Legacy Site Decontamination Experience as Applied to the Urban Radiological Dispersal Device

J.L. Drake, J.A. MacKinney
U.S. Environmental Protection Agency
Office of Research and Development
National Homeland Security Research Center
26 Martin Luther King Drive, West, Cincinnati, OH 45268
USA

ABSTRACT

Pursuant to the National Response Plan, Nuclear/Radiological Incident Annex [1], the Environmental Protection Agency (EPA) is assigned lead agency responsibility for decontamination and clean-up efforts following a domestic terrorist event involving a radiological dispersal device (RDD). An RDD incident in a modern city environment poses many of the same issues and problems traditionally faced at “legacy” clean up projects being performed across our country. However there are also many aspects associated with an urban RDD clean-up that have never been faced in legacy site remediation. For example, the demolition and destructive technologies widely used in legacy remediation would be unacceptable in the case of historically or architecturally significant properties or those with prohibitively high replacement cost; contaminated properties will likely belong to numerous small private entities whose business interests are at stake; reducing the time required to decontaminate and return a city to normal use cannot be overemphasized due to its tremendous economic and political impact. The mission of the EPA’s National Homeland Security Research Center (NHSRC) includes developing the best technology and tools needed for field personnel to achieve their goals should that event occur. To that end, NHSRC has been exploring how the vast experience within the legacy site remediation community could be tapped to help meet this need, and to identify gaps in decontamination technology. This paper articulates much of what has been learned over the past year as a result of efforts to identify these technology and procedural needs to address the urban RDD. This includes comparing and contrasting remediation techniques and methodologies currently used in nuclear facility and site cleanup with those that would be needed following an urban RDD event. Finally, this presentation includes an appeal to the radiological decontamination community to come forward with ideas and technologies for consideration to help meet this nationally significant need.

INTRODUCTION

According to the National Response Plan, Nuclear/Radiological Annex, the US Environmental Protection Agency (EPA) will assume the role of Coordinating Agency[1] for clean-up activities following a domestic terrorist event involving a radiological dispersal device (RDD) or an improvised nuclear device (IND) in the United States. This report summarizes the results of an EPA-sponsored interagency workshop held in July of 2005 in Washington DC, which focused on radiological dispersal device clean up technical requirements. The workshop, presented by Argonne National Labs (ANL) under contract to EPA’s National Homeland Security Research

---

[1] The Coordinating Agency is the lead implementing agency for a particular task.

Center (NHSRC), examined current practices in radiological decontamination activities conducted at DOE legacy clean-up sites across the DOE complex in the context of what would be required to address a major urban RDD. The workshop convened 38 subject matter experts from EPA, DHS, DOE, DOE National Labs, DOD/USACE, and DOD/DARPA. Presenters were private sector and federal experts. The workshop was formatted around a series of nuclear facility decommissioning training modules[2] that spanned project planning and management, to clean up technologies, to final status surveys and close out. The presenters were weighted toward private sector experts, while the participants were weighted toward EPA radiological scientists, response and remediation experts, and homeland security technical experts. This approach was taken to generate interaction and learning among these two groups of experts.

The workshop participants examined state-of-the-art knowledge, procedures, and technologies for site/facility clean up and drew conclusions on the applicability and transferability of current methodologies, procedures, and technologies to an urban RDD scenario; answering, for example, what will work and what will not work, and why, with the goal of identifying specific technology gaps. The workshop was scenario-based, utilizing Department of Homeland Security National Disaster Planning Scenario #11, Radiological Attack – Radiological Dispersal Devices [2]. Los Alamos National Laboratory (LANL) provided urban dispersion modeling of the event using a real but unnamed U.S. city. The LANL Quick Urban and Industrial Complex (QUIC) model approximates full-scale computational fluid dynamic code modeling of an urban environment on a laptop computer platform. The workshop was intended to help focus EPA-sponsored technology research and development efforts in directions that would meet the unique needs of a major RDD clean up. The workshop was also intended to help identify impact areas for which further analysis may not be warranted, given a limited amount of resources. Secondary goals included identifying organizational or procedural needs, such as project planning, worker health and safety, and quality assurance/quality control, and guidance and policy gaps.

CHARACTERISTICS OF A RADIOLOGICAL DISPERSAL DEVICE

A radiological dispersal device (RDD) refers to any method used to deliberately disperse radioactive material in the environment in order to cause harm. An explosive RDD, also called a “dirty bomb,” may be produced by packaging explosives, such as dynamite, with radioactive material which would be dispersed when the bomb went off. Other possible RDDs include passive (i.e., nonexplosive) methods of dispersing radioactive material, such as using sprayers or simply spreading radioactive material by hand. In reality, it is impossible to absolutely predict the “how, what, where, and when” of an RDD attack. A large number of different types of radioactive sources are available in the world, there are numerous ways in which the material could be prepared and dispersed, and there are countless environments that could be attacked. Attempting to evaluate all possible combinations and permutations in detail quickly becomes an intractable problem. The EPA report “Preliminary Scoping and Assessment Study of the Potential Impacts from Communitywide Radiological Events and Subsequent Decontamination Activities on Drinking Water and Wastewater Systems”[3] provides an excellent overview of the

---

[2] The workshop utilized the Facility Decommissioning Training Course, Argonne National Laboratory (ANL). ANL was contracted to develop the materials, present the modules, and help with report development.

