

REDUCING THE THREAT OF A SERIOUS ^{137}Cs DIRTY BOMB

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ABSTRACT

Presently, one of the gravest anticipated terrorist threats to the United States, the United Kingdom and European Union countries involves a class of weapons known as radiation dispersal devices (RDDs) or dirty bombs. Dirty bombs use a conventional bomb, such as a car bomb, to disperse radioactive materials in a populated area to cause great economic and social disruption disproportionate to their actual radiological effects and well beyond the physical destruction from their conventional bomb components. A program is underway to greatly reduce the threat of a serious dirty bomb attack by 2010. The severity of the long-term threat of dirty bombs to our national security will depend upon finding alternative matrices for the radioactive sources best suited for use in dirty bombs, e.g., the $^{137}\text{CsCl}$ powder that is a standard material used in industrial irradiators and the rapidly-growing sterilization industry. Cumulatively, $^{137}\text{CsCl}$ powder has the greatest dispersibility, penetrating radiation, and specific activity (highest levels of radioactivity per mass of material) of all potential RDD materials. Our research has shown that a combination of a simple, inexpensive technical step in the production of $^{137}\text{CsCl}$ for use in the sterilization industry, plus focused legislation and international treaties, can substantially reduce the threat of a devastating ^{137}Cs dirty bomb. In addition, first responders must learn to deal with the aftermath should one be successfully detonated. New guidelines from the DHS on exposure levels for police, fire, and EMTs address total dose, e.g., 5 rem, but do not provide guidance on how to implement emergency response activities after an intentional radiological event. We have implemented a first-responder training program at NMSU that is targeted to dirty bombs. Our experience with first-responder training along the WIPP nuclear waste transportation corridor is ideally suited as a basis since a dirty bomb is more similar to a radwaste spill than any other type of event. Finally, we have devised a reasonable rapid response to an RDD attack that is presently executable and available to all metropolitan target areas.

INTRODUCTION

RDDs, or dirty bombs, are devices that disperse radioactive materials. They take many forms, from containers of radioactive materials wrapped with conventional explosives, to aerosolized materials sprayed by conventional equipment, to manual dispersion of fine powders into the environment [1]. Also included are radiation-exposure devices (REDs), used to expose people to dangerous beams or particles of radiation. RDD attacks can produce general panic, immediate death and long-term increases in cancer incidence, long-term loss of property use, disruption of services, and costly remediation of property and facilities.

Radioactive materials are used in many fields in almost all countries around the world, particularly for medical, research, and industrial applications [2]. Dozens of radiological source producers and suppliers are found on six continents, and about a billion sources exist worldwide although most, like household smoke detectors, have such low activities that they pose no threat [3,4]. With the increase of radioisotope applications in nuclear medicine diagnostics and therapeutics, in sterilization and food irradiation, the radiological source production and fabrication industry is an emerging growth industry in several countries, particularly in areas with depressed economies (Figure 1). The rise in the number

of terrorist acts during the last ten years has raised concerns about these radiological sources being used in radiation dispersal devices (RDDs), or dirty bombs, that could create panic and potentially large economic consequences [4]. Because the general public is so frightened about anything radioactive, panic must be anticipated even if there is no real health threat from the radioactive component. The degenerate case of a phantom RDD, where no radioactive material is used but an implication or anonymous tip indicates there is, could still cause considerable panic with large economic consequences.

