Large Scale, Urban Decontamination; Developments, Historical Examples and Lessons Learned

R.L. Demmer
Idaho National Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-7113
USA

ABSTRACT

Recent terrorist threats and actions have lead to a renewed interest in the technical field of large scale, urban environment decontamination. One of the driving forces for this interest is the prospect for the cleanup and removal of radioactive dispersal device (RDD or "dirty bomb") residues. In response, the United States Government has spent many millions of dollars investigating RDD contamination and novel decontamination methodologies. The efficiency of RDD cleanup response will be improved with these new developments and a better understanding of the "old reliable" methodologies.

While an RDD is primarily an economic and psychological weapon, the need to cleanup and return valuable or culturally significant resources to the public is nonetheless valid. Several private companies, universities and National Laboratories are currently developing novel RDD cleanup technologies. Because of its longstanding association with radioactive facilities, the U. S. Department of Energy National Laboratories are at the forefront in developing and testing new RDD decontamination methods. However, such cleanup technologies are likely to be fairly task specific; while many different contamination mechanisms, substrate and environmental conditions will make actual application more complicated. Some major efforts have also been made to model potential contamination, to evaluate both old and new decontamination techniques and to assess their readiness for use.

There are a number of significant lessons that can be gained from a look at previous large scale cleanup projects. Too often we are quick to apply a costly "package and dispose" method when sound technological cleaning approaches are available. Understanding historical perspectives, advanced planning and constant technology improvement are essential to successful decontamination.

INTRODUCTION

In additional to the infamous events of September 11, 2001, recent terrorist threats and actions have focused interest on decontamination plans and decontamination research in various areas. The most obvious of case is the anthrax contamination events of October 2001. These events lead to "field trials" of various chemical/biological decontaminants that was termed a "research project" and "Decontamination 101" in testimony before the House Science Committee.[1] The threat of terrorist radiological events grew with the discovery of mature plots in the United States (U.S.) and an actual radiological dispersal device (RDD) placed in Moscow, Russia; thankfully there has been no actual explosion of this kind of device. This intense interest in decontamination methods has lead to the development of new products. Some of these products have a sound basis in previous decontamination art and many are being tested in diverse conditions and facilities around the U.S.

The types of a terrorist radiological contamination event that might occur are as diverse as the research programs involved in mitigating the threat. A RDD is simply an apparatus designed to spread radioactive contamination by ejecting it (explosively, as a spray, or in a similar manner) into a target area. The term "dirty bomb", commonly used for an RDD, is a bit misleading as the dispersal could occur without employing an explosive but even by simple distribution such as a crop duster type or even a common handheld agricultural sprayer[2], which may produce a limited but potentially more difficult decontamination concern.

The RDD is not truly a weapon of "Mass Destruction" but one of "Mass Disruption" because the terrorist intention is to cause fear, panic and deny access to target areas. The denial of access to target areas, due to fear of radiological hazards, may have tremendous economic and social impact in the U.S. In one estimate, a radiological device detonated in Manhattan would cause few acute, direct casualties but would cause the loss of several billion dollars in revenue and perhaps more indirect casualties during evacuation and due to latent disease, trauma and stress.[3, 4] A building or monument of historical or social significance may also be a potential target, for instance a historical site in Washington D.C, instilling a national sense of cultural loss.

Because of the real and horrific nature of an RDD event, the importance of decontamination and recovery from this type of event cannot be overemphasized. There is a tremendous amount of information available about what decontamination technologies have proven to be effective and the areas where research should still move ahead in resolving difficulties. It is the responsibility of the experts in decontamination and cleanup, particularly those in the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), the U.S. Department of Defense (DoD) and the U.S. Nuclear Regulatory Agency (NRC), to team in demonstrating a truly unified national response. The need for action is summed up well in a recent book, *The Four Faces of Nuclear Terrorism*, "Therefore, even as strategies are implemented to improve controls over these materials slowly but steadily, preparing for the actual use of an RDD would be the most urgent priority. Preparatory measures can include education efforts to immunize the public psychologically against panic in the face of an RDD attack, which is unlikely to cause mass casualties; investment in the development of technologies for wide –area decontamination; training of first responders and governmental authorities' and advance stockpiling of emergency response equipment and therapeutics".[5]

