Evaluation of Terrorist Interest in Radioactive Wastes

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ABSTRACT

Since September 11, 2001, intelligence gathered from Al Qaeda training camps in Afghanistan, and the ensuing terrorist activities, indicates nuclear material security concerns are valid. This paper reviews available information on sealed radioactive sources thought to be of interest to terrorists, and then examines typical wastes generated during environmental management activities to compare their comparative "attractiveness" for terrorist diversion.

Sealed radioactive sources have been evaluated in numerous studies to assess their security and attractiveness for use as a terrorist weapon. The studies conclude that tens of thousands of curies in sealed radioactive sources are available for potential use in a terrorist attack. This risk is mitigated by international efforts to find lost and abandoned sources and bring them under adequate security. However, radioactive waste has not received the same level of scrutiny to ensure security.

This paper summarizes the activity and nature of radioactive sources potentially available to international terrorists. The paper then estimates radiation doses from use of radioactive sources as well as typical environmental restoration or decontamination and decommissioning wastes in a radioactive dispersal device (RDD) attack. These calculated doses indicate that radioactive wastes are, as expected, much less of a health risk than radioactive sources. The difference in radiation doses from wastes used in an RDD are four to nine orders of magnitude less than from sealed sources.

We then review the International Atomic Energy Agency (IAEA) definition of "dangerous source" in an adjusted comparison to common radioactive waste shipments generated in environmental management activities. The highest waste dispersion was found to meet only category 1-3.2 of the five step IAEA scale. A category "3" source by the IAEA standard "is extremely unlikely, to cause injury to a person in the immediate vicinity".

The obvious conclusion of the analysis is that environmental management generated radioactive wastes have substantially less impact than radioactive sources if dispersed by terrorist-induced explosion or fire. From a health standpoint, the impact is very small. However, there is no basis to conclude that wastes are totally unattractive for use in a disruptive or economic damage event. Waste managers should be cognizant of this potential and take measures to ensure security of stored waste and waste shipments.

INTRODUCTION

Radionuclide sources are frequently mentioned in the literature as items of interest to terrorists for construction of RDDs or “Dirty Bombs.” Regens presented estimates of radionuclide deposition from an RDD composed of 1000 or 3000 Ci of Cs-137 [1]. These authors previously presented information on release fractions estimated from wastes from an RDD [2]. This paper reviews typical Environmental Restoration wastes and wastes from Decontamination and Decommissioning (D&D) of nuclear facilities to assess comparable attractiveness for terrorists in creating health impacts with radionuclides. The paper does not address terrorist potential to use radioactive wastes to create disruptions or economic damage. Inherent in this assessment is whether existing Safeguard and Security measures for wastes are adequate.

The characteristics and sizes of radionuclide sources available to terrorists are discussed followed by a summary of reported illicit trafficking of radionuclides. This background provides order-of-magnitude identification of what a terrorist could conceivably obtain. Subsequently, estimates of airborne releases are generated to support dose estimates resulting from dispersion of from both radionuclide sources and wastes. These estimates allow comparison of the doses resulting from dispersion of the activity from diverse sources using common dispersion assessments. For confirmation, the IAEA has published information on “dangerousness” of radionuclide sources. This IAEA information is used to compare/support conclusions developed from the dose estimates.

COMPARISON OF RADIONUCLIDE SOURCES AND ENVIRONMENTAL MANAGEMENT WASTES FOR A RADIOLOGICAL DISPERSAL DEVICE

Radionuclide sources available

Radioactive sources are potentially attractive to terrorists to disrupt communities by dispersion in the environment or infrastructure and thereby take advantage of the public’s aversion to anything radioactive. The radioactive sources in use and historical sources still accessible for use in an RDD are well documented [2 through 11]. Table I lists some common radioactive source sizes and uses. Airborne dispersion is usually assumed to be by explosive means, but fires are also an option.