Major Radioisotope Producers

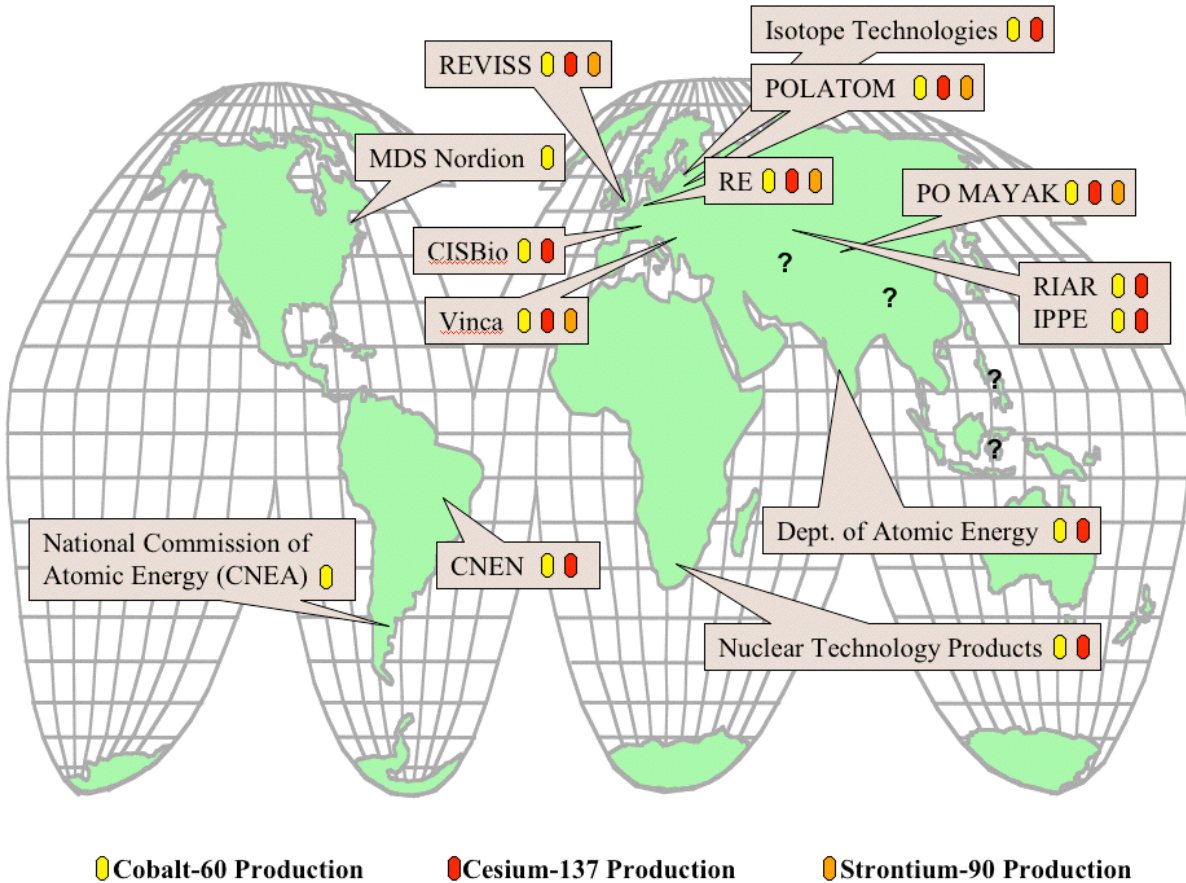


Figure 1. The major producers of radiological source materials. Note the locations in economically depressed regions (from van Tuyle et al. 2003 [4]).

The real radiological threats come from large RDDs containing thousands to hundreds of thousands of curies (Ci) of activity. These could cause significant and lasting health and contamination problems. Although many variables determine the effectiveness of an RDD attack, the key factor is the quantity and type of radiological source material that is dispersed. Briefly, the differences in sources relate to their specific activity (the type and amount of radiation emitted), and its chemical form (whether it is a powder, and non-metal solid or a metal). Gamma radiation (γ) can penetrate great distances and, depending upon the energies, requires shielding of about 18 cm of lead (Pb) or 3-feet of reinforced concrete. Beta radiation (β) can only penetrate a short distance and the personal protective gear of a firefighter can block much of the dose. Alpha radiation (α) is the least penetrating of all and can be stopped by a piece of paper or ordinary clothing. The most important pathway of accumulating dose

from α or β sources is ingestion or inhalation where the emitter is directly adjacent to tissue for long periods of time. For γ sources, mere proximity is all that is required for significant doses and personal protective gear is almost useless. For RDD discussions, isotopes of Pu, Am and U are primarily α emitters, ^{60}Co and ^{137}Cs are γ emitters, and ^{90}Sr is a β emitter. ^{60}Co usually occurs as a metal (either pellets or small rods), ^{137}Cs and ^{90}Sr are as powders, primarily chloride, and Pu, Am and U are various oxides, salts and non-metal solids. Although the public generally thinks of Pu and enriched-U when hearing the word radioactive, these are not considered RDD materials of choice because they are primarily α emitters, are costly, cannot be obtained in large amounts, are well-tracked and secured, and are more useful to terrorists in the production of actual nuclear weapons than in being wasted in an RDD. In this sense, ^{60}Co and ^{137}Cs are much more effective as RDD materials.