RECOVERY PLANNING FROM A RDD EVENT

Recovery from an RDD event is a complicated, multi-staged process. The United States Department of Homeland Security (DHS) has issued *The National Response Plan* (NRP) (Nuclear Radiological Incident Annex) that gives concepts and guidance for the national RDD response.[6] The plan details who is responsible for everything from the characterization of an RDD that has become an Event of National Significance to the determination of the final cleanup levels. The actual federal agency that leads the recovery may change depending on what kind of radiological material was used (NRC, DOE or DoD owned) or where the event took place (at a licensed facility, public land). These team members, along with others, each have a characteristic role in an integrated RDD response. The NRP provides "big picture" guidance, but direction involving the cleanup of the radioactive material is a small portion of that response. The choice (and use) of particular decontamination technologies is a small factor in comparison to the magnitude of the overall response around this type of event. Many government agencies, particularly the EPA, DOE, DoD and the NRC, become quickly involved. If summed with stakeholder input, criminal investigation (by the Federal Bureau of Investigation (FBI)), and state and local interest, one can envision that integration will be vital.

A model for integrating these overlapping functional areas can be seen in the EPA Risk Assessment Framework. This framework evolved from the Superfund process of combining technical, quantitative solutions with qualitative needs and attributes.[7] This time-tested coordination framework seems a good fit for recovery efforts and is an example of ready tools available from recovery team members. It involves technically based standards with the involvement of political, social and stakeholder criteria to develop remediation decisions. It is shown graphically in Figure 1. An approach using this framework and possibly incorporating a modified Data Quality Objectives (DQO) process to identify technical issues (such as decontamination waste management) will allow stakeholder input in determining what contaminated items are treated and what treatments are included.

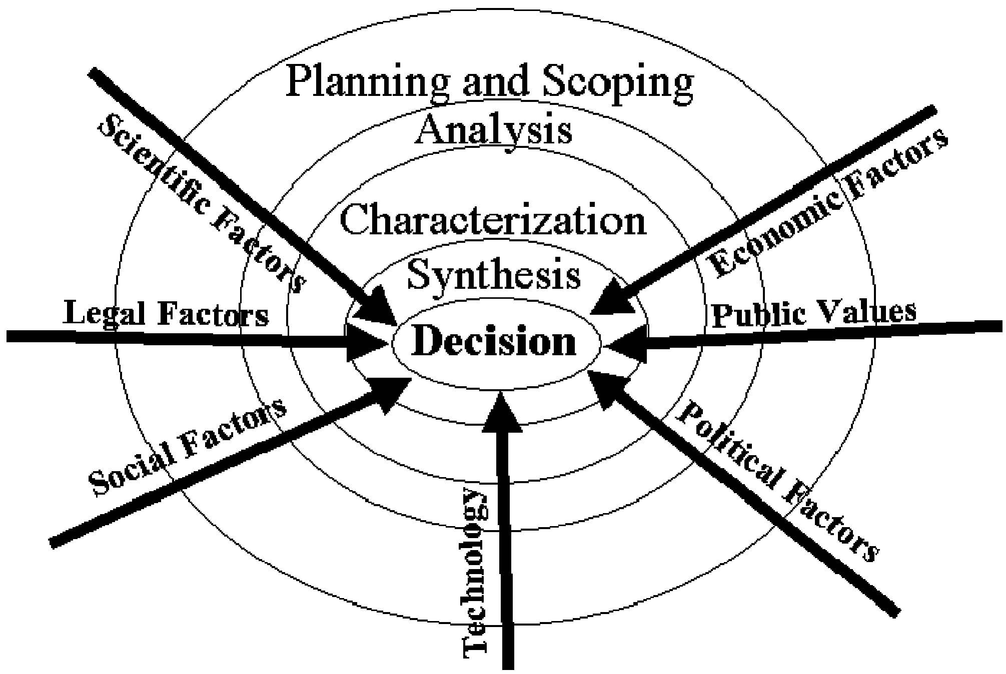

Figure 1. EPA risk management decision framework

The technical issues involved in decontamination of the RDD residues, while not trivial, are not as difficult to navigate as some of the other integration issues surrounding a RDD recovery. A very important prerequisite for decontamination is characterizing the physical and chemical nature of the contaminants. Characterization, along with understanding the environmental conditions and the operating parameters, will begin to develop the scope of the decontamination requirements. The Idaho National Laboratory (INL) has developed an extensive criteria basis for selecting decontamination technologies.[8] This basis can provide a framework for a scoping exercise, allows flexibility in decision making, and is fairly inclusive of technical and operational parameters. A few of these criteria are shown below:

- Type of contaminant (radionuclide, chemical nature and physical form)
- Type of substrate (which building material and configuration)
- Weather conditions
- Desired endpoint levels
- Ease of application
- Cost

Even these few technical issues draw a significant discussion. Often a decontamination system that works well with one type of contaminant on one substrate (for example, cesium on concrete) works poorly with other types of contaminants on other substrate. But these are usually issues that can be resolved via published data or simple tests. The database for available decontamination technologies and their technical data is extensive.

The INL has also prepared simple technology guidelines for different conventional types of decontamination methodologies. These are reviewed in another paper included in this session and were published in a handy reference.[9] These evaluations have performed to compare the decontamination of everything from highly contaminated processing equipment to large, lightly contaminated buildings and represent a diverse body of experience that can be used to screen different technologies.[10]

RDD DECONTAMINATION TECHNOLOGY DEVELOPMENT

A number of different technology development programs are being funded by U.S. agencies to provide effective, alternative decontamination methodologies. The DoD, by way of the Defense Threat Reduction Agency (DTRA), the Defense Advanced Research Projects Agency (DARPA) and the Technology Support Working Group (TSWG), has several development programs. The Department of Energy laboratories are participating in many RDD decontamination research programs and have amassed a huge amount of decontamination literature during decades of nuclear facility D&D. The EPA conducts RDD research programs, but is generally focused on evaluation of commercial techniques and modeling than on development of new technologies. It is virtually impossible to detail each development program, and some are considered classified and little is known about them. But a synopsis of most of the RDD decontamination development programs is listed below.

DARPA Funded development programs:
DARPA has been very active in the development of novel decontamination methods for RDDs. The main emphasis has been the decontamination of a tenacious type of contaminant that has been locally applied (as by a sprayer) to items of high cultural significance. The program has rigorous standards that require high levels of decontamination along with no real degradation of the contaminated surface. Several participants, including the INL, Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL) and the ISOTRON Corporation have made tremendous strides in removing contamination from building material coupons.[11] The testing is independently coordinated at the INL.

DTRA Funded development programs
DTRA has research programs focused on the fundamental RDD contamination problem as well as other interests. A program known as "Discrete Fury" seeks to model the type of contamination based on actual explosions of surrogate contaminants at the SNL.[12] DTRA is also collaborating with other countries to support security in the area of RDD recovery.

TSWG Funded Programs
The Technology Support Working Group (TSWG) performs a variety of services for the DoD including the operation of some general research and development programs. The mission of the TSWG is to conduct the U.S. National Interagency Research and Development (R&D) Program for Combating Terrorism. Two particular RDD decontamination development programs that feature in the TSWG arena are the Argonne

National Laboratory (ANL) cleanup gel and the ISOTRON Corporations new contamination fixative designed to stabilize RDD contamination.[13, 14]

Department of Energy Programs
Several of the DOE National Laboratories are conducting RDD decontamination research, either with another agency (as noted above) or by themselves. There is currently no DOE directed RDD development, but the labs are being used by DTRA, TSWG, DARPA and DHS as research centers for this work. Since the DOE Environmental Management (DOE-EM) division led the way in decontamination research throughout the 1990s, a tremendous amount of decontamination literature is available within the DOE Complex. Lawrence Livermore National Laboratory (LLNL) is also involved in RDD decontamination development with a program focusing on urban grime influence and cleanup in removal of radionuclides.

Environmental Protection Agency Programs
One area where the EPA has led the field is that of RDD modeling. Through their work with LANL and others the EPA has developed mathematical models that predict the plume direction and contamination spread from an RDD.