The literature consistently identifies Cesium-137, Cobalt-60 and Strontium-90 as the major sources available for a RDD. Americum-241 is also listed as available in significant but lower activity sources than the first three. Plutonium-238 is included for its use in radioisotope thermoelectric generators (RTG), almost exclusively for spacecraft. Tritium is readily available in self-luminescent signs. Large numbers of signs are in use and abandoned, each of which can contain more than 20 curies, and are poorly controlled. A large activity from tritium signs could be collected with relative ease. While a tritium attack would not be expected to provide a significant dose, it could contaminate a region for a long period of time above detectable levels. Table 1 provides some common radioisotope source activities and uses.

Table I. Common Activities and Uses of Radionuclide Sources

Isotope	Typical Source Activity (TBq (Ci))	Source Use
Cs-137	330 (9,000)	Irradiator
Co-60	370 (10,000)	Irradiator
Sr-90	3000 (80,000)	RTG
Am-241	0.74 (20)	Well logging
Pu-238	0.11 (3)	RTG
Ir-192	3.7 (100)	Radiography
Cf-252	0.05 (1.4)	Well logging
I-131	0.004 (0.1)	Medical
H-3	0.7 (20)	Luminescent signs

In addition, available information on illicit trafficking in radioactive materials provides further insight into the radionuclides of concern. The statistics confirm the availability of radionuclides on the black market. Fig. 1 shows radionuclide illicit trafficking from 1993 through 2002. Four selected radionuclides for this study are highlighted

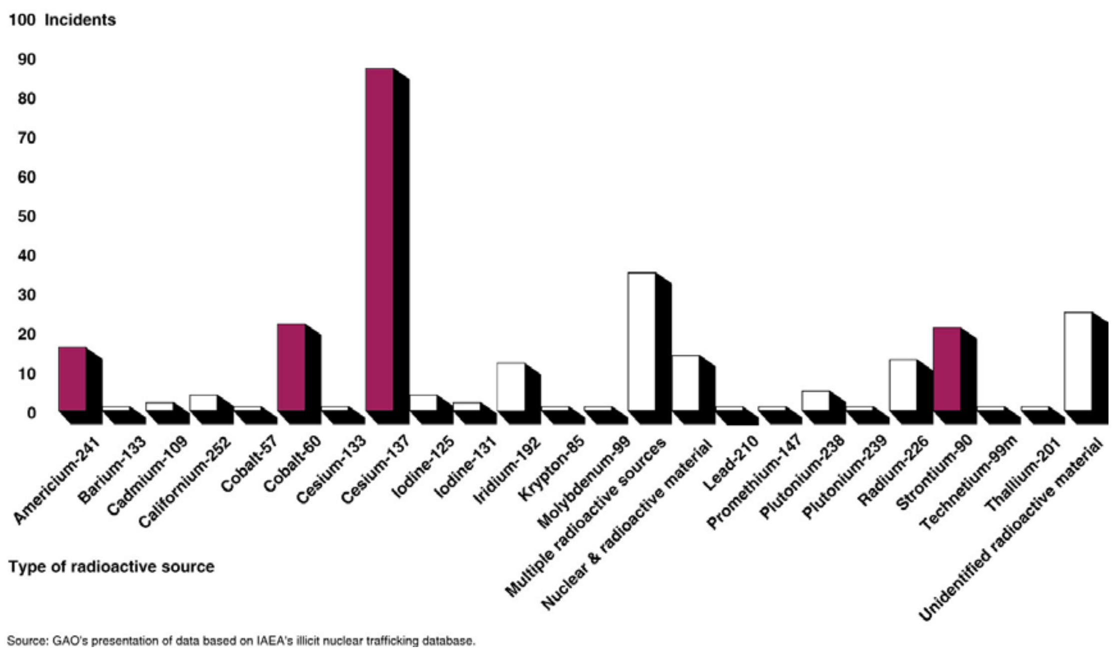

Fig. 1. Illicit radionuclide trafficking [7]