THE GLOBAL INVENTORY OF POSSIBLE RDD MATERIALS

Because many more inconsequential radiological sources exist than large sources, there is a natural starting point in reducing a serious RDD threat, i.e., reduce access to large RDD source materials and/or make them less useable in RDDs. A survey of the vulnerabilities associated with large radiological source materials completed by Los Alamos researchers [4] revealed that there are relatively few of the very large sources greater than 1000 Ci. The study also assessed the global commerce and use of the larger radiological source applications. Although suppliers are easy to identify and contact, the users can be more difficult to identify. There is incomplete information about the number of sources sold, utilized, re-sold, recycled, and disposed of, and a significant number are disused or orphaned, and untraceable.

Most nuclear and radiological source materials currently reside at nuclear reactors, particle accelerators, chemical and mechanical processing facilities, and local holding points or facilities [3,4]. Radiological sources are used for many purposes, all of which fit into three categories: to kill or otherwise alter organisms or tissue, to generate energy, and to provide analytical measurements. The first category includes weapons and sterilization applications in the food and medical industries; the second includes radioisotopic thermal generators (RTGs); and the third includes well-logging and diagnostic applications. A general list of radiological sources, grouped in terms of these uses, is provided in Figure 2. The sources near the top of the pyramid can utilize thousands to millions of curies of radioactive materials per source, whereas sources near the bottom use a fraction of a curie. Although it has been difficult to quantify, there are over 10,000 sources that exceed 1000 Ci, and perhaps a thousand that exceed 100,000 Ci. Note that the largest sources use ^{60}Co , ^{137}Cs or ^{90}Sr . This is because their applications are such that the larger the sources, the more cost-effective the application, e.g., for food irradiation applications, the larger the source, the faster the conveyer belt carrying the food can move below the source, the higher the through-put and the higher the profit [5,6,7]. Market-driven forces to increase source activity in these industries will continue, particularly in the case of ^{137}Cs or ^{90}Sr , which are produced from reprocessing nuclear fuel. The economic pressure to utilize waste products that otherwise have no path forward is too strong to expect their use to be discontinued, particularly in economically depressed regions such as Russia and India. An example of a large source irradiator is the YCF-1 mobile irradiator (Figure 3) manufactured by BINE (Beijing Institute of Nuclear Engineering). It consists of a 250,000-curie ^{137}Cs irradiator. Because food and produce irradiation can greatly extend shelf life, and the USDA approved importation of irradiated food in 2002, there are now greater incentives for deploying irradiators in counties that export produce into the United States.