[3] This is a draft report and is expected to be released in Jan 2007. Advance copies may be requested from the author of this paper.

radiological, physical, and chemical characteristics of radiation sources considered most likely to be used in an RDD.

The aforementioned DHS National Disaster Planning Scenario #11 (which provides a sound starting point for use in response planning and preparation) proposes a cesium chloride source as the likely radionuclide for use in an RDD. In this scenario, the explosive (3,000-pound truck bomb) and a stolen shielded cesium-137 source are smuggled into the country, detonator cord is stolen from a mining operation, and all other materials are obtained legally in the United States. For resource planning purposes, the scenario describes devices detonated in three separate, but regionally close, moderate-to-large U.S. cities. Cesium-137 is commonly found in the form of CsCl and is a fairly fine, light powder with a typical mean particle size of about 300 microns.

EFFECTS OF A RADIOLOGICAL DISPERSAL DEVICE

The "dirty bomb," depending on the radioactive material type, form (e.g., solid, liquid, or powder), chemical composition, and amount (curies), would cause short-term radiation health effects in people located nearby, serious economic costs, social disruption associated with the evacuation and subsequent cleanup of the contaminated area, and possible long-term health risks associated with the dispersed radioactive material. The potential magnitude of the impacts would depend in part on the location of the attack. Although the location of an RDD attack is impossible to predict, it is generally believed that it would most likely occur in an urban area because of the high density of people, high commercial value of the real estate, the potential to cause economic disruption, and the ability to achieve maximum propagandist effect..

Again, the DHS Scenario #11 provides a reasonable starting point for evaluation. The cesium-137 material, when dispersed by an explosive RDD, will have deposited principally as particles within the first 1,000 to 2,000 feet (depending on such variables as wind velocity and profile), whereas the very smallest particles, not subject to immediate gravitational settling, would remain airborne and would move downwind in what is referred to as a "plume." The movement of the plume would be greatly complicated by the effects of building structures and street canyons which result in highly variable wind speeds and directions, eddies and vortices, thermal updraft, and very complex deposition of aerosols. As wind speeds drop, radioactive aerosols would settle out, contaminating the ground, building surfaces, vehicles, and other property.

Although the level of contamination would depend on the characteristics of the dispersal device and the weather conditions at the time of the event, the concentrations of contaminants in the plume and deposited on the ground would generally decrease relatively quickly with distance from the point of origin. A dirty bomb attack that results in minimal generation of fine aerosols (under 10 microns) would result in a relatively small contaminated area with a high concentration of radioactive contamination and a much larger area with low contamination that would decrease with distance from the source. Passive (non-explosive) methods of dispersal could also result in widespread radioactive contamination if fine aerosols were achieved.

Radiological response operations are divided into phases to assist emergency planners and to facilitate execution of protective actions. The Early phase would focus on incident control and protecting the injured and potentially exposed, including taking any immediate life-saving measures (such as treating blast victims) and initiating downwind evacuations or shelter-in-place. The Intermediate phase would involve characterizing the extent of contamination, taking measures to control further spread of contamination, and minimizing additional human exposures. During the Intermediate phase discussions and planning for clean up and recovery would begin. The Late phase would involve cleanup and recovery, including decontamination and remediation of contaminated property. Cleanup after an RDD attack would be conducted according to applicable and appropriate federal regulations and guidance.

PREDICTIVE MODELING AS AN AID TO PLANNING FOR RESPONSE

In the EPA workshop, the DHS Scenario 11 was modeled with a computational fluid dynamics computer model called Quick Urban & Industrial Complex or QUIC, developed at Los Alamos National Laboratory (LANL)[4]. This model is a fast-running dispersion model which employs parameterized and sometimes empirical calculations to solve the dispersion problem. QUIC computes a time history of the three-dimensional wind patterns and dispersion of airborne contaminants around building clusters thru employment of three modules: a wind model, a Lagrangian dispersion model, and a graphical user interface.