Capability of terrorist organizations to handle dangerous materials

The above data indicate that there are radionuclide sources available to terrorists and that there is a market for the primary listed radionuclides, whose purpose is most likely to be RDDs. The chemical form/matrix for the radionuclide sources listed above is varied. Cs-137 is frequently available in a highly water soluble chloride form. Sr-90 from RTGs is commonly found in a ceramic form. For an RDD to be effective, the chemical form should be readily dispersible. It is well understood that terrorists have access to and knowledge on how to construct explosive devices. An RDD takes additional technical expertise. In a recent study of radionuclide use for disruptive events, Shaw made the following assumptions:

- Large activity sources are available to an international terrorist organization.
- Insiders can be solicited to identify the most effective location/application of the radionuclides.
- The terrorist organization has technically trained people who obtain, import, and manage lethal quantities of radionuclides for delivery.
- Terrorists can perform relatively simple processing to make the radionuclide deliverable (dispersible). (Complex chemical processing is not plausible, but simple dissolution or leaching can be accomplished.)

Simply stated; it is assumed that terrorists either have or can secure technical resources adequate to handle and deliver the radionuclides in an RDD or other method of environmental dispersion.

Specific attractiveness of wastes

Wastes could be attractive to terrorists for an RDD or environmental dispersion attack if they have enough activity to cause injury or economic damage and can be effective dispersed. The wastes could be 1) dispersed from their current position, 2) stolen and then dispersed in a strategic location, or 3) stolen, processed and then dispersed in a strategic location. Wastes with the greatest attractiveness for an attack would have the highest activity, lowest security, and be in or be capable of being moved into an effective location.

Environmental restoration wastes are relatively low activity, and are generally contained in large quantities of soil or debris. The information on what wastes are generated at a remediation site are readily available in the public record. Terrorist could pick shipments from higher risk sites based on characterization reports, published remediation schedules or insider information. D&D waste from reactors has equipment/components of high activity but the radionuclides are bound to the large equipment and would be difficult to effectively obtain, manage, and disperse.

Estimation of doses from airborne releases from RDDs using sources and wastes

Doses from RDDs detonations were estimated using models with selected example radioactive wastes and a radionuclide source. The intent is to demonstrate an order-of-magnitude comparison of the impact of these selected examples. Fig. 2 presents the general approach to the dose estimation;

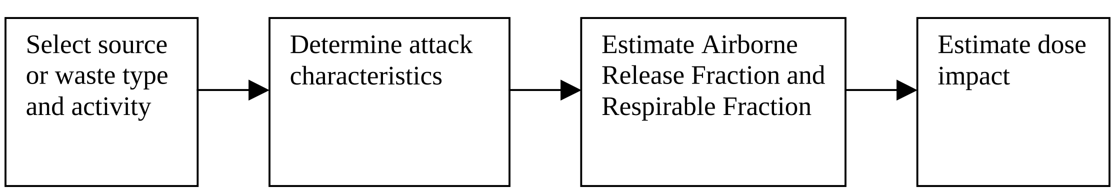

Fig. 2. Dose estimation process

Select Source or Waste Type and Activity

Four radionuclide sources were selected for modeling. Based on information available for the typical radionuclide source activity, source activities were selected based on the larger (but not largest) source activity commonly manufactured. Table II shows the activity used here.

Table II. Radionuclide Activity Selected for Modeling

Isotope	Source Activity (TBq (Ci))
Cs-137	330 (9000)
Co-60	370 (10000)
Sr-90	3,000 (80,000)
Am-241	0.7 (20)

Drummed Waste

For this analysis, drummed radioactive waste is assumed to be low level waste (LLW) from a variety of waste streams including environmental remediation waste, commercial waste, D&D waste, and waste from research activities. This waste is in the form of contaminated soil/sediments, anti-contamination clothing, D&D waste small enough to be drummed, manufacturing and research waste (Fig. 3).

