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Title: SHIELDING ANALYSIS FOR PORTABLE GAUGING
COMBINATION SOURCES

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Shielding Analysis for Portable Gauging Combination Sources

1. BACKGROUND

Radioisotopic decay has been used as a source of photons and neutrons for industrial gauging operations since the late 1950s. Early portable moisture/density gauging equipment used Americium (Am)-241/Beryllium (Be)/Cesium (Cs)-137 combination sources to supply the required nuclear energy for gauging. Combination sources typically contained 0.040 Ci of Am-241 and 0.010 Ci of Cs-137 in the same source capsule. Most of these sources were manufactured approximately 30 years ago. Collection, transportation, and storage of these sources once removed from their original device represent a shielding problem with distinct gamma and neutron components.

The Off-Site Source Recovery (OSR) Project is planning to use a multi-function drum (MFD) for the collection, shipping, and storage of AmBe sources, as well as the eventual waste package for disposal. The MFD is an approved TRU waste container design for DOE TRU waste known as the 12" Pipe Component Overpack (Figure 1). As the name indicates, this drum is based on a 12" ID stainless steel weldment approximately 25" in internal length. The existing drum design allows for addition of shielding within the pipe component up to the 110 kg maximum payload weight. The 12" pipe component is packaged inside a 55-gallon drum, with the balance of the interior space filled with fiberboard dunnage (see Figure 1). This packaging geometry is similar to the design of a DOT 6M, Type B shipping container.

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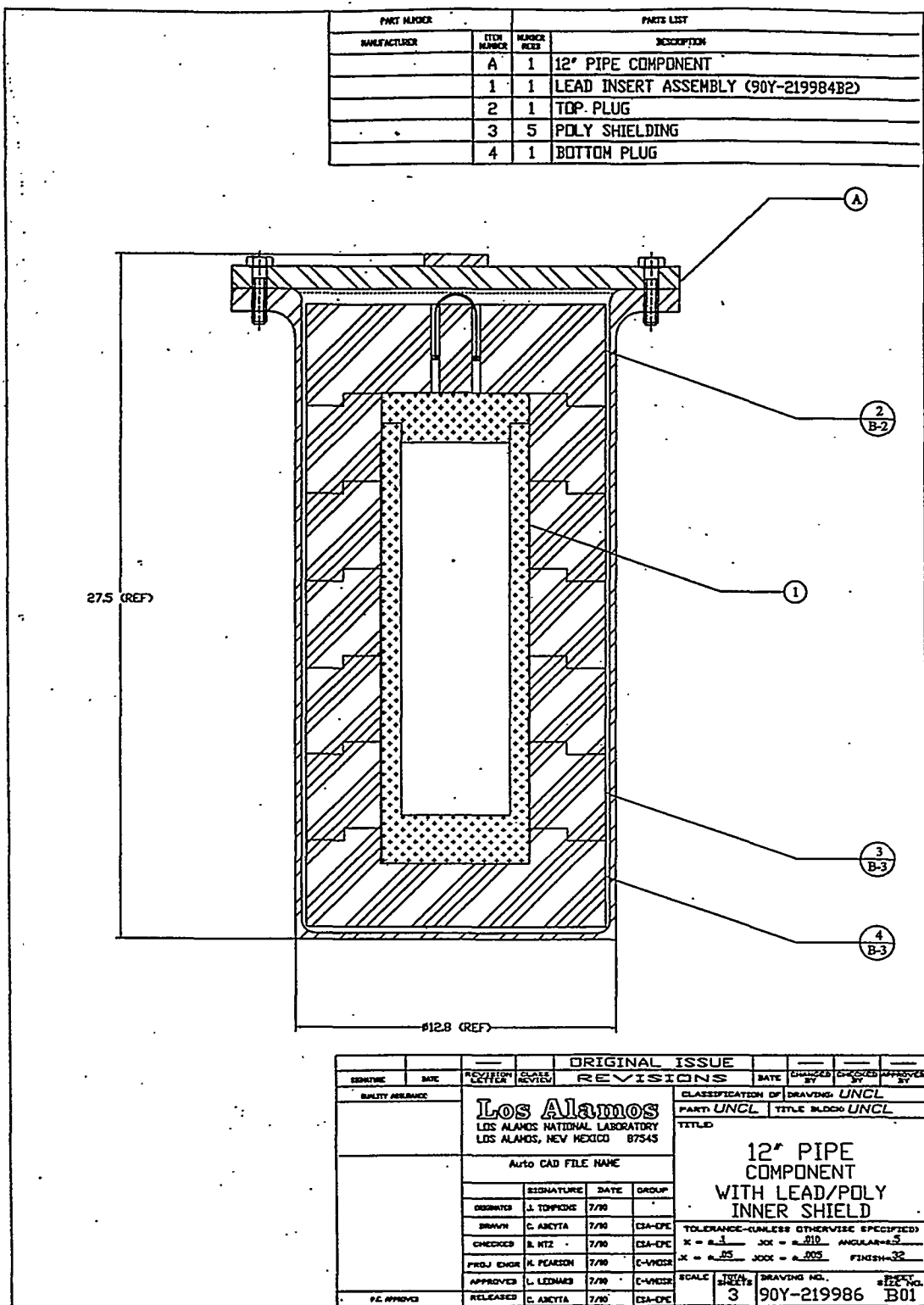