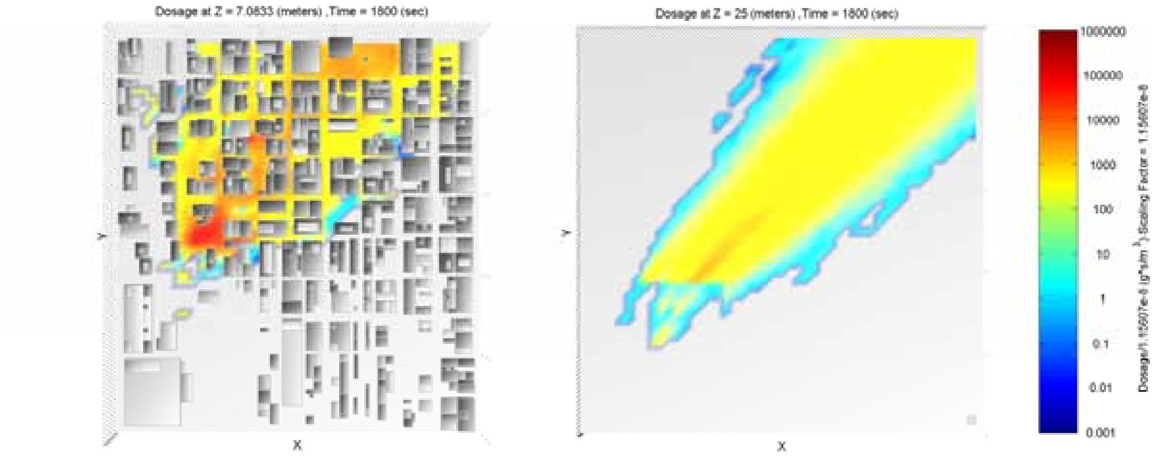


Figure 1. Airborne plume patterns in time-integrated concentrations (uCi/s/m3) 30 min. post-detonation. Left picture shows the inner grid at 20 ft above ground surface; right picture shows the outer grid out to 5 km at 75 ft above ground surface.

QUIC uses empirical algorithms and mass conservation to estimate the wind velocities around buildings (based on scaled 3-dimensional models). The dispersion model tracks the particles' movement as they disperse away from the source term. The wind model predicts the turbulent flow around buildings using a random walk method. QUIC has been used in neighborhood-scale problems in cities such as New York, Chicago, Washington D.C., and Salt Lake City.

This particular analysis, performed by LANL, was based on DHS Scenario 11 with minor modifications. A 2300 curie cesium chloride source is assumed to be explosively detonated in a downtown area with 500 lb of high explosive. The detonation was assumed to produce a particle size distribution ranging from 1 to 400 microns. A prevailing wind was assumed with direction

---

[4] Quick Urban and Industrial Complex (QUIC) model, N. Becker et. al., Los Alamos National Laboratory

from the southwest with wind velocities increasing in elevation according to a power law distribution such that it produces wind of 5.5 mph at 30 ft. QUIC modeled the subsequent air dispersion and deposition onto horizontal surfaces, such as streets, sidewalks, and rooftops, and vertical deposition onto building walls. Fig. 1 shows the air concentrations that developed as a result. Fig. 2 shows the subsequent deposition from the release point (center-left of the graphic). Both show results 30 minutes post-detonation.

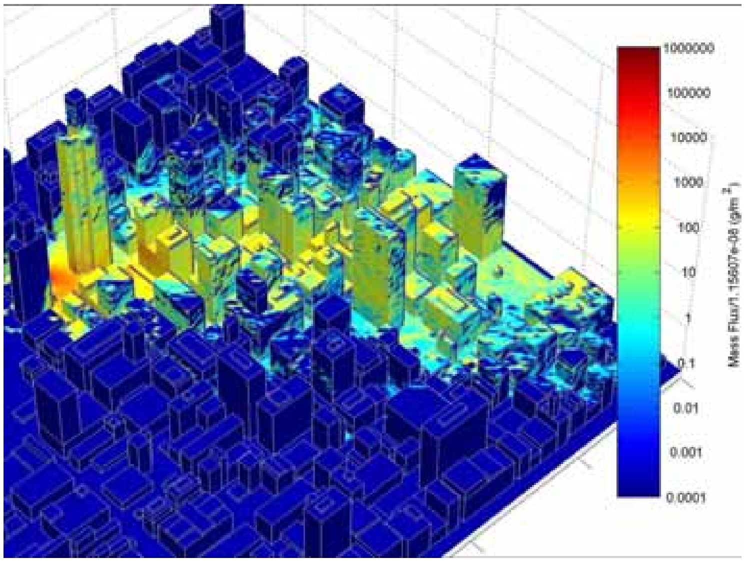


Fig. 2. Cesium deposition from Quick Urban & Industrial Complex (QUIC) model

LEGACY SITE DECONTAMINATION COMPARED TO URBAN RDD CLEANUP

Many large federal sites and some commercial sites in the United States were contaminated during the early phases of the Nation's nuclear weapons development and nuclear power reactor programs. Due to the extent of anticipated contamination and the migration of these contaminants over time, high cost, and typically rural locations, these sites are generally slow to be cleaned up. A number of these larger clean ups will take decades to complete. Since most date from the early days of nuclear technology development, they are often called "legacy" sites. Many of the facilities/sites licensed by the NRC are not referred to as legacy sites because they are not as old, and regulatory and license requirements result in relatively prompt facility decommissioning and clean up (often called decommissioning and deactivation, or D&D) which is initiated upon application for operating license termination. For purposes of this report however, all current and past radiological site clean ups will be referred to as "legacy" clean ups, because they result from formerly operating radiological sites or facilities and generally some length of time has passed prior to commencement of clean up.

