CS-137 DISPERSION BY A RADIOLOGICAL DISPERSION DEVICE IN A TERRORIST INCIDENT

J. L. Regens
Institute for Science and Public Policy, University of Oklahoma
100 East Boyd SEC 510, Norman, OK 73019-1006 USA

ABSTRACT

This analysis uses a semi-empirical model to estimate the spatial extent (km2) and radioactivity (Ci) of contamination within an urban area following the initial dispersion of Cs-137 after a RDD explosion in a terrorist incident. The results indicate explosion of a RDD containing a relatively small amount of Cs-137 has the potential to contaminant a relatively large area with the extent of contamination (area and activity) being dependent on Cs-137 particle size, the height of release, and local weather conditions.

INTRODUCTION

Significant amounts of non-fissile radioactive materials are stored in medical centers to diagnose and treat illnesses, research laboratories, processing plants to irradiate food to eliminate microbes, radiothermal generators, and oil well surveying instruments. Although those facilities lack the types or volumes of materials suitable for producing nuclear weapons, they contain large amounts of radioactive material such as cesium-137, cobalt-60, strontium-90, and iridium-192. The possibility of terrorists using conventional explosives coupled with those non-fissile radioactive materials to create a radiological dispersion device (RDD) commonly called a 'dirty bomb' has transformed concerns about illicit trafficking in radioactive materials from a relatively obscure topic into a major international security concern (1-6).

A radiological attack would not produce the mass casualties due to the blast and significant radiation exposure associated with a nuclear event, but it nonetheless could result in radiation concentrations exceeding International Commission on Radiological Protection (ICRP, www.icrp.net) guidelines for limiting exposures to gamma radiation. Such an incident could create a variety of impacts ranging from extensive contamination requiring remediation, panic and economic disruption, to long-term exposure of civilian populations to low levels of radiation exceeding natural background levels (7). The actual impact of terrorists releasing non-weapons grade materials is contingent upon a variety of factors including the specific isotope used, the amount of material released, the aerosol properties of the particles released, local-scale meteorological conditions within a distance $\leq$ 10km from the initial release point (i.e., wind speed, wind direction, other key meteorological parameters), local-scale typography (i.e., location and size of buildings), and the type of device used to release the material (i.e., conventional explosive).

Two scenarios (12g and 35g) are evaluated for initial aerosol dispersion with effective release heights of 50m and 100m under varying local-scale atmospheric conditions. Contamination densities of $\geq$5, $\geq$30, $\geq$50 Ci/km^2 are used to assess probable consequences.

METHODS

Semi-empirical modeling is used to estimate the spatial extent and radioactivity of Cs-137 contamination, a beta and gamma emitter with a half-life of 30 years, within an urban area after a RDD explosion in a terrorist incident. Two scenarios are assumed for modeling purposes. In the first scenario, approximately 12 grams of Cs-137 equaling 1,000 Ci (3700 x 10^{10} Bq) is released using a conventional explosive such as TNT. In the second scenario, terrorists detonate a RDD containing approximately 35 g of Cs-137 equaling 3,000 Ci (11,100 x 10^{10} Bq). These amounts of cesium were chosen for modeling because they are comparable to the amounts typically available in commercial sources. Although the total radiological source will exceed this mass due to additional components such as Cs-133 typically in commercial products, the additional mass does not change the underlying computations and conclusions.

A simplified conceptual model of an 'urban canyon' is used to simulate dispersion for different wind velocities, meteorological conditions, and heights of release. Because Pasquill's stability classification scheme defines six discrete classes based on wind speed at 10 m for incoming solar radiation during the day or cloud cover at night, routine meteorological data can be used (8). The VOGT model for puff size takes into account the influence of roughness length on plume growth (9). Urban complexes are considered in terms of uniform roughness. Initial dispersion and deposition of aerosols are affected by release height. For this analysis, aerosol dispersion and deposition are estimated for effective release heights of 50m and 100m above street level.