Figure 1. 12" Pipe Component with Lead/Poly Inner Shield

2. PROBLEM

The basic problem is to design an internal shield for the 12" pipe component that meets the following criteria:

- incorporates gamma and neutron shielding materials with a maximum weight of 105 kg
- contact dose rate less than 100 mrem/hr, TI < 10
- volumetric efficiency close to 100%

Standard lead (Pb) and water extended polyester (WEP) were used as the basic shielding materials.

3. METHODOLOGY

Analysis of radiation dose rates at contact and at 1m were performed with the Monte Carlo n-Particle (MCNP) (ver. MCNP4B2) shielding code. MCNP is a Monte-Carlo type shielding code that requires the specification of a geometry and the materials of construction. Once the code for the problem is set up, large numbers of simulated particles are randomly generated within the source cavity and followed through the shielding material. The radiation dose rate at a given point on the object of interest is determined by summing contributions from the random particles generated. For this particular problem, 10 or 40 million photons or neutrons were used to analyze the dose rates for photons and neutrons independently. The internal source geometry was evaluated with varying cavity radii, in an attempt to maximize the number of combination sources that could be contained in the MFD while maintaining surface contact dose rates (neutron + gamma) at less than 100 mrem/hr.

Neutron source generation rates were based upon the range of empirical measurements for AmBe sealed sources yielding $2.2E6$ neutrons per Ci - s¹. The energy distribution of the neutrons from an AmBe source was assumed to match that found in the literature²:

The MCNP calculations were used to evaluate a cylindrical geometry with varying internal cavity diameters. For each cavity diameter a series of calculations was performed with varying thicknesses of Pb and WEP, to find the optimum thickness for a particular cavity ID. These calculations are summarized in Table I. Many more calculations were run for small cavity ID than the larger since our initial volumetric measurements were made for a standard source 5/8" OD x 3/8" length, which approximates the actual source volume. In reality these sources were incorporated into a stainless steel rod 5/8" OD and 24" long. This rod has been truncated to a source size of 5/8" OD x 2" to simplify storage of these units. When the information on the actual source became available, calculations were focused on larger sized cavities since the number of sources per unit volume declined by a factor of five. The larger sized cavities are severely limited by the 110 kg maximum weight of the loaded pipe component. The lead shield for the larger diameter cavities cannot be as thick, since the amount of lead required for an equivalent thickness increases with the square of the lead shield diameter.

¹ Health Physics and Radiological Health Handbook, Revised Ed., 1992, pp. 288, Table 7.5

² Compendium of Neutron Spectra and Detector Responses for Radiation Protection Purposes, IAEA Tech Report Series No. 318, Vienna, 1990, pp. 71, Table 4-VIII.