For such legacy clean ups, substantial and credible experience exists, and an extensive suite of technologies has been developed to meet clean up goals at these sites, and to reduce the costs of decontamination. Periodically new technologies are developed to address a particular need, such as a certain hard-to-reach component or a new waste minimization technique. There are some obvious similarities between a legacy site clean up and the restoration which will be required following an urban RDD event. In both cases, the physical environment is composed chiefly of buildings, outdoor areas and contaminated equipment (such as vehicles, utilities, and industrial facilities). However, there are many significant differences between legacy clean ups and clean up of an urban area following a large RDD incident. These differences may be grouped into 4 main categories: time, regulatory requirements, location and architecture, and technology.

Time

In legacy clean ups, the time allotted to clean up the site is an expectation based on meeting regulatory environmental clean up goals established for the site through lengthy planning, analysis, and public meetings. That is, time to complete the task is a function of the size and complexity of the site, available funding, technical feasibility issues (including meeting established criteria), available waste capacity, and local public pressure. At the start, considerable time may be allowed to pass before clean up or D&D is executed. In many cases, this is due to lengthy license closure requirements, reviews of clean up plans and negotiations with stakeholders. In other cases, as with reactors, this is part of the clean up strategy taking advantage of radioactive decay and thus minimizing worker doses in accordance with ALARA[5] requirements. Lower radioactivity may also reduce waste packaging, transport, handling and disposal costs. This strategy, called SAFSTOR (Safe Storage; sealing and maintaining the site until sufficient decay has taken place), is an established management option for many NRC licensed sites. If a contaminated facility is located far from populated areas, there may be less pressure to decontaminate immediately.

In the case of an urban terrorist RDD, however, the contamination has suddenly come upon an unsuspecting and otherwise "clean" metropolis. Evacuations and emergency response operations are presumed to be undertaken. Unlike a legacy clean up, no advanced site planning and assessment will have taken place. In addition, no shutdown and deactivation strategy, cost estimation, technology assessment, stakeholder discussions concerning clean up and site utilization, or contractual arrangements to clean up the area will have taken place. The potentially large amount of privately owned property contaminated after an RDD event will have enormous economic and psychological impact, and enormous political pressure from all sides, with considerable time pressure for rapid clean up and restoration.

Regulatory Requirements

Radiological clean ups today are performed under various statutory authorities, the most important of which are the Comprehensive Environmental Response, Compensation, and Liabilities Act (CERCLA, 1980 as amended), administered by EPA, the Atomic Energy Act (AEA, 1954 as amended), administered by the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and environmental laws and regulations of individual states. Other radiological clean ups occur under more specific laws and regulations, such as the Uranium Mill Tailings Radiation Control Act, and under programs such as the Formerly Utilized Sites Remedial Action Program which is administered under CERCLA authority.

When the federal government undertakes or requires environmental clean up, specific legislative (statutory) authorities are cited. Such authorities not only make the action legal, they also may provide for (or require) funding, implementing regulations, and standards that offer consistency in actions and confidence the job will be done according to expectations. EPA does almost all radiological clean up under CERLCA authority. The NRC requires it's licensees to perform

---

[5] ALARA stands for "as low as reasonably achievable." It is a principle for dose reduction planning and procedures; in this case, to keep worker radiation doses to the lowest limit reasonable. ALARA procedures can have a substantial impact on costs.

clean up pursuant to regulations under the AEA. Most DOE site clean ups are subject to CERCLA, though some may be performed under DOE's AEA authority or other laws[6]. EPA CERCLA clean-ups follow requirements established in regulations found in 40CFR300 of the Code of Federal Regulations. These regulations prescribe a process and a public health risk range which clean-ups must achieve, require public participation, and are funded either by legal action against the responsible party or from the "Superfund" account established by CERCLA. NRC licensees must fund the clean up of their own facilities, and DOE utilizes the Congressional appropriations process to fund clean up. NRC and DOE regulations also entail very prescriptive processes and radiation dose goals that must be achieved. In each case, a system is in place and one federal agency controls the process for a given site.

In the case of a terrorist RDD in an urban area no federal law clearly prescribes clean up standards or procedures. EPA's CERCLA, or "Superfund," authority could be utilized, but CERCLA does not automatically apply upon the release of contamination to the environment; a designation of the site as a CERLCA Superfund site would have to be made. Experience in New York City with the clean up of the World Trade Center area after the September 11 attacks, which was not designated a CERCLA Superfund site, leads one to believe that most mayors and state governors would not want their cities named as Superfund sites. This has been a standing assumption among federal agency staff and management considering clean up after a major urban RDD. The Homeland Security Act of 2002 gave DHS overall authority for the management of consequences from acts of terrorism, but does not contain provisions for regulatory oversight of post-terrorism clean up, nor does it explicitly authorize funding for such a clean up. An underlying assumption in this analysis is that an urban RDD clean up would not be performed under existing environmental legislative authorities, such as CERCLA[7]. Rather, it is assumed both the authority and the funding for clean up of a major RDD incident would come from the Robert T. Stafford Disaster Relief and Emergency Assistance Act (the Stafford Act), under the overarching authority of the Department of Homeland Security, and in accordance with the National Response Plan. The Stafford Act, which DHS administers, does provide for infusion of funds for a wide-ranging variety of actions and is now widely considered to be the means to pay for an RDD clean up. What is lacking under DHS is *how* to clean up RDD contamination in an urban area. The DHS published draft federal interagency consensus guidance[8] proffering the use of "optimization," a flexible approach that accounts for such factors as technical feasibility, cost-effectiveness, public involvement, land use options, and other issues relevant to site-specific clean up planning [3, 4]. The guidance does not provide dose or health risk requirements or recommendations; rather use of existing legal/regulatory benchmarks is advised as reference points in the site-specific clean up process. Further, while DHS has overall oversight over the process, other federal agencies (in particular EPA), state and local governments, and local stakeholders will have significant sway in the clean up decision-making process.