The diffusion and deposition of the Cs-137 puff can be illustrated by considering the influence of effective release height on the dissemination of contamination. The radioactive plume grows in size with distance due to the convective diffusion and reaches ground level after a defined time interval elapses. As the cloud spreads, the maximum concentration of radioactive substances reduces due to dispersion and deposition in the downwind direction. The deposition velocity of Cs-137 largely depends on the particle size. The deposition velocity is proportional to r^2 for gravitational sedimentation and rapidly increases with increasing particle size. Accounting for horizontal and vertical transport makes it possible to derive an upper bound estimate of the distance moving away from the location of initial release of the Cs-137 to the location at which the contamination density will be smaller than some threshold value. There are some conditions under which the radioactive puff does not create contamination exceeding the threshold level. For example, if the radioactive puff increases in size very quickly, the Cs-137 deposition rate can become low enough to preclude significant deposition. This makes it possible to estimate the maximum contamination density and ground-level concentration released by a dirty bomb.

RESULTS

The process of puff depletion and the resulting spatial distribution of Cs-137 can be modeled by calculating radioactive fallout for the time interval Δt and subsequent subtraction of the activity from the source. Simulation modeling provides estimates of the radioactive contamination associated with the detonation of a Cs-137 'dirty bomb' by terrorists have been performed with the example of instant release of radioactive materials with a total activity of 1,000 Ci and 3,000 Ci at heights of h=50m and 100m. A detailed description of the computer code developed for this analysis is presented in (10).

Table I presents estimates of the extent of the contaminated area measured in km^2 and contamination density expressed as total activity (Ci) for contamination levels higher than 5, 30, and 50 Ci/km^2 for different states of the atmosphere, surface wind speed, and deposition velocities. For example, with a 1 kCi release at 50 m and atmosphere stability class F, the spatial extent of the area contaminated greater or equal to 5 Ci/km^2 is given in the first row of the last column. The total activity of this area is indicated in the fourth row of the last column. The results of the numerical calculations show that the spatial extent of the area with a high level of contamination strongly depends on the deposition velocity (i.e., the particle size) and local meteorological conditions including atmospheric stability and wind velocity. If the deposition velocity is low, the plume increases in size over a time interval during which substantial Cs-137 deposition does not occur. In this case, Cs-137 is scattered on large territories with a relatively small contamination density. On the other hand, if atmospheric conditions are stable and deposition velocities are ~ 1 cm/sec, the contaminated area can reach several km^2.

Table II presents the results of an analysis of with and without a rainfall event subsequent to the initial release of Cs-137. For example, with a 1 kCi release at 50 m, the spatial extent of the area contaminated greater or equal to 5 Ci/km^2 is presented in the first row and total radioactivity is in the fourth row of the 50 m release column. The analysis indicates, if the initial formation of the puff occurs when there is no precipitation and rainfall occurs after some time elapses, the shift in atmospheric conditions can result from extensive contamination of a relatively large area. As noted above, precipitation can result in the removal of radioactive material from a plume. Two separate processes, washout and rainout, may be considered. Washout removes material by raindrops falling through a plume (i.e. below cloud removal) while rainout removes material incorporated into raindrops within the cloud. Because precipitation affects the entire plume, the deposition rate is dependent on the total amount of activity contained in the plume instead of the ground-level air concentration. Deposition rates are calculated using the washout coefficient, defined as the fraction of the dispersing material removed in unit time. For this analysis, to calculate washout intensity, it is assumed that in the control volume the part of the mass is deposited for the time interval dt:

$$dQ_w = Q_w V_w P \, dt \; [1] \qquad \text{(Eq. 1)}$$

where Q_w is the mass in the control volume with the height equal a height of the cloud; dQ_w is a mass deposited due to the washout; V_w is the washout constant [hr/s/mm]; P is the rainfall rate [mm/hr]. When describing a dispersing puff, the time history of the precipitation for only that part of the puff passing through the precipitation is depleted.

Table II reveals that washout of Cs-137 results in more extensive contamination within a city, with both the size of the contaminated area and the contamination density being dependent on the time interval for a dry atmosphere, the rainfall rate, and rainfall duration. Moreover, if significant runoff occurs due to a large rainfall volume, widespread re-distribution of the radioactive particles can occur subsequent to their initial deposition from the atmosphere.