The "source term: the waste is assumed to be the maximum allowed by DOT for Type A containers for each radionuclide.

Fig. 3. Drummed waste being surveyed for transportation

Fig. 4. Bulk waste being loaded into Gondola car

Bulk Waste

Bulk waste is from environmental remediation or D&D. Waste shipped in bulk generally has lower activity per volume than those requiring containerization. Bulk waste is shipped by rail or by rolloff. Rail shipment has the larger volume and was used as the bulk waste worst case in this analysis (shown in Fig. 4). It was assumed that the attack involved two rail cars containing bulk waste at the maximum activity level allowed in bulk waste. The bulk waste is assumed to be Low Specific Activity (LSA-I) waste for source term calculation purposes.

D&D Debris

D&D debris and equipment includes both reactor and radiation facility D&D waste. The waste assumed for this study is smaller components that could fit in a sealed cargo container, and be shipped by truck. The attack assumes one truckload of sealed cargo containers at the maximum activity allowed in a shipment.

Our study does not include spent reactor fuel assemblies and other high activity waste. Nor did we address large D&D Components such as steam generators or reactor vessels that are transported and disposed as LSA or Class B or C waste which are typically associated with commercial nuclear decommissioning projects and are closely monitored by the NRC and State Regulators. Typically the pieces of equipment themselves are self-protecting due to their large size and extraordinary transportation requirements.

Determine attack characteristics

Radiological wastes are consolidated for shipment and transported subject to applicable radioactive material transportation rules. Thus, various waste forms were conservatively evaluated as shipments prepared under US Department of Transportation regulations at the maximum allowed radionuclide activities for that shipping form. This is very conservative in that radioactive waste is almost never shipped at concentrations near the shipping limits and in many cases the shipment dose rate limits prevent concentrations at these levels. Waste requiring shipment in more substantial shipping containers (Type B containers) were not considered a credible terrorist target because of the substantial packaging and the physical tracking received by such shipments.

The effectiveness of the attack will depend on how effectively the waste is dispersed. Two general categories were examined: improvised explosive devices and purpose-built devices. An improvised explosive device involves detonating explosives on or near the waste containers or fire engulfing the waste containers. A purpose-built device is one that was designed to provide improved dispersal of the waste. These devices incorporate the waste into the dispersal device. The waste is generally removed from its packaging to aid dispersal. Relatively simple processing, such as dissolution or resizing can make the radionuclide deliverable. The advantage of purpose-built devices is a much higher efficiency in producing airborne radioactivity and the resulting radiation dose.

The release mechanisms are defined by considering each waste form in either an improvised radiological dispersion attack or a purpose-build RDD. Only two purpose-built RDD scenarios are considered credible; radionuclide sources and drummed waste. Theft of rail cars of waste requiring processing for dispersion is not assumed a credible attack scenario due to the low activity in typical waste shipments and the difficulty in making the limited amount of activity airborne. Similarly, theft of a sealed cargo container filled with radioactive debris would not provide terrorists with material that could be readily processed into a form appropriate for an RDD. Thus, these latter two purpose-build RDD scenarios were not considered further.

Estimate Airborne Release Fraction and Respirable Fraction

Airborne Release Fractions (ARF) and Respirable Fractions (RF) for each waste type and attack scenario were taken from a US Department of Energy handbook for accident analysis [12]. Source releases were based on unshielded blast effects on powders, with the improvised RDD taking credit for some source capsule protection. The drummed waste release fractions are based on venting of pressurized gasses through a powder, with the improvised RDD taking credit for some drum and drum pieces protection of the material. The bulk waste (rail cars) release fractions were based on unshielded blast effects on powders, but due to the bulk, only 10% of the powder was assumed to be available for dispersion. Finally, for debris packaged in sealed cargo containers, blast effects, shielded by the bulk of the waste, were considered to affect the 10% of the radionuclide contamination available on the surface of the waste.

