Survey of Costs Arising From Potential Radionuclide Scattering Events

Robert E. Luna, PhD, PE, Consultant
Albuquerque, NM 87111

H. Richard Yoshimura and Mark S. Soo Hoo
Sandia National Laboratories*
Albuquerque, NM 87185

ABSTRACT

The potential effects from scattering radioactive materials in public places include health, social, and economic consequences. These are substantial consequences relative to potential terror activities that include use of radioactive material dispersal devices (RDDs). Such an event with radionuclides released and deposited on surfaces outside and inside people's residences and places of work, commerce, and recreation will require decisions on how to recover from the event. One aspect of those decisions will be the cost to clean up the residual radioactive contamination to make the area functional again versus abandonment and/or razing and rebuilding.

Development of cleanup processes have been the subject of experiment from the beginning of the nuclear age, but formalized cost breakdowns are relatively rare and mostly applicable to long term releases in non-public sites. Pre-event cleanup cost estimation of cost for cleanup of radioactive materials released to the public environment is an issue that has seen sporadic activity over the last 20 to 30 years. This paper will briefly review several of the more important efforts to estimate the costs of remediation or razing and reconstruction of radioactively contaminated areas. The cost estimates for such recoveries will be compared in terms of 2005 dollars for the sake of consistency. Dependence of cost estimates on population density and needed degree of decontamination will be shown to be quite strong in the overall presentation of the data.

LITERATURE OVERVIEW

Techniques used for cases of released radioactive materials in the event of an accident during transport have been a principal source of cost estimating techniques. These are contained in the RADTRAN transport risk assessment codes that were first produced in 1974 for use in preparing NUREG-0170 (NRC, 1977). That version, RADTRAN I, had several revisions in succeeding issues of the code to the present version contained in RADTRAN VI. Two non-RADTRAN

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methodologies are also notable. First, is an analysis completed to estimate the cost of cleaning up plutonium scattered as a result of a nuclear weapons accident that was completed in 1996 (Chanin, 1996). Second is a computer code developed in the UK (and apparently only usable for UK government purposes) called CONDO (Charnock, 2003). In addition, some cleanup cost estimates have been put forward in a paper (Reichmuth, 2005) for the Department of Homeland Security that gives cleanup cost estimates for high population density areas based on RADTRAN IV calculations and actual costs for remediation of the World Trade Center (WTC) site in New York City.

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The methodology for estimating cleanup costs uses two principal parameters. The first and most basic is the acceptable residual level of contamination determined for each nuclide released that will avoid a given level of radiological dose to persons who will remain living/working in the contaminated area. The acceptable dose and, hence, the residual contamination level for each nuclide, is likely to be negotiated for each release event (DHS, 2007). The second parameter is the Decontamination Factor, DF, which can be rationalized in two ways:

- At any point at the site of the radioactive material release, it is the ratio of the local contamination level for a released nuclide to the acceptable residual contamination level, (DF_s)
- A measure of the capability of a given cleanup method (like water hosing) to reduce the contamination level for a given surface material. Thus, it is the ratio of contamination level before treatment to contamination level after treatment, (DF_m)

Specific cleanup technologies applied to specific surfaces and nuclides are characterized by the maximum DF_m achievable. If the DF_s is less than the effects of all the cleanup processes that could be applied sequentially, $DF_s < \Sigma\ DF_m$, then cleanup is successful, but if the DF_s is greater than the effects of all the cleanup processes that are applied sequentially, $DF_s > \Sigma\ DF_m$, then other alternatives, like razing and rebuilding, or interdiction must be applied.

The methodologies used in the all of the cited literature recognized the limitations of cleanup and employ razing or interdiction in the event that the required DF_s for a given situation could not be achieved by standard cleanup processes. For most of the early cost estimation techniques, it was assumed that a DF_m of 50 was generally attainable, but more recent data, nicely summarized in the CONDO report, suggest that a DF_m greater than 10 or so (with some isolated exceptions) is unlikely to be attained. This suggests that the earlier cost estimates would be expected to be somewhat low, since cleanup costs are generally lower than raze and rebuild or interdiction methods.