Small & Insignificant Sources Greatly Out-Number Large & Hazardous Sources

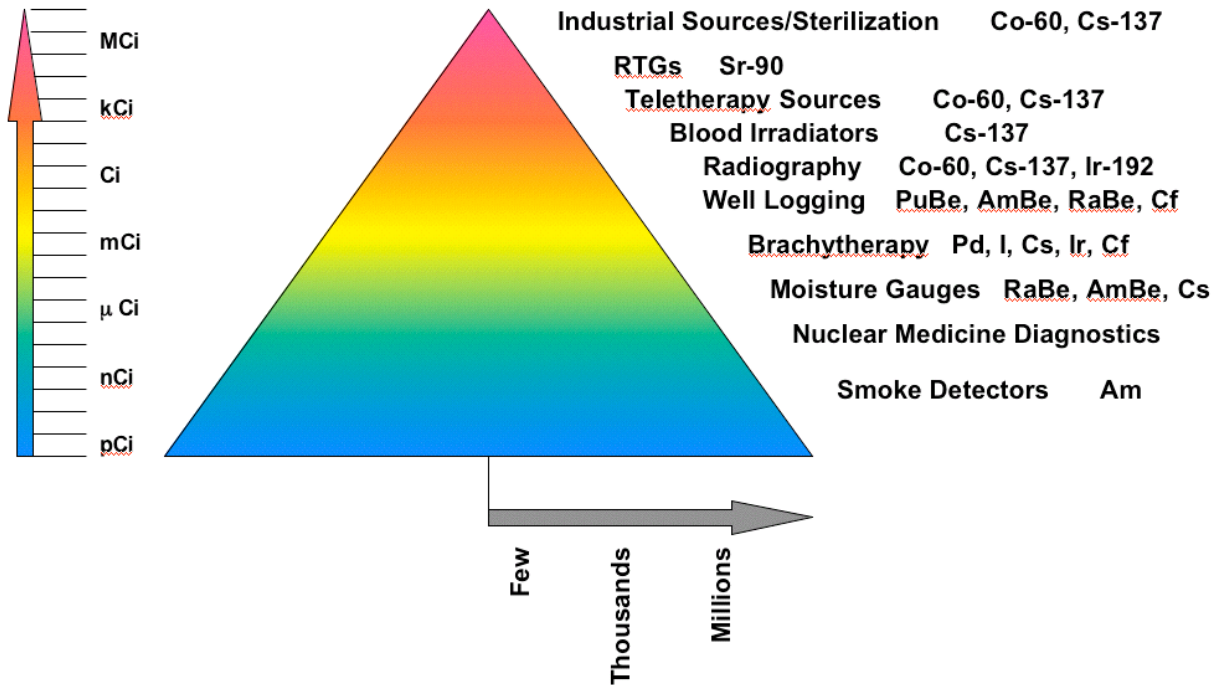


Figure 2. The primary uses, specific isotope and activity levels of radiological source materials. Note that the largest sources use only ^{60}Co , ^{137}Cs or ^{90}Sr (Courtesy of Greg van Tuyle).

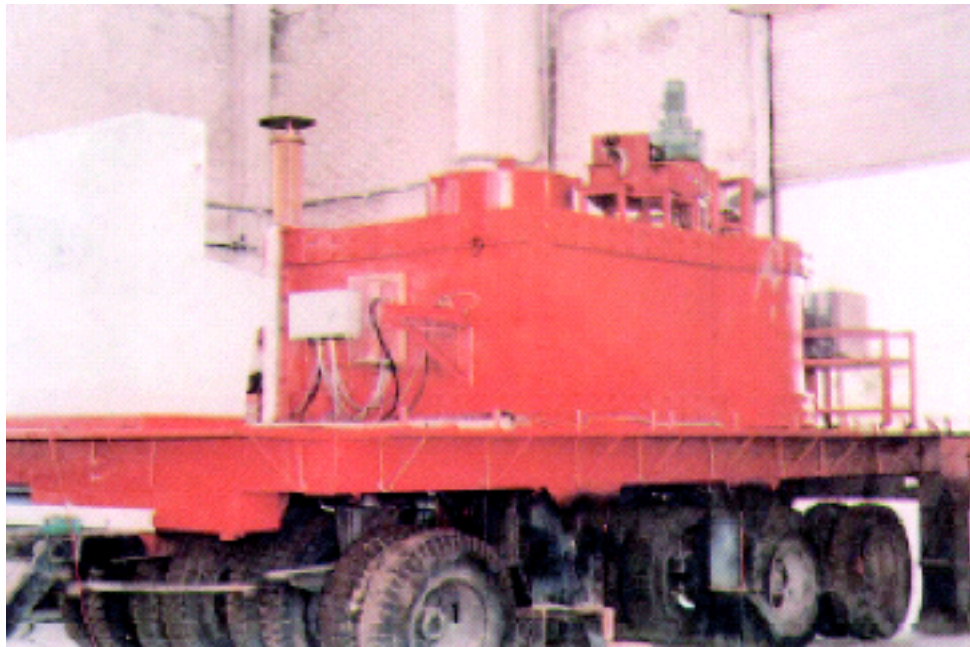


Figure 3. The YCF-1 mobile irradiator, manufactured by the Beijing Institute of Nuclear Engineering, contains a 250,000-curie $^{137}\text{CsCl}$ irradiator (from van Tuyle et al. 2003 [4]).

OPTIONS REGARDING RDD VULNERABILITY

Although inclusion of any radioactivity, no matter how small, in a dirty bomb will cause disruption at some level, the real health and economic threat resides in large sources because the radioactivity even after dispersion over many city blocks will be above public health limits and will have to be remediated before normal activities can resume. As an example, a 25-gram ^{137}Cs source (about 2,200 Ci) is lethal after about 1 hour of exposure at 1 meter (dose $\sim 1,000$ rem/hr), however, it is not lethal if spread over 10 city blocks (dose < 1 rem/yr or about four times natural background). On the other hand, a 2.5 kg ^{137}Cs source (about 220,000 Ci) that is used in some large irradiation units is still well above public health limits even spread out over 10 city blocks. Therefore, concern has focused on the upper region of Figure 2. In addition, neither ^{60}Co , ^{137}Cs nor ^{90}Sr are special nuclear materials (those able to be used to make an actual nuclear weapon) and so have not generally been covered under non-proliferation treaties or strategies, are relatively inexpensive ($< \$2/\text{Ci}$), and can be obtained in kg-sized quantities. Combined with the realization that terrorists groups are no longer deterred by the risk of death, ^{60}Co , ^{137}Cs and ^{90}Sr then become the materials with the greatest RDD threat. Of these three isotopes, ^{137}Cs is probably the largest threat as it is obtainable primarily as a fine powder (Figure 4), is easily dispersible and able to be reconfigured into a dirty bomb, has a half-life of 30 years, and is a hard gamma emitter maximizing the radiological health effects and making clean-up extremely difficult.