---

[6] For example, under the Uranium Mill Tailings Radiation Control Act, 1978.

[7] The site could be named a Superfund site under the Comprehensive Environmental Response, Compensation, and Liabilities Act (CERCLA) in which case EPA would clean up the site using that authority and implementing regulations.

[8] The legal authority and funding apparatus appear to suffice, but rigorous, tested implementing standards, regulations, and procedures, which are imperative among environmental laws, are nonexistent.

Location and Architecture

Typically the location of legacy sites is relatively remote. Most DOE weapons facilities for example, tend to be located in relatively remote or low population density areas as are fuel production facilities (mining, milling, etc.), commercial power reactors, and major TENORM sites. Very few nuclear facilities are located in downtown business districts where one would expect an RDD attack to occur[9]. Thus, when contamination occurs at existing facilities, from a spill or release, contamination in downtown city areas is not normally seen. As a result, planning for such large scale radiological incidents in high density downtown areas doesn't normally occur[10].

All facilities used for significant processing or management of radiological or nuclear material are designed to control radioactive materials used or processed at the facility, and to contain or minimize off-site spread of contamination in the event of an accident. These facilities are often designed with the understanding that portions of the facility may become contaminated and require subsequent decontamination. For example, radiological "hot cells" are controlled, enclosed units where highly radioactive substances are processed. Some are built with very thick concrete walls and completely lined with stainless steel for easy decontamination in the event of a spill. Such facilities have highly engineered air handling and filtration systems and are specifically designed to minimize the number and size of rooms, passageways and components that may become contaminated. Special coatings may be used to avoid penetration into concrete and other materials, and to facilitate decontamination. In theory, operators know where contamination exists and what areas are "clean," but surprises do occur. Environmental clean up at legacy facilities becomes significant and costly in part because early safety and environmental requirements were less rigorous, or, as was common in the 1940's through the '60's, wastes were simply dumped in trenches for expediency.

The importance of location as a factor in RDD clean-up has to do with public expectations, economic impact, complications arising from privately held lands, and the degree of societal upheaval from an RDD incident. Most downtown districts are composed of lands and buildings with high real estate values. The number of impacted stakeholders of privately owned lands and buildings as well as local government and others can be very high. Population densities are also presumably high, which translates into high numbers of impacted individuals, and a large number of vehicles and complex transportation systems. With a large impacted population comes a correspondingly large degree of business disruption and job displacement. Some locations deemed at high risk for terrorism have unique or sensitive features, such as historic buildings, monuments, or sites of national significance like the National Archives building in Washington, DC. Many urban cityscapes may warrant special consideration for contaminated runoff mitigation or control. The potential for unintentional, direct spread of contamination by

---

[9] Small academic research reactors may be found on university campuses, but they use very small fuel quantities. Certain other facilities, that use, process or manufacture smaller amounts of radioactive materials, may be in or near populated areas pursuant to siting requirements. In some cases, such as DOE's Rocky Flats facility outside Denver, CO, development gradually spread out to sites bringing the population closer over time.

[10] The exception may be with respect to commercial nuclear power plants (NPPs) which by law must implement emergency planning procedures and coordinate with local emergency management officials. However, most NPP accident scenarios postulate the release mainly of noble gases, with few particulates and therefore off-site clean up is not anticipated. The Three Mile Island accident, for example, required no off-site remediation.

those self-evacuating the incident is high. For all these reasons, location is a key factor affecting RDD clean up. Cities were never designed to be radioactively contaminated and decontaminated, and sewer and storm drainage systems were not designed to control radioactive runoff. Rather than controlling contamination and minimizing contaminated areas, everything potentially becomes contaminated, exacerbating the terror effect and the difficulty of clean up.

Related to the location/architecture factor is the fact that aerosolized radioactive material can be expected to spread far and wide, depositing on building surfaces up to high heights, into building interiors, and down into subterranean structures. Contamination is easily transported and spread by vehicles, foot traffic, wind, and rain. In the end, the biggest issue in RDD clean up is the size of the incident, i.e., the scope of the contamination spread. On a small scale, virtually anything can be decontaminated to very low levels. But, as the size and scope of the contamination event increases, the overall difficulty tends to increase geometrically. A number of interrelated factors associated with size and scope increase this difficulty (the workshop did not attempt to prioritize these factors):

- the total area to be decontaminated increases
- the three-dimensional geometry of the affected area (breadth, height, surface features, subterranean features) becomes more complex
- the potential for cross-contamination and recontamination increases
- the potential for significant off-site contamination increases
- the number of necessary technologies for contamination control, mitigation, decontamination, and dose management increases
- the number of site clean up units, options, and sub-options in the clean up strategy increases
- the amount of generated radioactive waste increases
- the number of workers increases (including workers with very specialized expertise)
- the worker health and safety program grows larger and more involved
- the size of the required logistical support system increases (command, communications, data management, engineering support, motor pool, etc)
- the number of stakeholders increases
- the total value of the affected property increases (hence, the political/social/economic impact)
- the time to completion increases
- the total cost increases.