The results of the estimates are shown on four tables to indicate the overall airborne activity resulting from each of the waste type/scenario combinations. Table III provides the respirable airborne release for RDD events using radioactive sources of typical activities. Tables IV and V and VI provide comparable data for truckloads of waste, railcars of waste, and cargo containers, each containing the maximum shippable activity of a specific radionuclide in the package.

Table III. Selected Isotope Airborne Release for Two Scenarios with Radioisotope Sources

Isotope	Source Activity (TBq (Ci))	Purpose-Built Attack Release (TBq (Ci))	Improvised Attack Release (TBq (Ci))
Cs-137	300 (9000)	170 (4500)	55 (1,500)
Co-60	370 (10000)	190 (5000)	61 (1,700)
Sr-90	3,000 (80,000)	1,500 (40,000)	480 (13,000)
Am-241	0.7 (20)	0.37 (10)	0.12 (3.3)

Table IV. Airborne Release for Truckload Shipments of Drums (Type A Containers)

Isotope	LLW Truck Shipments (TBq (Ci))	Purpose-built Attack Release (TBq (Ci))	Improvised Attack Release (TBq (Ci))
Cs-137	31 (850)	2 (60)	0.5 (10)
Co-60	22 (580)	2 (40)	0.4 (10)
Sr-90	16 (430)	1 (30)	0.3 (8)
Am-241	0.053 (1.4)	0.004 (0.1)	0.0009 (0.03)
Pu-238	0.053 (1.4)	0.004 (0.1)	0.0009 (0.03)

Table V. Airborne Release for Bulk Rail Shipment of LSA-I Waste

Isotope	LSA 1 Railcars (2) Shipment Activity (TBq (Ci))	Improvised Attack Release (TBq (Ci))
Cs-137	0.054 (1.5)	0.00001 (0.0003)
Co-60	0.054 (1.5)	0.00001 (0.0003)
Sr-90	0.54 (15)	0.0001 (0.003)
Am-241	0.0054 (0.15)	0.000001 (0.00003)
Pu-238	0.0054 (0.15)	0.000001 (0.00003)

Table VI. Airborne Release for D&D Shipment of LSA-I Waste

Isotope	LSA-II Cargo Container(s) (one truckload) Shipment Activity (TBq (Ci))	Improvised Attack Release (TBq (Ci))
Cs-137	860 (23,000)	0.2 (5)
Co-60	590 (16,000)	0.1 (3)
Sr-90	440 (12,000)	0.09 (2)
Am-241	1.5 (39)	0.0003 (0.008)
Pu-238	1.5 (39)	0.0003 (0.008)

These four tables provide input to dose modeling from an RDD.

Estimate dose impacts

The airborne releases tabulated in the estimates above were used as input to the Hotspot Model. This model was created to provide emergency response personnel and emergency planners with a fast, field-portable software tools for evaluating incidents involving radioactive material. The software is also used for safety-analysis of facilities handling nuclear material. Hotspot codes are a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials. The Hotspot codes are designed for short-term (less than a few hours) release durations. Four general programs - Plume, Explosion, Fire, and Resuspension - estimate the downwind radiological impact following the release of radioactive material resulting from a continuous or puff release, explosive release, fuel fire, or an area contamination event. Hotspot is a hybrid of the well-established Gaussian plume model, widely used for initial emergency assessment or safety-analysis planning. Virtual source terms are used to model the initial atmospheric distribution of source material following an explosion, fire, resuspension, or user-input geometry.

The radionuclide sources are generally small quantity materials and were made airborne using 0.45 kg (TNT equivalent) of plastic explosive and the airborne fractions presented above. For equivalency, the drummed waste RDD was powered by ammonium nitrate/fuel oil (ANFO) explosive inputting the same energy per mass as used with the sealed sources. The improvised attack on bulk waste and D&D debris would require very large quantities of ANFO, so it was assumed that the attack involved ignition of a 30,000 liter truckload of gasoline beside the railcars or cargo containers. Table VII summarizes these RDD attack and explosive configuration assumptions.