Table I Dependence of calculated values of area contaminated and radioactivity on the height of Cs-137 release and atmospheric stability (U=3 m/s, U_g=0.01 m/s)

Q=1 kCi

		Contamination density, Ci/km^2	Stability classes B	Stability classes D	Stability classes F
H=50m	**Area, km^2**	**≥5**	1.51E+00	2.36E+00	1.70E+01
		≥30	2.48E-01	2.48E-01	4.50E-02
		≥50	6.75E-02	1.35E-01	0.00E+00
	Activity, Ci	**≥5**	2.75E+01	4.53E+01	1.75E+02
		≥30	1.41E+01	2.14E+01	1.37E+00
		≥50	7.50E+00	1.75E+01	0.00E+00
H=100m	**Area, km^2**	**≥5**	1.35E+00	4.57E+00	8.53E+00
		≥30	9.00E-02	2.03E-01	0.00E+00
		≥50	6.76E-02	4.50E-02	0.00E+00
	Activity, Ci	**≥5**	1.89E+01	5.37E+01	5.30E+01
		≥30	5.05E+00	8.49E+00	0.00E+00
		≥50	4.21E+00	2.28E+00	0.00E+00

Q=3 kCi

		Contamination density, Ci/km^2	Stability classes B	Stability classes D	Stability classes F
H=50m	**Area, km^2**	**≥5**	4.88E+00	6.95E+00	4.49E+01
		≥30	7.65E-01	1.08E+00	6.19E+00
		≥50	4.28E-01	6.98E-01	2.12E+00
	Activity, Ci	**≥5**	1.11E+02	1.74E+02	7.82E+02
		≥30	6.66E+01	1.10E+02	3.00E+02
		≥50	5.43E+01	9.58E+01	1.42E+02
H=100m	**Area, km^2**	**≥5**	4.12E+00	1.63E+01	4.00E+01
		≥30	5.85E-01	1.85E+00	0.00E+00
		≥50	3.83E-01	8.55E-01	0.00E+00
	Activity, Ci	**≥5**	7.90E+01	2.55E+02	4.56E+02
		≥30	4.13E+01	1.06E+02	0.00E+00
		≥50	3.38E+01	6.94E+01	0.00E+00

Table II Effect of Rainfall on Area Contaminated and Radioactivity

U=2 m/s, U_g=0.01 m/s without rainfall

Activity		Contamination density, Ci/km^2	Height of release, m	
			50	100
Q= 1 kCi	Area, km^2	≥5	3.29E+00	7.00E+00
		≥30	5.63E-01	6.75E-01
		≥50	1.80E-01	1.58E-01
	Activity, Ci	≥5	7.42E+01	9.37E+01
		≥30	4.53E+01	2.95E+01
		≥50	3.03E+01	1.06E+01
Q= 3 kCi	Area, km^2	≥5	1.05E+01	2.44E+01
		≥30	1.60E+00	2.97E+02
		≥50	1.01E+00	1.31E+00
	Activity, Ci	≥5	2.82E+02	4.23E+02
		≥30	1.86E+02	1.98E+02
		≥50	1.65E+02	1.32E+02

U=2 m/s, U_g=0,01 m/s with rainfall[1]

Activity		Contamination density, Ci/km^2	Height of release, m	
			50	100
Q= 1 kCi	Area, km^2	≥5	1.22E+01	1.45E+01
		≥30	3.83E+00	4.75E+00
		≥50	2.23E+00	3.29E+00
	Activity, Ci	≥5	4.79E+02	7.34E+02
		≥30	3.66E+02	5.98E+02
		≥50	3.05E+02	5.40E+02
Q= 3 kCi	Area, km^2	≥5	1.68E+01	2.05E+01
		≥30	8.98E+00	1.05E+01
		≥50	6.19E+00	7.74E+00
	Activity, Ci	≥5	1.48E+03	2.26E+03
		≥30	1.37E+03	2.11E+03
		≥50	1.26E+03	2.00E+03

[1] Rainfall starts 10 min after release and lasts 1 hour; rainfall rate is 20 mm/hour.

CONCLUSIONS

The results indicate a relatively small amount of Cs-137 has the potential to contaminant a relatively large area with the extent of contamination dependent on Cs-137 particle size, the height of release, and local weather conditions. As a result, the magnitude of the consequences of terrorists acquiring non-weapons grade nuclear materials and releasing those materials with a 'dirty bomb' is contingent on a number of factors beyond the scope of active countermeasures, especially the RDD's design elements and local-scale meteorological conditions. Modeling the dispersion of radioactive aerosols throughout an urban landscape, especially with accurate 3-D representation of its complex geometry and meteorology, is indispensable for assessing the potential consequences of a terrorist incident and implementing effective emergency response, health services, and decontamination decisions.

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