po-210	0.000	0.0	--	--	--	--	--	--	--	--
21	Pu-238	75	43	0.68	--	0.16	--	0.13	--	0.03	--
22	Pu-239	0.000	0.0	--	--	--	--	--	--	--	--
23	Pu-240	0.000	0.0	--	--	--	--	--	--	--	--
24	Pu-241	10	0.0	0.43	--	0.08	--	0.08	--	0.03	--
25	Pu-242	0.000	0.0	--	--	--	--	--	--	--	--
26	Ra-226	0.000	0.0	--	--	--	--	--	--	--	--
27	Ru-106	0.000	0.0	--	--	--	--	--	--	--	--
28	Sc-46	0.000	0.0	--	--	--	--	--	--	--	--
29	Se-75	0.000	0.0	--	--	--	--	--	--	--	--
30	Sm-145	0.000	0.0	--	--	--	--	--	--	--	--
31	Sr-90	0.000	0.0	--	--	--	--	--	--	--	--
32	Tm-170	0.000	0.0	--	--	--	--	--	--	--	--
33	Yb-169	0.000	0.0	--	--	--	--	--	--	--	--
34	Zn-65	0.000	0.0	--	--	--	--	--	--	--	--
35	Zr-95	0.000	0.0	--	--	--	--	--	--	--	--
I	Be	0.000									
	Totals	85	43	1.12	--	0.24	--	0.21	--	0.06	--

References

1 Abramczyk, G. and Blanton, P. S., *Safety Analysis Report for Packaging Model 9977*, S-SARP-G-00001, Revision 2, (August 2007).

2 *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (December 2006).

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4. S. J. Nathan, B. M. Loftin, G. A. Abramczyk, and J. S. Bellamy, *Packaging Certification Program Methodology for Determining Dose Rates for Small Gram Quantities in Shipping Packagings,* Paper presented at the 53rd Annual Meeting of the INMM (July 2012)

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