Various options are available to reduce the vulnerabilities associated with large radiological sources in each stages of their life cycle, from production to fabrication, to transportation to the user, to recycling, reusing, disposing or discarding. Major efforts are underway to recover disused and orphan sources, provide rapid



Figure 4. $^{137}\text{CsCl}$ powder (right) presently used in the irradiation industry. At left are shown abandoned $^{137}\text{CsCl}$ seed irradiators. ^{137}Cs emits a hard gamma ray at 0.66 MeV requiring about 18 cm of lead or three feet of concrete to shield. It has a high specific activity (87 Ci/g) and a half-life of 30.17 years, and so must be cleaned up after a ^{137}Cs dirty bomb attack. In the environment, CsCl dissolves easily into Cs^+ and Cl^- . Chemically and biochemically, Cs^+ behaves like K^+ and is readily taken up by plants and animals.

security upgrades for particularly vulnerable sites and facilities overseas, strengthen international agreements and regulations particularly regarding secure handling of large sources and import/export practices, and develop better paths forward for disposing of used sources [4,8]. Development of alternate technologies could also reduce the risks significantly. All of these options are being pursued to varying degrees but progress must come on all fronts in order to significantly reduce vulnerabilities.

Although there are major efforts under way to detect radioactive materials and secure/control/track materials of concern, limitations in physics and economics will eventually limit the effectiveness of detection and interdiction [4]. Because the risks can never be driven to zero, preparation for an RDD attack is vital. Public panic is expected, regardless of the true radiological threat. This will result in an over-taxing of the health care system, compounding the difficulties in treating people that are truly at risk. Environmental and infrastructure contamination problem may or may not be significant, but the public will probably be confused by conflicting opinions and statements regarding the dangers posed. However, in the event a large source RDD that is well dispersed, the decontamination challenges in a densely populated urban environment are daunting and have never been attempted in practice. It is imperative that the few existing response options be available to all probable target areas, that is, areas with large population densities and large economic or political significance, e.g., downtown Manhattan, the north end of The Mall in Washington, D.C., and Michigan Avenue in Chicago.

Along with the many efforts being pursued by many agencies, there are three relatively simple strategies that can be implemented immediately, particularly for ^{137}Cs and ^{90}Sr , the most dispersible of the large RDD materials:

1. dirty bomb training programs for first responders (not National Guard 101st Airborne or DOE RAP teams)
2. ^{137}Cs and ^{90}Sr chloride melting programs for the irradiation industry (a more RDD-resistant form), and
3. a rapid MetroDetection and Response system to minimize the health and economic effects of the aftermath.

First Responder Dirty Bomb Training

The first strategy, first responder training, is already underway in many programs across the country, although there is a recognized need to standardize the programs. Because a dirty bomb attack is closer to a radwaste spill than to any other event, the training programs have logically adapted RadWorker II programs that have been used for decades to train radiation workers in the nuclear, clean-up and disposal industries. As an example, New Mexico State University at CEMRC in Carlsbad is offering a three-day, two-credit training course in the College of Engineering entitled “Dirty Bombs and Radiation Dispersal Devices.” CEMRC is a 26,000 ft² radiochemistry facility that includes environmental and radiochemistry laboratories, a plutonium-uranium-actinide laboratory, an *in vivo* bioassay facility, mobile laboratories, field programs and computing operations. The course includes classroom, laboratory and field exercises in the following areas:

- the basic concepts of radiation physics and chemistry
- biological effects of radiation
- hazard recognition
- characteristics of a dirty bomb: the source and the explosives
- the nuclear fuel cycle
- nature of the various radioactive materials, their sources and numbers worldwide
- how dirty bombs are packaged and how they can be dispersed
- initial response actions
- incident control and command
- radiological survey instrumentation and dosimetry devices
- Department of Homeland Security Guidelines for RDD events and what that means to first responders
- clean-up and ways to mitigate the effects of dirty bombs
- decontamination, disposal and documentation
- when to respond and help with normal personal protective gear (α,β -bombs) and when not to (γ -bomb),
- when to return to work and living spaces after a dirty bomb attack