Table VII. RDD Detonation Characteristics

Radionuclide Material	Type of Attack	RDD explosive used
Sealed Sources	Purpose-built (radionuclide removed from container)	Plastic explosive (0.45 kg TNT equivalent)
	Improvised (radionuclide in unopened container)	Plastic explosive (0.45 kg TNT equivalent)
Drummed Waste	Purpose-built (loose waste on top of explosive)	6400 kg of ANFO (TNT energy equivalent to explosive used in sealed source RDD but scaled for waste quantity)
	Improvised (drummed waste still in truck, but adjacent to truck of explosive)	6400 kg of ANFO (TNT energy equivalent to explosive used in sealed source RDD but scaled for waste quantity)
Bulk Waste	Improvised (fuel tanker parked beside rail cars)	30,000 l tank truck of gasoline ignited
Debris	Improvised (fuel tanker parked beside cargo containers)	30,000 l tank truck of gasoline ignited

The results of the Hotspot model calculations using explosive or fire module and the above assumptions are shown in Table VIII.

Table VIII. Hotspot Model Results from Detonation of RDD with Various Sources of Radionuclides

Radionuclide material type	Type of attack	Radionuclide	Maximum dose to and individual (REM)
Sealed source	Purpose-built	Cs-137/Ba-137	15
		Co-60	37
		Sr-90/Y-90	890
		Am-241	250
	Improvised	Cs-137/Ba-137	4.9
		Co-60	12
		Sr-90/Y-90	290
		Am-241	82
Drummed waste	Purpose-built	Cs-137/Ba-137	0.0029
		Co-60	0.0044
		Sr-90/Y-90	0.011
		Am-241	0.042
	Improvised	Cs-137/Ba-137	0.00074
		Co-60	0.0011
		Sr-90/Y-90	0.0028
		Am-241	0.011
Bulk waste	Improvised	Cs-137/Ba-137	1.8E-09
		Co-60	4.0E-09
		Sr-90/Y-90	1.4E-07
		Am-241	1.5E-06
Debris	Improvised	Cs-137/Ba-137	0.00003
		Co-60	0.00005
		Sr-90/Y-90	0.00014
		Am-241	0.00040

Table VIII shows that the purpose-built drummed waste RDD dose is four orders of magnitude less than the equivalent sealed source attack. Improvised attacks are almost "non-events" in comparison to the attacks using sealed sources.

Attractiveness or dangerousness of radioactive materials

As an alternative approach to assessing the attractiveness of waste, a method developed by the IAEA was applied [3]. The IAEA used a ratio of the radionuclide source activity (Ci or TBq) to an activity above which the radioactive source is considered to be "dangerous." This process ranks sources on a scale of 1 to 5 and provides a potential measure of their attractiveness for an RDD. Table XI summarizes the relevant items of this scale. The last column of Table IX tabulates the minimum activity that would qualify a radionuclide source to that category.

Table IX. IAEA Dangerousness Categorization Scale for Dispersed Radioactive Material

