Sources for Dirt Bomb Radiation

References 1 and 2 provide at length an evaluation of sources of gamma radiation that terrorists might use for the construction of a dirty bomb, also known as a radiological dispersal device (RDD). Those of significant threat in the above data are summarized in Tables I and II.

TABLE I. – Summary of Co-60 sources considered to be of significant threat

Co-60, Source	World-wide number of sources	Number of capsules	Radioactivity per capsule, Ci	Pellets per capsule	Radioactivity per pellet, Ci	Pellets each	Activity per source, Ci
Medical, Radiotherapy	10,000	60	2000	1000	2	60000	1.E+05
Industrial, Product irradiation	300	500	2000	1000	2	500000	1.E+06
Inductrial, small	several thousand	1	2000	1000	2	500	1.E+03

TABLE II. – Summary of Cs-137 sources considered to be of significant threat

Cs-137 Source	World-wide number of sources	Activity per source, Ci
Medical, Radiotherapy	?	1.E+05
Industrial, Product irradiation	a few	1.E+06

There are other isotopes, such as Ir-192, Sr-90, Pu-238, Am-241, and Cf-252, that will not be treated in this discussion of GamXRAD at this time.

Cobalt and Cesium Radiation Fields

The Health Physics Department at McMaster University, Canada provides a Health Physics manual on its WEB Page, Ref. 2. The manual provides an inventory of radiation-related information. This information includes the dose rate in tissue-equivalent material (mSv(tem)/h) for a non-shielded, 1-mCi point source for a host of radioactive isotopes. Table III is for the two isotopes spoken of in the preceding section.

TABLE III. – Dose rates for 1-mCi Co-60 and Cs-137 in units of Sevierts

Isotope	Energies (MeV)	mSv(tem)/h at 10 cm
Co-60	1.173, 1.332	1.25
Cs-137	0.662	0.33

The weighting factor for gamma is 1.0, hence Table III may be rewritten, as shown in Table IV, in terms of Gray (100 rad).

TABLE IV. – Dose rates for 1-mCi Co-60 & Cs-137

Isotope	**Energies (MeV)**	**cGv(tem)/h [rad(tem)/h] at 10 cm**
Co-60	1.173, 1.332	0.125
Cs-137	0.662	0.033

Alpha and Beta radiation are also present, but since the penetrations of these are small compared to that for Gamma then shielding sufficient for Gamma will also be sufficient for Alpha and Beta are taken into account.

Two assumptions are made for Co-60 (half life = 5.26 years) or Cs-137(half life = 30 years) that might fall into the hands of terrorists:
- That the source is at least 30 years old,
- That for a particular radioactive source there has never been refreshment, as may be expected to be the case for an abandoned or orphaned case,

TABLE V. – Dose rates for 30-year old sources of 1-mCi Co-60 & Cs-137

Isotope	**Energies (MeV)**	**cGv(tem)/h [rad(tem)/h] at 10 cm**
Co-60	1.173, 1.332	0.002
Cs-137	0.662	0.017

Thus, using Tables I, II, IV and V, the approximate doses for the sources are shown in Table VI.

TABLE VI. – Dose rates for New & Aged medical & industrial sources of C0-60 & Cs-137

Source	**Activity, cGv(tem)/h [1 rad(tem)/h] at 10 cm**	
	New Source	**Aged (30-year) Source**
Co-60 Medical	1.25E+04	2.00E+02
Cs-137 Medical	3.30E+03	1.70E+03
Co-60 Industrial	1.25E+05	2.00E+03
Cs-137 Industrial	3.30E+04	1.70E+04

But this is for a non-dispersed source. If we assume rectangular dispersion areas as shown in Table VII the doses at the center of the area decrease with increasing area. (The reader is urged to understand that this progression of values is an example only.)