For the data presented below the original cleanup cost estimates presented in the source documents were extracted and converted to 2005 costs using standard cost deflators (Williamson, 2006). In general, costs were stratified by the initial level of contamination as represented by DF_s values. Light contamination corresponded to a DF_s <5: medium, 5< DF_s <10; and heavy, DF_s >10. Costs in the RADTRAN reports were further stratified by a specification relating to population density (rural, suburban, and urban) corresponding to mean population densities of about 10, 750, and 3800 persons per km^2 respectively. In the Chanin report, the urban population density values were taken to be about 1350 persons/ km^2 (corresponding to a mean population density in areas identified as urbanized by the census bureau). Reichmuth stated that population densities (PD in persons/km^2) were as follows:

Rural	0 < PD < 50
Urban	50 < PD < 3000
High Density Urban	3000 < PD < 10,000
Hyper Density Urban	10,000 < PD

As is obvious from the above, there is no strict translation of words describing population density terminology in quantitative terms, but there is enough specificity to compare various costs estimates as a function of population density.

The SNL study (Chanin, 1996) provided a fairly detailed methodology in which to estimate costs. For an urban area, the overall results that came out of the effort is shown in Table I.

Table I. Urban Area (1344 persons/km^2) Remediation Costs for Year 2005 in $M/$km^2$ from Appendix G (Chanin, 1996).

	Costs per sq. km				**Area Weighted Costs**		
Area Usage Type	**Light (2<DF_s<5)**	**Moderate (5< DF_s<10)**	**Heavy (DF_s >10)**	**Area Fraction**	**Light (2<DF_s<5)**	**Moderate (5<DF_s<10)**	**Heavy (DF_s >10)**
Residential[a]	$72.4	$163.9	$301.2	0.316	$22.9	$51.8	$95.2
Commercial	$195.3	$295.5	$851.2	0.173	$33.8	$51.1	$147.3
Industrial	$674.0	$704.2	$1,245.9	0.064	$43.1	$45.1	$79.7
Streets	$15.9	$18.5	$247.7	0.175	$2.8	$3.2	$43.3
Vacant Land	$81.1	$85.7	$95.2	0.272	$22.1	$23.3	$25.9
				Overall Cost per sq. km	$124.6	$174.5	$391.4

[a] includes single and multiple family dwellings and apartment houses

Table I demonstrates the methodology used as well as results. Costs were estimated for generic land use areas and then weighted by the fraction of the overall area in that land use class. Short of repeating the considerable effort in developing the report results, what options exist for estimating the cleanup cost for higher population density areas? If data is available for the land use area fractions in the higher population area, then an estimate can be made by plugging in those values in the 5^{th} column of Table I. In addition, an adjustment for population density can be made by noting that higher population density implies that there are more dwelling units per km^2 and that the costs shown in Table I are based on individual dwellings. As a result, multiplying the residential costs by a ratio of population density should adjust for higher populations in the same area. In addition, since commercial space is likely to expand with population density, the commercial values would also be adjusted in a similar manner. These are approximate methods and useful only for order of magnitude estimates. The result of such adjustments is shown in Table II.

Table II. Estimated Remediation Costs for New York City Reflecting Land Use Distribution and Population Density.