IAEA Category	Description of Impact	Minimum Source Activities in Category TBq (Ci)
I-1.2	"amount of radioactive material if dispersed by explosion or fire … likely to be life threatening to persons in the immediate vicinity"	Cs-137 - 100 (3000) Co-60 – 30 (800) Sr-90 – 1000 (30,000) Am-241 – 60 (2000)
I-2.2	"amount of radioactive material if dispersed by explosion or fire … could possibly, but unlikely to cause injury to a person in the immediate vicinity"	Cs-137 – 1 (30) Co-60 – 0.3 (8) Sr-90 – 1.0 (300) Am-241 – 0.6 (20)
I-3.2	"amount of radioactive material if dispersed by explosion or fire … could possibly, but extremely unlikely to cause permanent injury or to be life threatening…"	Cs-137 – 0.1 (3) Co-60 – 0.03 (0.8) Sr-90 – 1 (30) Am-241 – 0.06 (2)
I-4.2	"very unlikely that anyone would be permanently injured"	Cs-137 – 0.001 (0.03) Co-60 – 3E-04 (0.008) Sr-90 – 0.01 (0.3) Am-241 – 6E-04 (0.02)
I-5.2	"could not permanently injure anyone"	Cs-137 – 0 Co 60 - 0 Sr-90 – 0 Am-241 – 0

Any source at or exceeding the activities indicated in Category I-2.2 of Table IX is a radiological health concern. The activities of the last column of Table IX are not directly applicable to wastes which have large volumes, low "activity density" and are therefore much more difficult to disperse than the activity from radionuclide sources. We "corrected" the source activities of Table IX by applying ratios of airborne release factors from the previous discussion. That factor is derived by dividing the release fractions from the purpose-built radionuclide source RDD by the release fractions for the waste forms dispersion scenarios. Table X shows the result of that correction and evaluation of wastes on the IAEA scale. The radionuclides from the waste are assumed to be dispersible if an explosive device or fire can make the material airborne. The last columns of Table X indicate the equivalent IAEA category for the wastes used in the prior discussion.

Table X. Attractiveness of EM/D&D Wastes Using IAEA Dangerousness Categories

Waste Stream/ Attack	Dispersible	Accessible	Factor	IAEA Category (Adjusted)			
				Cs-137	Co-60	Sr-90	Am-241
Drummed Waste – Purpose Built	Yes	Limited Security	7	1-4.2	1-4.2	1-3.2	1-4.2
Drummed Waste – Improvised	Yes	Limited Security	29	1-4.2	1-4.2	1-4.2	1-4.2
Bulk Waste	Yes – in fire	Limited Security	2500	1-5.2	1-5.2	1-5.2	1-5.2
Debris	Yes – in fire	Limited security	2500	1-4.2	1-5.2	1-4.2	1-5.2

Table X shows that strontium-containing drummed waste in purpose-built RDD attack could meet the criteria of 1-3.2, the highest category of any of the four wastes evaluated, and would be considered extremely unlikely to cause permanent injury from the radioactivity dispersed.

What does this mean for the waste manager?

The study estimates the relative attractiveness for an RDD using radioactive sealed sources compared to various types of radioactive waste using two methods of comparison. The dispersion and dose modeling estimates data show that sealed sources are vastly more effective in delivering a radiation dose to an individual. The IAEA dangerousness scale for sealed sources gives a similar result and indicates that wastes are extremely unlikely to result in any health effects when used in and RDD. Wastes are therefore assumed to be less attractive.

However, the terrorist goals of disruption or economic damage could be achieved with an attack using waste. We cannot totally discount the attractiveness on the basis of health effects alone. Understanding that there is a remote, but finite possibility of diversion, a waste management review of security controls for waste storage and transportation is prudent.

CONCLUSION

Two evaluations of the potential for use of environmental cleanup or D&D wastes in an RDD indicate that the wastes should be less attractive than available radionuclide sources. The sources result in many orders of magnitude more dose to the maximum individual than estimated for wastes in and RDD event. Wastes are substantially less attractive than the sealed radioactive sources in the construction of an RDD, as wastes would require more explosive and would be much more conspicuous than a "backpack" RDD. Support for this conclusion is the evaluation the IAEA attractiveness scale for radionuclide sources The wastes considered only meet the third highest category of the IAEA scale, which is estimated as "extremely unlikely" to result in any health impact.

The analysis suggests that attacks using the waste types in the study are only credible in causing disruption and/or economic impact, which may be a terrorist objective.

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