Technology

The technical field of clean up of radiologically contaminated legacy sites is mature and not lacking in experience. Numerous radiological clean ups have been performed around the country at commercial/industrial and federal government sites and facilities spanning several decades under a variety of legislative authorities, and by federal and states agencies utilizing various commercially contracted clean up firms. These constitute the base of knowledge and experience upon which officials may draw when confronting RDD contamination in an urban area. A very wide assortment of decontamination technologies have been developed to meet the criteria and cost constraints of radiological site clean ups. The simplest approach and the one most often utilized at legacy sites, is the complete removal of structures for disposal. This is largely a cost decision, but inherent in that decision is that there is no compelling need or desire to preserve the structures for reuse. To this can be added a wide selection of physical, chemical, and even biological decontamination technologies with varied effectiveness on different substrates, different costs per unit area, different waste implications, and different use and operational constraints. As a general rule, it costs more to meet more stringent criteria. Cost is principally driven by the amount of material removed for disposal (including packaging, shipping and disposal costs), and the time and manpower necessary to meet established criteria[11]. Legacy radiological clean up technologies are mostly relatively "low tech," that is to say, have a low degree of technical sophistication. With regard to structures, most radiological decontamination is performed by demolition. The work is generally preceded by techniques that physically remove outer layers containing contamination, as with scabbling, grinding, shaving, or abrasive blasting, to reduce dose and minimize waste generation. In some cases, contamination can be removed from surfaces relatively non-destructively with chemical chelants or acids, strippable polymeric coatings, laser ablation, and even electro-kinetic techniques. These techniques can be used effectively only when contamination is constrained to shallow depths of penetration (millimeters or less). These more "high tech" approaches may be chosen to minimize waste generation, preserve the underlying substrate, access hard to reach locations, or achieve good decontamination of particularly resistant contaminants on some surfaces. But, if these prove ineffective or costs run too high, the whole may be trucked off for disposal where efficiencies of scale may make the unit cost attractive[12].

Experts in the field of radiological decontamination and clean up largely agree that virtually anything can be "decontaminated." In the case of a major urban RDD, the technical experts face a dilemma; very large surface areas must be decontaminated, on the order of thousands to millions of square meters, including vertical surfaces reaching challenging heights, very complex surfaces, sewer and stormwater systems and, potentially, drinking water systems. But, the most common technique used at legacy sites, demolition and bulk removal for disposal, is without question the least desirable approach in an urban decontamination operation. Even surface decontamination technologies that remove thin layers of substrate, such as scabbling or abrasive blasting, would deface the city and require substantial renovation of the damaged structures. These surface removal techniques are slow and costly on a unit area basis. Low tech surface approaches, such as washing, brushing and vacuuming have the advantage of speed and low cost, but also may not meet restrictive criteria, especially as contaminants adhere and penetrate with the passage of time. Preliminary (unpublished) research performed at EPA is indicating that cesium penetrates rapidly and deeply into porous urban construction materials and is highly sensitive to relative humidity. An additional complication in any structural decontamination,

---

[11] Other important clean up costs include worker health and safety, operations and maintenance, regulatory compliance, other environmental requirements, public outreach, and capital costs.

[12] A key variable in this decision is the value of the structure and desire to restore and reuse it; usually, legacy clean ups do not try to preserve structures for a later user.

considered the bane of decontamination, is cracks, crevices, nooks and crannies. It is very hard to meet traditional criteria without accessing, or cutting out, cracks, crevices, nooks and crannies, and an urban environment has many.

While there is substantial overlap in experience and lessons from legacy clean ups, there are also important differences with respect to urban RDD clean up. It is the differences which must be accounted for in order to prepare for radiological terrorism with appropriate and effective technologies. If an RDD hits a U.S. city, the technical workforce requirements will be large, and the workforce will likely consist of federal, state and private sector experts that have been remediating U.S. legacy sites, including CERCLA Superfund sites, and decommissioning commercial facilities and DOE facilities. These personnel bring with them the best knowledge and experience in decommissioning and clean up. How well does this knowledge, experience and technology apply to an urban RDD? What should be expected to work well, and therefore, not require additional research and development? What approaches will not work, given the unique characteristics and constraints of an urban area widely contaminated with fine particulate radioactive material? What existing technologies will work, or may be modified to work for urban RDD clean up; and where should research and development funding be focused?