Table I

2.25" ID Internal Cavity

Shielding Pb/WEP (cm)	Contact			1 meter		
	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)
4.00 / 8.14	16.90	7.73	0.394	0.98	0.35	0.0190
4.50 / 7.64	9.61	7.96	0.366	0.55	0.36	0.0173
4.75 / 7.39	7.09	8.06	0.358	0.42	0.37	0.0168
4.88 / 7.28	6.28	8.11	0.356	0.38	0.37	0.0167
4.95 / 7.19	5.70	8.16	0.355	0.34	0.37	0.0166
5.00 / 7.14	5.31	8.19	0.354	0.32	0.37	0.0165
5.10 / 7.04	4.78	8.22	0.353	0.29	0.37	0.0164
5.25 / 6.89	3.63	7.57	0.321	0.25	0.39	0.0167

3" ID Internal Cavity

Shielding Pb/WEP (cm)	Contact			1 meter		
	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)
2.5 / 8.69	53.92	7.05	0.552	3.10	0.37	0.0304
3.0 / 8.19	32.22	7.46	0.460	1.76	0.38	0.0241
3.5 / 7.69	17.27	7.68	0.394	1.01	0.39	0.0207
4.0 / 7.19	9.53	7.63	0.361	0.58	0.40	0.0190
4.25 / 6.94	7.22	7.92	0.353	0.44	0.41	0.0185
4.5 / 6.69	5.44	8.18	0.355	0.34	0.41	0.0181
4.75 / 6.44	4.02	8.12	0.345	0.26	0.42	0.0180
5.0 / 6.19	3.10	8.54	0.357	0.20	0.42	0.0179

4" ID Internal cavity

Shielding Pb/WEP (cm)	Contact			1 meter		
	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)
2.5 / 7.5	52.5	8.14	0.588	3.3	0.43	0.0337
3.0 / 7.0	29.6	8.48	0.487	1.9	0.44	0.0271
3.5 / 6.5	16.5	8.78	0.434	1.1	0.46	0.0239
4.0 / 6.0	9.3	8.97	0.405	0.7	0.47	0.0223
4.5 / 5.5	6.7	9.41	0.410	0.4	0.48	0.0212
5.0 / 5.0	3.2	10.06	0.418	0.2	0.50	0.0210
5.5 / 4.5	1.7	10.34	0.422	0.1	0.51	0.0209

4.25" ID Internal cavity

Shielding Pb/WEP (cm)	Contact			1 meter		
	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)
1.97 / 7.63	57.6	8.4	0.625	3.2	0.38	0.0311
2.18 / 7.42	44.3	8.5	0.562	2.4	0.39	0.0277
3.94 / 5.90	6.1	9.5	0.411	0.4	0.43	0.0190

5" ID Internal Cavity

Shielding Pb/WEP (cm)	Contact Dose rate			1 meter Dose rate		
	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)	Gamma (mrem/hr /Ci ^{137}Cs)	Neutron (mrem/hr /Ci ^{241}Am)	Total (mrem/hr /source)
2.00 / 6.75	107.3	10.02	0.937	5.8	0.49	0.0486

Volumetric Loading Analysis

Cavity Size (ID x length)	Cavity Volume (in ³)	Perfect Stack Capacity (no. sources)	Dumped Source Capacity (no. sources)	Dumped geometry		
				Contact Dose Rate Utilization (% Rad Limit)	Volume Utilization (% Dumped Cap.)	Shield Weight (kg)
2.25" x 15"	60	55	42	13%	100%	103
3" x 15"	106	98	75	27%	100%	110
4" x 15"	188	180	133	78%	100%	108
4.25" x 15"	213	188	150	94%	100%	103
5" x 15"	295	270	207	100%	52%	108

Empirical Data

1.42	in ³ /source (5/8" OD x 2"), dumped geometry
1.08	in ³ /source (5/8" OD x 2"), perfectly stacked geometry
70.4	g/source

Contact Dose rate for Five Different Shield Geometries

Cavity ID (inch)	Shielding Ratio WEP/Pb	Contact (mrem/hr/ source)	Max. No. of Sources	Contact (mrem/hr)	Shield Weight (kg)	Limiting Condition
2.25	1.3	0.321	42	13	103	Vol.
3.00	1.8	0.361	75	27	110	Vol.
4.00	3.0	0.588	133	78	108	Vol.
4.25	3.9	0.625	150	94	103	Vol.
5.00	3.4	0.937	107	100	108	Dose rate _{contact}