HISTORICAL LARGE SCALE RADIOLOGICAL DECONTAMINATION

In addition to the current development programs, a historical look at large scale decontamination efforts provides valuable insight. There have been several unfortunate incidents involving urban decontamination of radiological materials. Unfortunately, the recovery was seldom the subject of intense scientific data gathering and some of the obvious lessons were not published nor even widely shared. Such is the case for any decontamination efforts that might have occurred in Hiroshima and Nagasaki; no literature was discovered detailing decontamination efforts in those cities. Other large scale contamination events, like some those involving incidents at nuclear waste dumps, military sites or processing plants during the cold war were not extensively documented, probably due to secrecy issues. However, two of the more recent events, the Chernobyl reactor explosion and the Goiania breakage of a sealed source, give significant opportunity to study large scale, urban decontamination methods. In depth study would require volumes (and volumes have indeed been written), but a brief synopsis of these events will be given and the highlights of decontamination will be summarized for Chernobyl and Goiania.

On April 26, 1986 the Chernobyl Reactor #4 exploded and caught fire in the early morning at a location in Eastern Europe just north of Kiev, Ukraine. A tremendous amount of radioactive material (about 10E18 Bq) was distributed into the atmosphere both during the initial explosion and because of the fire over the next few days. The contamination was very wide spread and included areas ranging hundreds of miles to the east, north and west of the reactor site. Hundreds lost their lives containing the fire and during cleanup immediately following the disaster. Hundreds of thousands were evacuated from their homes and many were unable to reoccupy those areas. The scale of the disaster is unprecedented and there is no way to truly appreciate the misery of people affected by this event.

Decontamination efforts began soon after the event. One fairly obvious, but not always considered factor, is characterizing the amount and location of the contamination in terms of radiation dose for residents. Because of the airborne nature of the contaminant, and the changing atmospheric conditions the contamination encountered as it swept across Europe, this was not always consistent. The location of contamination radiation dose was generally found to be in this order: soil (high), trees (moderate), roofs (moderate), walls (lower) and roads (lower).[15]

Because of this information, efforts were focused on removing soil and vegetation contamination along with cleaning roofs. While these tests and the overall decontamination effort were examples of the usefulness of available technologies, the actual volume of waste that was successfully decontaminated is small. This is a clear situation of how a planning effort dealing with what will and will not be cleaned up after an RDD would aid in recovery.

Several different kinds of decontamination techniques were chosen to decrease the radiation dose from Chernobyl contamination. These included flushing (hosing) of contaminants from building and paving materials, digging up and removing heavily contaminated soil, plowing contaminated soil, chemically treating building materials and using absorbents to extract contaminants. One article found that flushing of roads was moderately successful for cleaning roads, 45%-50%, removal and that dry sweeping with a rotary brush was less effective (27%-30%).[16] Another article showed that soil removal, while varying with depth removed, was up to 90% effective at removing overall dose rate; while plowing (simply turning the soil over) was not as effective.[17] This technique of removing contaminated topsoil and placing it under lower levels of soil was termed, triple digging. Other articles point out that the use of acids and ammonium nitrate, were more effective than simply water flushing, removing up to 90% of the cesium contamination.[18, 19] These results were compared in different situations for dry deposition and for contamination during rainy conditions showing that environmental factors create a complex need for different decontamination methodologies.[20] The use of clay absorbents was also found to be somewhat effective, with removals up to 80%.[21] Many of these different techniques were compared and collected into a table as shown in Table III below.[22]

Table III, Comparison of Decontamination Effectiveness for Common Urban Techniques

Technique	**Effectiveness, % removed**	**Age of contamination**
Low Impact		
Grass Cutting	32 (wet deposition)	recent
Firehosing of buildings	0 - walls, 30 - roofs	recent
Firehosing of buildings	0 - walls, 25 - roofs	old
Firehosing of roads	0	old
Sweeping roads	20	recent
Ammonium nitrate treatment of buildings	15 - walls, 20 - roofs	recent and old
Medium Impact		
Sandblasting buildings	40	
Firehosing of roads	45 (wet deposition)	
Grass cutting	65 (dry deposition)	
Vacuum-sweeping roads	50	
High Impact		
Washing vacuuming indoor surfaces	80	
Soil removal to 10 cm	80	
Road planning	100	
Firehosing of roads	95 (dry deposition)	
Sandblasting buildings	100	
Roof replacement	100	
Plowing soil to 30 cm	altered activity profile	up to 1 year
	0 - 1 cm 0.5%	
	1 - 5 cm 2%	
	5 - 15 cm 25%	
	15 - 30 cm 72.5%	