These types of training programs includes the basics of what every law enforcement, emergency responder, and cognizant citizen needs in order to recognize and respond to dirty bomb threats, and to make informed decisions in our society concerning the use and production of radionuclides that can be used in dirty bombs. These courses are not meant for advanced radiation event responders such as the National Guard 101st Civil Support or DOE RAP teams that will take over from local responders within 12 to 24 hours of the event, but are meant to provide local responders with sufficient information to provide incident control and command, determine the effected areas, address immediate concerns such as fire, aid citizens and medical personnel, provide support to the 101st and RAP teams, and generally keep panic to a minimum. This last point is critical; if the responders first on the scene do not understand what a dirty bomb event entails, that uncertainty will be communicated to the civilians in the area and attempts to contain the radioactivity may fail. Because there are over 200,000 first responders in the top 100 target areas in the United States, many such programs are needed.

¹³⁷Cs and ⁹⁰Sr chloride melting programs for the irradiation industry

The second strategy, irradiation industry programs for melting the ¹³⁷Cs and ⁹⁰Sr chloride powders used in most irradiation units, appears to be the only reasonable process for producing a more RDD-resistant form of these sources. At NMSU, we have been investigating alternative matrices for ¹³⁷Cs, the most effective RDD source material. Industry needs require that the material used in these units have a high loading capacity for Cs, and the ¹³⁷CsCl used at present, is about 79% Cs. Much less than 79% will require complete retooling and major changes in the manufacturing of the units which is unlikely to be adopted by a low-profit industry. Unfortunately, the chemistry of Cs dictates that the only solids able to be loaded with Cs in excess of 20% are salts. Table 1 shows the solids investigated, the loading capacity (%Cesium), the efficiency (%Yield) which is related to the cost of production, and the solubilities measured on the more promising solids. Many were too difficult or dangerous to make, and all would require implementation costs that are prohibitively high to the industry. All salts other than the chloride are much less soluble than the chloride, however, all are just as dispersible. On the other hand, the high solubility of the chloride is advantageous for clean-up and, at this point, it would be a mistake to make the solid less soluble without a large reduction in dispersibility.

Alternatively, the ¹³⁷CsCl can simply be melted in place to form a less dispersible, less easily handled material (Figure 5), and we have carried out this process in many ways, attempting to determine the optimal heating/cooling process for commercial applications. The melting point is relatively low on a commercial scale (645°C) and can be melted at the fabrication facility, right in the existing container, before being shipped to the user. This is a very inexpensive process that will not impact the economies of the industry and will not require any change in configuration of the units. Although not a cure-all, the solid mass of ¹³⁷CsCl is much more difficult to remove, smuggle or reconfigure into an optimal RDD without detection or death. While this would be easy for state-sponsored terrorist programs (which are not much interested in dirty bombs as opposed to actual nuclear weapons), it increases the difficulty to carry out an RDD attack for terrorist cells, to which dirty bombs are of most interest. Since SrCl₂ also has a fairly low melting point (850°C), a similar melting strategy should work for ⁹⁰SrCl₂. Because of the possible liabilities involved in the use of ¹³⁷CsCl obtained from an irradiator unit, industry leaders have already shown interest in the possibility of incorporating a simple melting step into the fabrication process. If this is adopted, then national and international laws can be adopted that prohibit the transportation of powdered ¹³⁷CsCl, existing powdered units could be melted in place, and the powdered form should disappear from the market, greatly reducing the threat of a ¹³⁷Cs dirty bomb. In addition, melting of powdered ¹³⁷CsCl would provide an added industrial benefit of reducing the minor, but important, problem of powdered ¹³⁷CsCl migration from sealed units, an issue that has prevented ¹³⁷CsCl from being used in some larger units. The melted form should not lose even minor amounts of ¹³⁷Cs from sealed containers.

TABLE 1. Alternative solid matrices investigated for ^{137}Cs .