1 m Dose Rate for Five Different Shield Geometries

Cavity ID (inch)	Shielding Ratio WEP/Pb	1 m (mrem/hr/ source)	Max. No. of Sources	1 m (mrem/hr)	Shield Weight (kg)	Limiting Condition
2.25	1.3	0.017	42	0.7	103	Vol.
3.00	1.8	0.019	75	1.4	110	Vol.
4.00	3.0	0.034	133	4.5	108	Vol.
4.25	3.9	0.031	150	4.7	103	Vol.
5.00	3.4	0.049	107	5.2	108	Dose rate _{contact}

The process was simplified by determining dose rates at contact and 1 m, on a per curie basis for gamma and neutron radiations from the two source materials. Once the contact dose rates were known on a per curie basis, a spreadsheet was used to evaluate the total dose rate (gamma + neutron) on a per source basis, with activities decayed by 30 years. The weight of shielding for that specific shield configuration was calculated from the cavity volume, and the thickness of the Pb and WEP components. The maximum number of sources that fit within a specific shield configuration was calculated based upon empirical measurements for both dumped and stacked geometries. Lastly, a contact dose rate/source was used to determine how many sources could be stored in that diameter cavity with less than or equal to 100 mrem/hr contact dose rate and with a total 12" pipe component loading of about 105.kg.

The ultimate goal of these calculations was to determine the maximum number of sealed sources that could be contained on a per drum basis while maintaining the contact dose rate at less than 100 mrem/hr and a loaded pipe component weight limit of less than 110 kg.

4. RESULTS

The results are shown in Figure 2. The shield which most closely met all criteria had a WEP/Pb ratio of 3.9 (7.14/2.00 cm) with an internal cavity of 4.25" (10.8 cm) ID and 15" (38.1 cm) length. With this configuration, about 150 combination sources could be loaded into the specified shield (dumped geometry). This configuration uses 100% of the volumetric capacity, 94% of the contact dose rate capacity, and 97% of the pipe component load limit (110 kg). For the estimated total of 900 combination sources this would result in a total of 6 drums of combination sources. The change in gamma ray contact dose rate with respect to the shielding thickness and cavity ID is shown in Figure 3.

5. DISCUSSION

A review of the contact dose rate limits for shipping containers would indicate that 200 mrem/hr is the maximum dose rate for a non-exclusive use shipment. The OSR Project has selected the Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria (WAC) guidelines, that we selected for use as a packaging standard, indicate that 200 mrem/hr is the Contact Handled (CH) dose rate limit. The 100 mrem/hr contact handled dose rate design limit selected for these shipping/storage drums is a conservative attempt to keep worker exposures ALARA during package preparation, shipping, and 6-10 years of storage. The estimated total of about 1,000 drums for the entire OSR Project is very small compared to the current inventory of 44,000 TRU waste drums in the LANL, TA-54 storage area. OSR Project drums will constitute only 2% of the total anticipated drums to be stored at LANL. The six estimated combination source drums are insignificant compared to 1,000 OSR Project drums. The lower contact handled dose rates resulting from the 100 mrem/hr limit will allow the packaged waste drums to be stored in the existing structures at TA-54 Area G without the need for storage in a new shielded facility, in trenches, or pits.

The absolute volumetric capacity of the internal cavity limits the quantity of sources that can be loaded into this storage/disposal configuration. This is a highly desirable characteristic since with the specified 5/8" OD x 2" long source, the drum cannot be overloaded in terms of the contact dose rate desired by the OSR Project. There are two potential changes that would allow loading

Shielding Analysis for Combination Sources in an
Internally Shielded 12" Pipe Component/55-gallon Drum Geometry

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Figure 2

2.25" ID Cavity		42	Sources γ_{max}
Shielding Ratio WEP/Pb	Contact (mrem/hr)	1 meter (mrem/hr)	Weight Shield (kg)
2.04	18.5	0.80	83.1
1.70	15.4	0.73	90.1
1.58	15.0	0.71	93.7
1.50	14.9	0.70	95.4
1.45	14.9	0.70	97.0
1.43	14.9	0.69	97.8
1.38	14.8	0.69	99.9
1.31	13.5	0.70	101.7

3" ID Internal Cavity		75	Sources γ_{max}
Shielding Ratio WEP/Pb	Contact (mrem/hr)	1 m (mrem/hr)	Weight Shield (kg)
3.48	41.2	2.3	79.6
2.75	34.3	1.8	87.2
2.20	29.4	1.5	95.8
1.80	26.9	1.4	104.7
1.63	26.3	1.4	109.5
1.49	26.5	1.4	114.2
1.36	25.7	1.3	119.1
1.24	26.7	1.3	124.4