		Area Weighted				**Population and Area Weighted**		
Land Use	**Area Fraction**[a]	**Light** $(2<DF_s<5)$	**Moderate** $(5<DF_s<10)$	**Heavy** $(DF_s>10)$	**PD Multiple**	**Light** $(2<DF_s<5)$	**Moderate** $(5<DF_s<10)$	**Heavy** $(DF_s>10)$
Residential	0.287	\$20.31	\$45.99	\$84.51	6.82[b]	\$138.55	\$313.64	\$576.38
Commercial	0.164	\$32.09	\$48.55	\$139.84	6.82[b]	\$218.84	\$331.12	\$953.80
Industrial	0.068	\$45.51	\$47.55	\$84.12	1.00	\$45.51	\$47.55	\$84.12
Streets	0.250	\$3.97	\$4.62	\$61.88	1.00	\$3.97	\$4.62	\$61.88
Vacant Land	0.238	\$19.29	\$20.38	\$22.64	1.00	\$19.29	\$20.38	\$22.64
	1.00							
Overall Cost (\$M/km^2		\$121.2	\$167.1	\$393.0		\$426	\$717	\$1,699

[a] derived from New York City data (http://www.nyc.gov/html/dcp/pdf/landusefacts/landuse_tables.pdf)
[b] ratio of New York City population density to that in Table I (9166/1344 = 6.82)

The process used to produce Table II can be used to derive remediation cost estimates for other population density areas as shown by the triangle points in Figure 1. Figure 1 also contains remediation cost data from the source documents discussed above.

The Legend in Figure 1 is quite large, but is color keyed for some addition clarity. Red lines and symbols are for $(DF_s > 10)$, orange for $(5 < DF_s < 10)$, and green for $(1 < DF_s < 5)$. Purple symbols are for estimates that are unspecific about the DF_s they apply to, but the values could be as large as 50.

Figure 1 shows a fair amount of variability in the costs estimated by the various methods and sources covered in this overview. The three straight lines penciled in on the plot are intended to suggest how the costs might vary with population density and degree of contamination. The lines are a reasonable representation of much of the information, but some data points deviate substantially and will be discussed here. The two red disc points that are well above the curves are from the paper by Reichmuth and are based on estimates of cost derived to clean up and restore (not rebuild) the 16 acre WTC site in New York City after 9/11. The cost to replace the facilities is estimated to be an order of magnitude larger (not shown on the plot).