Cesium Salt	Solid Name	% Cesium	% Yield	Solubility g/100mL @25°C
Cl^-	Cesium Chloride	79.0	99.0	> 200
BF_4^-	Tetrafluoroborate	60.5	77.6	0.32
N_3^-	Azide	76.0	---	---
PF_6^-	Hexafluorophosphate	47.8	20.0	0.74
OCN^-	Cyanate	76.4	---	---
SCN^-	Thiocyanate	69.6	---	---
MnO_4^-	Permanganate	52.8	40.5	0.30
$\text{S}_2\text{O}_4^{2-}$	Dithionite	Up to 67.5	---	---
$\text{B}_4\text{O}_7^{2-}$	Borate	Up to 63.1	---	---
WO_4^{2-}	Tungstate	Up to 51.7	---	---
$\text{P}_2\text{O}_7^{4-}$	Pyrophosphate	Up to 75.3	---	---
BPh_4^-	Tetraphenylborate	29.4	92.4	0.00
ClO_3^-	Chlorate	61.4	54.0	1.71
BrO_3^-	Bromate	51.0	70.5	1.54
VO_4^{3-}	Vanadate	Up to 77.6	---	---
IO_3^-	Iodate	43.2	72.8	0.68



Figure 5. CsCl after simple melting to 650°C and cooling in a beaker. It becomes a hard mass like rock salt.

MetroDetection and Rapid Response System

The third strategy, developing a rapid MetroDetection and Response system, is more complicated, but more essential to weathering a serious dirty bomb attack involving either ^{60}Co or ^{137}Cs . Present-day gamma detectors are very reliable (few false positives, unlike alpha detectors), networkable and relatively inexpensive. Just as large office buildings are replacing ordinary glass with anti-terrorist glass on their ground floors at significant cost, these same buildings can easily install a gamma detector on their exterior, preferably near the primary air intake, at a much lower cost. The devices can shut down the air intake system if gamma were detected above a preset detection level. If most

large buildings in the top 100 target areas in the United States emplaced one such device, suitably networked to the nearest emergency response command post, then several important advantages ensue (Figure 5). First, there would be a constant surveillance system that would detect a dirty bomb attack minutes after the detonation or dispersal and identify it as such to a command post. First responders would know they were dealing with a dirty bomb event. Also, the plume would be delineated in real time as detectors relayed information, producing a real-time plume map, not a model. The command post can then alert the National Guard 101st Civil Support and DOE RAP teams allowing them to respond in the shortest time possible.

Next, if networked properly, the system could shut down the air intakes of all buildings in the affected area (preset radius from each detector). This would result in preventing radioactive particulates from entering buildings where it will be infinitely more difficult and costly to control and subsequently clean up.



Figure 5. A MetroDetection system quickly detects and responds to a ^{137}Cs or ^{60}Co RDD. Within minutes of dispersal, a networked system of inexpensive gamma detectors (inset right) can simultaneously shut down air-intakes in surrounding buildings (lower left), alert the 101st Airborne and DOE RAP teams, and trigger an old-fashioned type of air raid siren to signal civilians to immediately enter the nearest building. (Courtesy of Middle East Intelligence Bulletin; Ian McNiel NMSU PSL; and Canberra, Inc.)

Finally, a siren would be sounded that alerts people that they should immediately seek shelter inside the nearest building or other suitable shelter, similar to the old civil defense sirens. It is critical that people do not remain outside as the plume increases and moves outward. However, this is only viable if there is a detection system in place that can respond within minutes.

Once the attack has happened, there are limited options for response. Many researchers are investigating spray-on fixatives to prevent secondary migration beyond the affected area and to make subsequent clean up easier. These may be ideal for the most heavily affected areas such as the immediate blast area, and for specific source materials such as α -emitters. However, there are many technical aspects that are being investigated for which there is no practical experience as no RDD attack has yet occurred, and a few accidental releases, such as Goiania, serve as the only guides [9].

One of the properties that make a ^{137}Cs dirty bomb a worst case RDD, may create the best option for rapid clean up. $^{137}\text{CsCl}$ is so soluble (Table 1) that it can be washed off of surfaces very easily with water. Although the scale of an RDD attack is daunting (a ten by ten block area in downtown Manhattan has approximately one billion square feet of surface area), a hundred fire hydrants operating for 24 hours delivers about one hundred million gallons of water, sufficient to wash off such a large area and wash most of the Cs into the stormwater drainage system. If necessary, the outflow from the storm water runoff can be treated at the outflow points using inexpensive materials such as gabions of zeolitic gravel (\$80/ton), that are extremely specific for Cs and Sr.

Figure 6. Concrete, limestone and granite used in Cs removal and diffusion experiments.



Table 2. Cs removal efficiencies from building and paving materials: Test 1 - concrete.