LEGACY SITE DECONTMINATION AND DECOMMISSIONING PROCESSES AND TECHNOLOGIES: CAPABILITIES, GAPS, AND R&D

During the course of the EPA RDD clean up workshop the principal processes involved in the conduct of a legacy clean up were examined as to the state of the practice and to their applicability to the urban RDD event. These processes can be grouped into (1) planning and project management functions, (2) field operations, and (3) verification of the final end state of the site. Discreet tasks and processes within theses broad categories included site characterization, planning and cost estimating, project management, industrial health and safety, decontamination technologies, waste management, storage, transport, and disposal of radiological wastes, and final status surveys. Some of these, such as worker safety and health, would transfer seamlessly to a successful urban RDD clean up. The most notable exception was that the technology, tools, and processes normally used for the decontamination of legacy sites were as a whole not well suited to the particular needs of the urban RDD. The two key differences between the legacy sites and an urban RDD site which make traditional legacy site decontamination tools and technologies unsuitable are (1) that the location is presumed to be urban so the desire is to re-use and reoccupy the remediated buildings and areas, and (2) the assumed size of the RDD-contaminated area and the associated complications such as the time required to complete the remediation.

Addressing the first of these differences, as mentioned previously the vast majority of the technologies and processes most widely used to decontaminate buildings and facilities at legacy sites are destructive by nature and involve significant surface removal (up to several inches, due to the tendency of radionuclides to migrate through building materials such as concrete) in order to remove radioactive contaminants. For legacy sites this is normally not an issue, as most of the buildings are slated for demolition, and decontamination is performed principally to reduce the quantity of radioactive waste which must be disposed, thereby reducing overall remediation costs, and to reduce dose to workers[13]. For urban RDD sites, however, defacing or destroying building facades, or removing buildings completely will not be acceptable on a large scale. Plus, reoccupation and re-use requires much lower residual levels of radioactivity than has often been required and achieved at legacy (non-reoccupied) sites. Occasionally a legacy site end state will include some level of facility re-use, and those facilities are typically reoccupied in such a way as to limit personnel exposure, restricting personnel entry to trained radiation workers and implementing occupancy restrictions. Contamination may be intentionally left in place and managed using specially constructed shielding and engineering or administrative controls.

The second significant difference which makes the majority of current decontamination technologies inadequate for RDD remediation revolves around the speed with which they can decontaminate a given surface area. Most current decontamination technologies operate in the realm of square feet per hour, which in the case of a clean up covering tens of city blocks, would be completely impracticable. The surface area which would be required to be decontaminated in an urban RDD clean up could easily approach several hundred million square feet, accounting for the geometric complexity of the urban environment. Many traditional decontamination technologies require either multiple steps or repeated application (or both) in order to reduce contamination to acceptable levels, which directly affects the overall time required to complete the clean-up. The magnitude of the area which must be decontaminated will probably be in the range of the largest of the legacy site remediation projects, but the extremely low residual radioactivity levels required for unrestricted reoccupancy coupled with the requirement to leave many building facades intact will significantly affect remediation cost and schedule.

An additional factor which contributes to the need for improved decontamination technologies and tools is the projected differences in skill mix between a legacy clean up and an RDD clean up. Legacy clean ups are generally performed by a contractor with many years of radiological field experience using skilled workers. Due to the emergent nature of an RDD event and the need to deploy large numbers of workers (to reduce remediation time) in a short period of time (rapid deployment), the work force may ultimately be less skilled and less experienced than is the case in legacy clean ups. This could impact not only the timeliness of decontamination, but also the selection of decontamination technologies and tools where less operator skill is needed, and which lend themselves to rapid operator training.

Technology Challenges

Table 1 presents a comparison of the relative performance of most of the mechanical decontamination technologies which have been used or explored for use in legacy radiological site clean ups. This information may be useful as an initial screening guide for technology selection, however it also serves to illustrate that no single technology will adequately meet all requirements, and in fact that even the best performing technologies, even if used in combination, are not adequate to effectively meet all the needs of the urban RDD clean up. There are a

---

[13] One notable exception is a legacy Manhattan Project clean up at the Battelle King Avenue facility in Columbus, OH. The buildings were cleaned up for unrestricted use per Reg. Guide 1.86 Termination of Operating Licenses for Nuclear Reactors, with limits for reuse of offices and lab areas by general non-radiation workers. The project had to address both the re-occupancy and time pressure issues as the decontamination activities took place in a facility where research activities were continuing.