TABLE VII. – Dose rate (rad/hr) per cm^2 at 10-cm for various areas of dispersion, for New & Aged (30-year) medical and industrial sources of C0-60 and Cs-137

Source	rad/h/cm^2							
	20 m x 20 m		40 m x 40 m		80 m x 80 m		160 m x 160 m	
	New	Aged	New	Aged	New	Aged	New	Aged
Co-60 Medical	3.13E-03	5.00E-05	7.81E-04	1.25E-05	1.95E-04	1.25E-05	4.88E-05	1.25E-05
Cs-137 Medical	8.25E-04	4.25E-04	2.06E-04	1.06E-04	5.16E-05	1.06E-04	1.29E-05	1.06E-04
Co-60 Industrial	3.13E-02	5.00E-04	7.81E-03	1.25E-04	1.95E-03	1.25E-04	4.88E-04	1.25E-04
Cs-137 Industrial	8.25E-03	4.25E-03	2.06E-03	1.06E-03	5.16E-04	1.06E-03	1.29E-04	1.06E-03

At a point at the center of these distributions, 10 cm above the ground, the dose rate for the entire distribution is shown in Table VIII.

TABLE VIII. – Dose rate at a point 10 cm above the ground at the center of the areas of dispersion for New & Aged (30-year) medical and industrial sources of C0-60 & Cs-137

Source	rad/h							
	20 m x 20 m		40 m x 40 m		80 m x 80 m		160 m x 160 m	
	New	Aged	New	Aged	New	Aged	New	Aged
Co-60 Medical	1.59E+03	2.54E+01	6.47E+02	1.03E+01	1.99E+02	3.18E+00	8.09E+01	1.30E+00
Cs-137 Medical	4.19E+02	2.16E+02	1.71E+02	8.80E+01	5.24E+01	2.70E+01	2.14E+01	1.10E+01
Co-60 Industrial	1.59E+04	2.54E+02	6.47E+03	1.03E+02	1.99E+03	3.18E+01	8.09E+02	1.30E+01
Cs-137 Industrial	4.19E+03	2.16E+03	1.71E+03	8.80E+02	5.24E+02	2.70E+02	2.14E+02	1.10E+02

The significance of the magnitudes of these values can be appreciated by comparison to the nominal Gamma exposure limits shown in Ref 3 and repeated in Table IX.

TABLE IX. – Maximum annual dose limits, rad

Dose Type	Workers	Public
Effective dose	50	5
Lens of the eye	150	15
Single organ	500	50
Hands and feet	500	50

If we assume the Warfighter or the First responder is classified as a 'Worker' then the maximum time in the respective radiation-dispersed environments is shown in Table IX.

TABLE IX. – Maximum time allowed in radiation-dispersed areas, hours

Source	hours							
	20 m x 20 m		40 m x 40 m		80 m x 80 m		160 m x 160 m	
	New	Aged	New	Aged	New	Aged	New	Aged
Co-60 Medical	0.032	1.971	0.077	4.831	0.252	15.740	0.618	38.606
Cs-137 Medical	0.119	0.232	0.293	0.568	0.954	1.852	2.340	4.542
Co-60 Industrial	0.003	0.197	0.008	0.483	0.025	1.574	0.062	3.861
Cs-137 Industrial	0.012	0.023	0.029	0.057	0.095	0.185	0.234	0.454

Before addressing the implications suggested by the maximum times in Table IX we should note that the values derive from the assumption made that these are dispersions of an entire amount of isotopes as in Table I. One could also argue either that the total amounts are too little or too small. Our purpose is not to engage in the actual amount of isotope but only to use this as an example. The reader can increase or lower the amounts to their preferences.

From table IX it is clear that a 'New' source of isotope presents a much greater problem than one that has 'Aged' for 30-years old. And it could be argued that terrorists are more likely to find an 'Aged' source available. Moreover, Cs-137 is more ideal for dispersion than Co-60 because the former is in the form of a CsCl powder whereas the latter is in the form of solid pellets on the order of 2-Ci each when "New". But again these are aspects better left to the experts on terrorists. Having said these things we will more on to the issue of the exposures in Table IX.

Table IX implies that it is critical that the Warfighter or the First Responder be able to quickly perform the duties required inside the dispersal area. From Appendix 1 in Ref 2, 150 appears to be about the maximum survivable dose, in which case the maximum exposure time are about three times those in Table IX, that is as little as about 2 minutes.

Gamma and X-Ray Shielding

Traditional shielding for Gamma and X-Ray radiation has been lead or a composite of lead, such as lead-vinyl garments for body-protection garments and lead-glass for protection of the eyes. Recently lead has been cited as being toxic, especially in the case of disposal of the lead-based composite. Another argument given is that lead is heavy. Non-lead, polymer-based composites have been argued as desirable replacements.