CsCl Application Pressure	CsCl Removal Efficiency with Water (fire hose @ 100 yd for 10 sec)
< 1 lb/ft ² (aerosol)	100%
200 lb/ft ² (foot traffic)	100%
1,000 lb/ft ² (vehicular traffic)	100%
10,000 lb/ft ² (bomb pressure)	--- (crumbling occurred)

It is imperative that this occurs quickly, within about a week, to preclude further effects such as diffusion into building materials, secondary migration, and cumulative dose effects. If the contamination is not removed quickly, then the economic disruption, so desired from this type of weapon, will occur, and more such attacks could be expected from a cost/benefit perspective alone. In fact, the efficiency with which the United States responds to the first such attack should determine the number of subsequent attacks. Figure 1 and Table 2 show some initial results for Cs wash down from building materials using water in a fire hydrant scenario, in this case concrete. The situation becomes more complicated when various conditions are added, such as the effects of soot on Cs chemistry.

One of the pressures to clean-up the radionuclide-deposited surfaces quickly is that over time the radionuclide diffuses into the building materials and becomes more difficult to remove, which is particularly problematic if the radionuclide is a gamma emitter, and diffusing an inch or so into the material does not significantly lower the dose. Diffusion rates are primarily a function of moisture content [10,11]. Table 3 gives the diffusion coefficient for Cs in building concrete and granite as a function of weather conditions. A rule of thumb for diffusion is that the distance, x , that a molecule or ion will diffuse in time, t , is related to the diffusion coefficient, D , by the following: $x = (Dt)^{1/2}$ [12]. Therefore, if the weather remains dry and sunny, little diffusion will occur, but if the surfaces become wet, or the surface is wet during deposition, then significant diffusion can occur quickly depending upon the material. If the surface is wet, then Cs could diffuse into concrete more than a quarter of an inch each week it is on the surface, while it would not diffuse that much into the granite even after several years, no matter what the conditions. Therefore, with a relatively modest amount of research into building materials with respect to RDDs, a rapid response to an RDD attack could be developed within a few years that would greatly reduce the aftermath of a large ^{137}Cs dirty bomb.

Table 3. Cs Cs Diffusion into Building and Paving Materials: Granite and Concrete.

Material	Dry (<50% RH)	Damp (100% RH)	Heavy fog (surface film)	Drizzle Rain (surface wet)
Granite	$10^{-15} \text{ cm}^2/\text{s}$	$10^{-13} \text{ cm}^2/\text{s}$	$10^{-11} \text{ cm}^2/\text{s}$	$10^{-10} \text{ cm}^2/\text{s}$
Concrete	$10^{-15} \text{ cm}^2/\text{s}$	$10^{-10} \text{ cm}^2/\text{s}$	$10^{-8} \text{ cm}^2/\text{s}$	$10^{-6} \text{ cm}^2/\text{s}$

$$x = (Dt)^{1/2}$$

CONCLUSION

The United States presently has the means to effectively deal with a dirty bomb attack, the most serious threat of which comes from $^{137}\text{CsCl}$ powder used in the irradiation industry. It is possible to make this material more RDD resistant by simply melting the sources at 650°C at the fabrication facilities to form a solid mass that is less dispersible and more difficult to handle, smuggle and reconfigure into an RDD. This process is inexpensive and easy and will not unduly burden the industry. At the same time, many programs are beginning to train the 200,000 first responders in the target areas across the country to the important aspects of dirty bombs, a necessary effort to reduce the effects during the aftermath and to keep panic to a minimum. Using present technology, a rapid MetroDetection and Response system can be emplaced at all target areas in the United States that can:

- detect a dirty bomb attack minutes after the detonation or dispersal and identify it to a command post
- alert first responders to the occurrence of a dirty bomb event

- delineate the radioactive plume in real time, producing a real-time plume map, not a model
- alert the National Guard 101st Civil Support and DOE RAP teams
- shut down the air intakes of all buildings in the affected area, preventing radioactive particulates from entering buildings
- sound a siren that alerts people that they should immediately seek shelter inside the nearest building or other suitable shelter, similar to the old civil defense system.

Once the attack has happened, ¹³⁷CsCl is so soluble that it can be washed off of surfaces very easily with water. Although a ten by ten block area in downtown Manhattan has approximately one billion square feet of surface area, a hundred fire hydrants operating for 24 hours delivers about one hundred million gallons of water, sufficient to wash off such a large area and wash most of the Cs into the stormwater drainage system where it can be treated at the outflow points using cheap materials such as gabions of zeolitic gravel (\$80/ton), that are extremely specific for Cs and Sr. It is essential that the United States responds quickly and efficiently should an RDD attack occur in order to minimize the long-term effects and deter future RDD attacks by showing a high-cost/low-benefit to terrorist groups for such weapons.

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