4" ID Internal Cavity		133	Sources γ_{max}
Shielding Ratio WEP/Pb	Contact (mrem/hr)	1 m (mrem/hr)	Weight Shield (kg)
3.00	78.1	4.47	100.9
2.33	64.7	3.60	111.1
1.88	57.6	3.17	121.5
1.50	53.8	2.98	127.1
1.22	54.4	2.81	132.5
1.00	55.5	2.79	138.1
0.82	56.0	2.77	144.2

4.25" ID Internal Cavity		150	Sources γ_{max}
Shielding Ratio WEP/Pb	Contact (mrem/hr)	1 m (mrem/hr)	Weight Shield (kg)
3.9	94	4.7	103.4
3.4	84	4.1	108.4
1.51	62	2.9	152.3

5" Internal Cavity		107	Sources γ_{max}
Shielding Ratio WEP/Pb	Contact (mrem/hr)	1 m (mrem/hr)	Weight Shield (kg)
4.4			
3.8			
3.38	100	5.2	109.4

	(mrem/hr) /Ci Cs-137)	(mrem/hr) /Ci Am-241)	(mrem/hr) /source)	(mrem/hr) /Ci Cs-137)	(mrem/hr) /Ci Am-241)	(mrem/hr) /source)
2.00 / 6.75	107.3	10.02	0.937	5.8	0.49	0.0486