The Goiania contamination was much smaller and more localized than the Chernobyl contamination requiring a limited response more closely approximating that of a RDD. In late September of 1987 an abandoned ^{137}Cs medical source (50.9 Tbq) was removed from its packaging and broken open. A total of 249 people were contaminated, four died and 28 suffered radiation burns, many requiring skin grafts.[23] An urban area of about 1 km2 was contaminated by the actions of the men who opened the source and by their families.[24] Subsequent surveys of the neighborhoods near the end of October 1987 found 45 homes and 45 points on public roads contaminated. Eight of the homes were demolished (not decontaminated) and removed as radioactive waste.[25]

Both the Brazilian Government and the International Atomic Energy Agency (IAEA) conducted a detailed investigation of the event. An IAEA report summarized the decontamination measures performed on those buildings not destroyed and removed.[26] Major decontamination work began in mid-November 1987. Residences furthest from the highest contamination areas were the first to be decontaminated. The belongings in the houses were placed outside on plastic, surveyed for contamination and cleaned if practical. Items with complicated or absorbent surfaces with no inherent value were disposed. Vacuum cleaners with high efficiency particulate filters were used to clean all interior surfaces. Painted surfaces were stripped and floors were cleaned with an acid/Prussian Blue mixture. Roofs were washed with pressurized water jets but with only about 20% reduction in dose. Trees were pruned and fruit was destroyed (along with many pets and livestock). New soil replaced contaminated topsoil.

CONCLUSION

While an RDD event is a disastrous prospect, it is none-the-less real and attention should be paid to technological needs and experience. The level of cooperation required in this situation will be exhausting for the agencies involved but there is much good that could be achieved from their synergism. Each agency (and subcontractor) has talents and resources to be applied and lines of communication should be opened across the different teams immediately. Development programs have been implemented to understand this kind of event and to provide solutions. Though some notable success has been achieved, development needs to continue until solutions are found to the more difficult, long-term decontamination problems. Certainly there are effective means of reducing contamination radiological dose beyond simply transferring everything to a waste dump, but bridging the gap from scientific study to application will be a challenge. There is a significant amount of decontamination experience and literature available. Balancing the development programs and the lessons from earlier events will provide better solutions that may even alleviate some of the terror inflicted by the RDD threat.

The lessons learned in the radioactive cleanups we reviewed are that recovery may be expensive, and time consuming, but can be accomplished. It is important to develop a plan and determine which materials are going to be decontaminated and which are not. Stakeholder input and focusing on rapid and long lasting dose reduction is vital to this planning. There is a huge database of information about available decontamination techniques and those under development. These need to be included in cleanup plans. A variety of different techniques must be considered because their effectiveness will vary based on the nature of the contaminant, the delivery mechanism, the substrate and how long it remains on the surface. Some of the more consistently effective techniques are vacuuming, firehosing, sandblasting, repainting and reproofing. These can be improved with the use of strippable coatings, chemical and clay applications.