One reason cited for non-lead, polymer-based composites are that they are not toxic. Another is that polymers are low-density materials and that this will contribute to a shield that is of less weight than one made of lead. We would agree with the first reason. The second one is entirely false and is based on a logic that seems to appear because the concept of shielding is entirely misunderstood. Simply said, shielding that reduces the dose by a factor equal to that of lead will weight about the same or more as lead, or more. Yes, the non-lead, polymer based shield may be of less density but it will have to be thicker than that of lead if it is to produce the same shielding performance. A rough rule-of-thumb is that thickness is inversely proportional to the density. Thus if a new material has a density half that of lead then it will have to be about twice as thick as the lead shield if it is to shield by an equal amount.

In the following section we compare pure-lead shielding to Demron, a currently popular shielding material for gamma and X-Ray radiation, and our material, GamXRAD, as it is currently developed. Other shielding materials, such as EarthSafe and Xenolite, are not included because papers have demonstrated that of the three, Demron, Earthsafe, and Xenolite, Demron possesses the best shielding performance, Ref 4.

Comparison of GamXRAD and Demron to Lead

Demron is a product made by Radiation Shield Technologies. References 5 -7 define much of the properties of this material and suggest it is a mixture of tantalum and one or more polymers, such as polyethylene and PVC-based polymer. Table X provides for comparison of the three shielding materials for the Gamma radiation from Co-60 and Cs-137.

TABLE X. Thickness and mass for factors of 2 and 10 dose reductions

Radiation	**Shield Material**	**Factor of 2 dose reduction**		**Factor of 10 dose reduction**	
		Thickness, cm	Mass for 1cm2 area, g	Thickness, cm	Mass for 1cm2 area, g
Co-60	Lead	1.04	11.80	3.45	39.16
	Demron	6.69	21.00	22.22	69.77
	GamXRAD	1.51	11.20	5.04	37.34
Cs-137	Lead	0.49	5.56	1.63	18.5
	Demron	2.21	6.94	7.33	23.02
	GamXRAD	0.80	5.94	2.64	19.59

The first observation from Table X is that although Demron's density, approximately 3.14 gram/cc, is about one-quarter that of lead, its thickness for equal absorption is 6.5 that of lead for Co-60 and 4.5 for Cs-137. So the mass/sqcm is larger than that for lead, as shown. In the case of Co-60 the areal mass is twice that of lead. So although it is not toxic it is more massive, as well as much thicker.

GamXRAD's performance is more equal to that of lead. It's thickness for equal absorption is nearly that of lead. Its thickness is on the order of that of lead and is much less than Demron's. Its mass is approximately that of lead, a little less for C0-60 and a little more for Cs-137. Very importantly, its mass it also like that of lead, and in all cases is much less than that of Demron's. So on the basis of thickness and mass we conclude that GamXRAD is superior to Demron.

The corresponding masses for a garment suitable for protection of only the trunk of the body of a nominal sized (5’ 10”, 170 lb) person are shown in Table XI. The table demonstrates well that to significantly reduce the dose to the body the shield, irrespective of the material, the weight of the shield is impractical, particularly so for Demron.

TABLE XI. Garment mass for protection of the body trunk of a 5’ 10”, 170-lf individual

Radiation	Shield Material	Garment Mass, kg		Garment Weight, lb	
		½ Thickness	1/10 Thickness	½ Thickness	1/10 Thickness
Co-60	Lead	109.9	365.0	242	803
	Demron	195.6	650.0	430	1430
	GamXRAD	105.0	349.0	231	767
Cs-137	Lead	51.7	171.8	114	378
	Demron	645.6	214.5	142	472
	GamXRAD	55.0	182.7	121	402

What is next for GamXRAD?

The present form of GamXRAD is a solid suitable for garments for individuals. It’s dose-reduction performance, as shown in Table X, is nearly equal to that of pure lead. Clearly, in terms of mass and thickness it is superior to Demron.

LTi is currently changing the formulation of GamXRAD so that is it both more flexible and higher density. This will reduce required thickness, although it will not significantly reduce garment mass. Because of the mass LTi has begun an alternative approach for the application of GamXRAD as radiation shielding for protection of Warfighters and First-Responders.

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