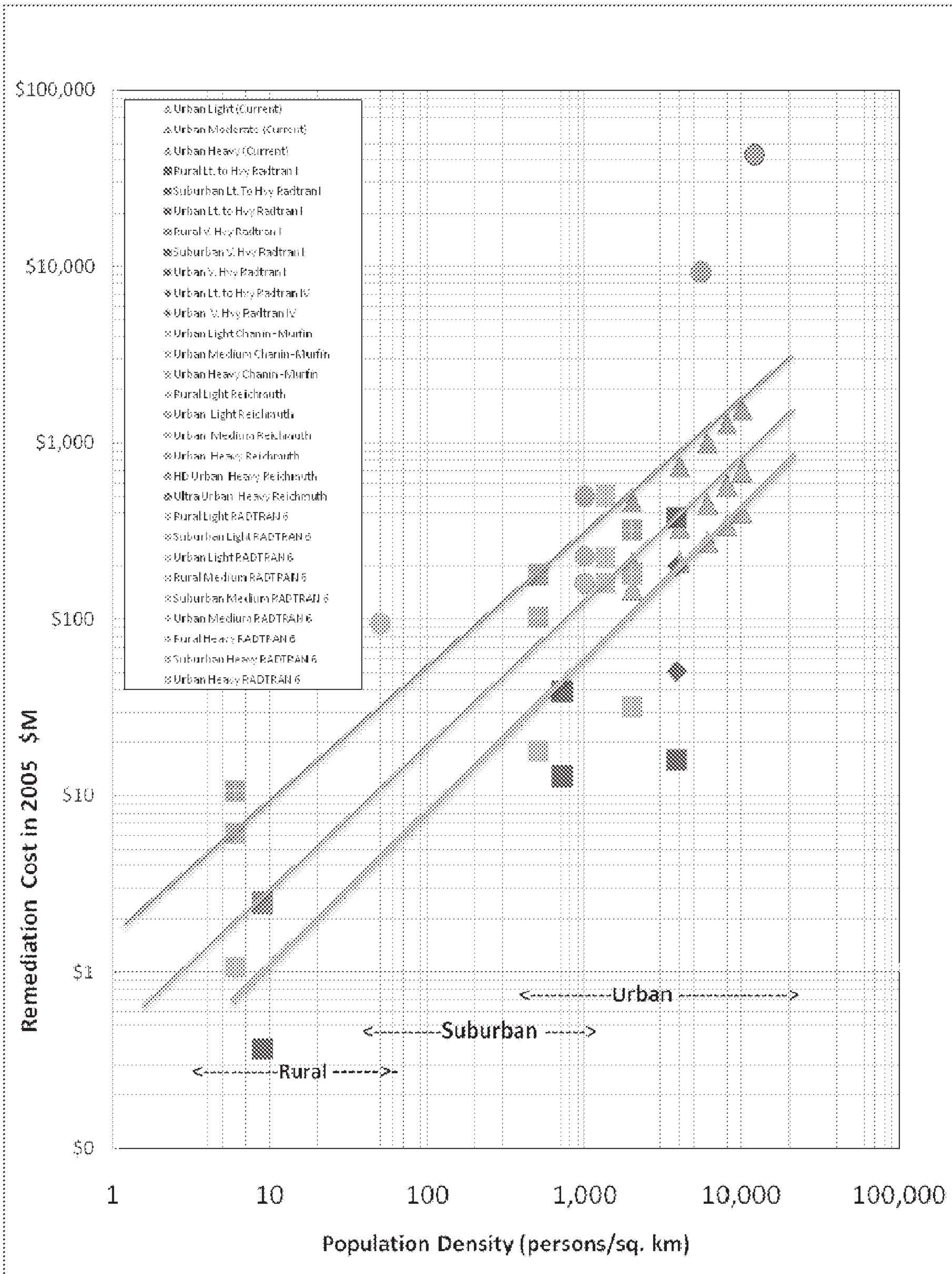

Figure 1: Remediation Cost Estimates Compared.

Since the estimated cost was based on the area of the WTC site, but the actual expenditure covered actions made over the surrounding areas and included actions somewhat beyond what would be expected in response to an RDD event, the actual cost/km^2 could be overestimated by 50% to 60%.

The purple squares below the curve represent the estimates that were done using RADTRAN I in the mid 1970's with an unsophisticated methodology. Moreover, the estimates are the oldest and most subject to uncertainty associated with selecting the best deflator statistic for updating costs. The RADTRAN 6 estimates (purple diamonds) also are below the trend lines but not as pronounced an effect as with RADTRAN 6 (Osborn, 2007). Note that the RADTRAN 6 values (squares with center crosses) fit much more closely with the other estimates and the trend lines. The trend lines favor the cost values generated by the Sandia study (Chanin, 1996), because of the detail involved in the initial estimates and the ability to project the costs to other population densities and land use area fractions.

CONCLUSION

The likelihood of a "Dirty Bomb" attack in the US or elsewhere is unknown. Most sources suggest (e. g., Karam, 2005) that the radiological consequences of such an attack are unlikely to be life threatening and that the greatest mortal danger is to persons exposed to blast from the device (assuming that is its mode of operation). However, the expenditures needed to recover from a successful attack using an RDD type device, as depicted in Figure 1, are likely to be significant from the standpoint of resources available to local or state governments. Even a device that contaminates an area of a few hundred acres (a square kilometer) to a level that requires modest remediation is likely to produce costs ranging from $10M to $300M or more depending on intensity of commercialization, population density, and details of land use in the area. As a result, it is important to put appropriate emphasis on the efforts now being taken by the Department of Energy, Nuclear Regulatory Commission, and the Department of Homeland Security to provide accountancy for radioactive materials used in the public and private sectors and to detect, as fully as possible, traffic in potential dirty bomb materials within and on the borders of the USA.

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