REFERENCES

1. Hall, Ralph M., “Anthrax Decontamination is Ongoing “Research Project”; Hart Building is a “Laboratory”, House Committee on Science (Ranking Democrat), November 8, 2001.
2. Mackinney, John, “Radiological and Nuclear Terror: Technical Aspects and Implications for Decontamination and Site Cleanup”, Report on the Workshop on Decontamination, Cleanup and Associated Issues for Sites Contaminated With Chemical, Biological, or Radiological Materials, EPA/600/R-05/083, October 2005.
3. David Howe, “Planning Scenarios”, Homeland Security Council, July 2004.
4. Maloy, T. K., “Report Warns of “Dirty Bomb” Economic Hit”, United Press International, January 24, 2004.
5. Ferguson, Charles D., Potter William C., “The Four Faces of Nuclear Terrorism”, Routledge Co., June 2005.
6. Nuclear/Radiological Incident Annex, National Response Plan, Department of Homeland Security, December 2004.
7. “Reopening Public Facilities After a Biological Attack”, National Research Council of the National Academies, National Academies Press, 2005.
8. Tripp, J. L., et al, “Criteria and Evaluation of Three Decontamination Techniques”, WINCO-1187, January 1994.
9. Merservey, R., Tripp, J. L., Demmer, R. L., “Decontamination Technologies”, Radioactive and Hazardous Waste Treatment, CRC Press, 2001.
10. Demmer, R. L., “Chemical and Nonchemical Decontamination Technologies”, IAEA/ANL International Decommissioning Training Course, invited speaker, March 9-27, 1998
11. Weiss, Peter, “Ghost Town Busters”, Science News Online, October 29, 2005.
12. Smith, J. M., Ansari, A., Harper, F. T., “Hospital Management of Mass Radiological Casualties: Reassessing Exposures from contaminated Victims of an Exploded Radiological Dispersal Device”, Health Physics. 89(5):513-520, November 2005.
13. “Gel Cleans Radioactive Concrete”, Chemical Processing, September 2004.
14. Shelton, Jayne, “Polymer Technology for the Lock-Down/Removal of Radiological Contamination”, USSOCOM Chemical, Biological, Radiological Conference & Exhibition, *Responding to the Terrorist CBRN Threat: "Preparation or Panic”,* Tampa, FL, 6-8 December 2005.
15. Andersson, K.G., Modelling External Radiation Doses in Contaminated Urban Areas: Implications for Devlopment of Decontamination Strategies, Proceedings of the IRPA9 International Congress on Radiation Protection, Vienna, Austria, ISBN 3-9500255-4-5, 1996.
16. Hewitt, C.N., et al, “Behaviour and Decontamination of Artificial Radionuclides in the Urban Environment”, Radioecology after Chernobyl, John Wiley and Sons, Ltd., 1993.
17. Brown, J., et al, “The Effectiveness of Various Decontamination Techniques for Reducing External Radiation Doses to People Living in an Urban Environment”, National Radiological Protection Board, NRPB-R288, 1996.
18. Witt, H., “Decontamination Strategies in Urban Areas After Nuclear Accidents”, Seminar on Methods and Codes for Assessing the Offsite Consequesnces of Nuclear Accidents”, EUR-13013/2, CONF-9005113, May 1990.
19. Thornton, E. W., “Decontamination of Some Urban Surfaces”, CBGR-TPRD/B/1064/R88, April 1988.
20. Roed, J., Sandalis, J., “Decontamination in the Urban Area”,

21. Movchan, N., et al, “Natural Sorbents for Decontamination Objects of Urban Territories”, The Raiological Consequences of the Chernobyl Accident, Prceedings of the First International Conference, March, 1996.
22. Brown, J., Haywood, S. M., Roed, J., “Effectiveness and Cost of Decontamination in Urban Areas”, Intervention Levels and Countermeasures for Nuclear Accidents – International Seminar, Cadarache, Oct. 1991.
23. Bandiera De Carvalho, A. “Post-Traumatic Stress Disorders: Aftereffects of the Goiania Radiological Accident”, International Workshop on Scientific Bases for Decision Making After a Radioactive Contamination of an Urban Environment, Rio de Janeiro and Goainia, Brazil, August 1994.
24. Pires Do Rio, M. A., Amaral, E. C. S., “The Spread of 137Cs by Resuspension of Contaminated Soil in the Urban Area of Goiania”, International Workshop on Scientific Bases for Decision Making After a Radioactive Contamination of an Urban Environment, Rio de Janeiro and Goainia, Brazil, August 1994.
25. Ferreira, W. M., “Public Monitoring During the Radiological Accident in Goiania”, International Workshop on Scientific Bases for Decision Making After a Radioactive Contamination of an Urban Environment, Rio de Janeiro and Goainia, Brazil, August 1994.
26. “The Radiological Accident in Goiania”, International Atomic Energy Agency, Vienna, 1988.