Contact Dose Rate vs. WEP/Pb Ratio

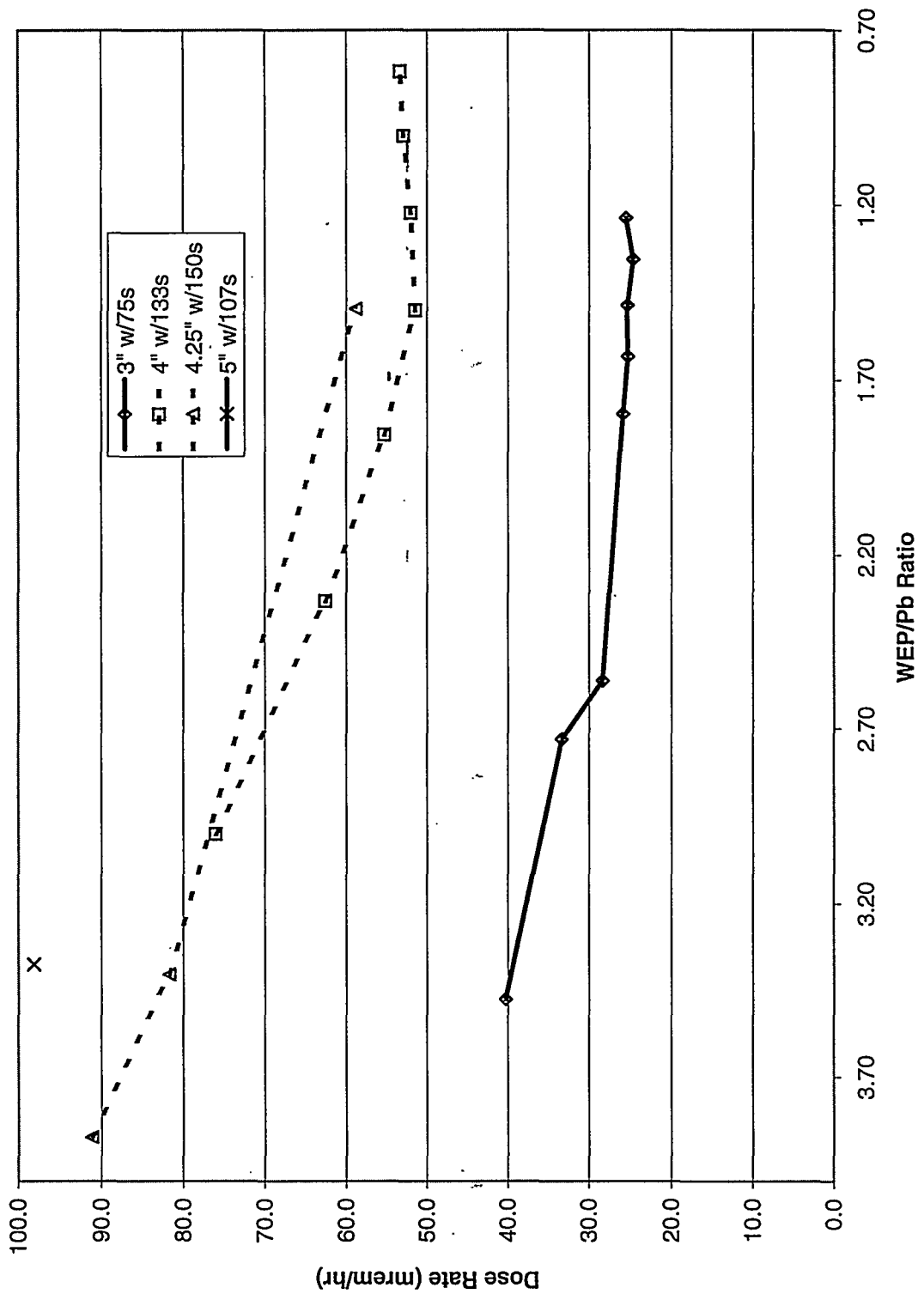


Figure 3

of a greater number of sources in each container. One is the shortening of the combination sources to less than 2" (5 cm). This seems unlikely since the source owners do not want the possibility of an Am-241 contamination event on their site from errors in source rod cutting. The other method of increasing the number of sources which can be packaged per container is to carefully stack each source, one on top of the other in the inner containers. This would increase the drum capacity by 22 %, giving a maximum contact dose rate of 115 mrem/hr. This drum would meet all regulatory compliance goals even though it does not meet the project specified ALARA contact dose rate goal. Perfect stacking of 5/8" OD x 2" rods would take additional equipment and planning in order to maintain doses ALARA during loading.

Dose rates from the unshielded load of 150 combination sources are 533 and 56 mrem/hr at contact for the gamma and neutron radiations, respectively. The total dose rate is 590 mrem/hr at contact for the pipe component package without additional shielding (WEP & Pb). This is substantially above the 200 mrem/hr dose rate at contact limit for CH TRU containers in a TRUPAC II, and is less than the 1,000 mrem/hr at contact limit for Type A exclusive use shipments. This high dose rate will require an accident effects analysis and a new NRC TRUCON code for the shielding material, if TRUPAC II shipments are planned for these containers at the planned 150 sources per drum. Another option would be to load only 37 sources/drum, which would guarantee the maximum dose rate after an accident would be less than 200 mrem/hr. This option would increase the total number of combination source drums from 6 to 24. The cost of those 18 additional drums is estimated at \$5,000 each, which would cost \$90,000 to the DOE. Since 91% of the contact dose rate for the hypothetical unshielded accident is generated by the Cs-137 photons, an engineering analysis of the ductile behavior of the Pb inner shield would allow credit for that shielding to be utilized, allowing the higher loading rate of 150 sources.

The WEP is a cost effective shielding material. However, for use in WIPP disposal drums the volatile organic compound (VOC) emissions, from un-reacted styrene monomer, are an issue if they are present at greater than 100 ppm in the headspace of the drum during storage. In the long run it may be cheaper to use a more expensive shielding to eliminate the VOC issue from consideration. Data collected at LANL by Bob Villareal and Walter Salazar indicate that WEP and Polycast™ both may have a problem passing the 100 ppm VOC limit. The impact of switching to a pure polyethylene or 5% borated polyethylene should be evaluated.

6. SUMMARY

The result which most closely met all criteria was a shield with a WEP/Pb ratio of 3.9 (7.14/2.00 cm) with an internal cavity of 4.25" (10.8 cm) ID and 15" (38.1 cm) length. With this configuration, about 150 combination sources could be loaded into the specified shield in a dumped geometry. This configuration uses 100% of the volumetric capacity, 94% of the contact dose rate capacity, and 97% of the pipe component load limit of 110 kg. For the estimated total of 900 combination sources, this shield and load configuration would require a total of 6 drums to package the combination sources.

Future work will involve fabrication and loading of such a shield with this particular type of radiation source, in order to validate the methodology.