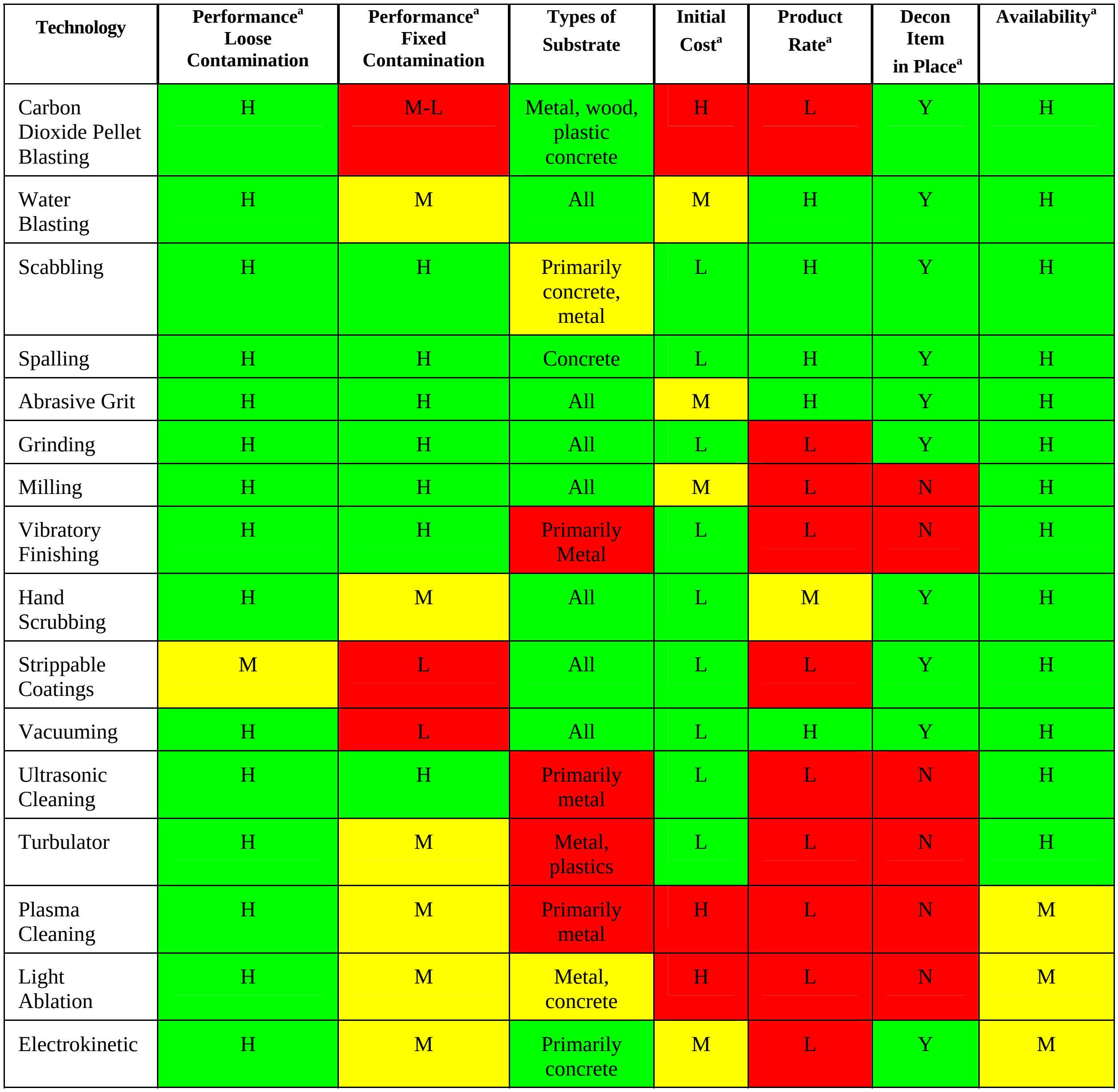
number of resources available which more fully characterize each of these technologies as well as chemically based methods. Among the best of these resources is a technology reference guide edited by Mr. Ed Feltcorn [5,6]so this paper will not attempt to include that information.

The fact that adequate commercial off-the-shelf technology is not currently available has not been left unrecognized by Federal agencies tasked with terrorist response and recovery preparedness missions. In fact, several Federal agencies are pursuing multi-year programs, with considerable budgets, in an effort to increase agency preparedness for an RDD event. The Departments of Homeland Security, Defense, and Energy, and the Environmental Protection Agency all fund acquisition and R&D efforts to develop and procure the tools and strategies which are and will be needed to adequately deter, prevent, detect, mitigate, and recover from such an event. Much valuable information has been generated from these programs, and will continue to be generated as they. However, to date there has been only minimal interagency coordination of this work, and increased coordination could significantly increase the effectiveness of these agency programs proceed (a current effort is underway within NHSRC to identify and document the status of Federal R&D programs and projects pertinent to urban RDD clean up). In addition, due to the significant aforementioned technical challenges posed by an urban RDD, much research is needed both in the arena of applied technology and in the basic science upon which these decontamination technologies are based. This paper has sought to articulate the technical challenges of an urban RDD clean up (and to a lesser extent the associated non-technical challenges), and to assess the applicability of legacy site experience and capabilities.

The following paragraphs present an overview of the status of existing research and development activities undertaken by NHSRC to address these challenges as they relate to its assigned recovery R&D mission. It does not address ongoing or planned efforts by other agencies, however such information would be welcomed. It also does not provide concrete recommendations regarding the need for improved interagency coordination in decontamination R&D.

The National Homeland Security Research Center is pursuing a research and development program which is intended to address R&D needs related to EPA's homeland security mission. This R&D is carried out by the Center's Decontamination and Consequence Management Division (DCMD), the Water Infrastructure Protection Division (WIPD), the Risk and Consequence Management Division (RCMD), and the Response Capability Enhancement Division (RCE). This paper will limit discussion to technology development and basic research being conducted or planned within the DCMD only.

Table I. Relative Performance Factors for Mechanical Cleaning Techniques [7]



Technology	**Performance[a] Loose Contamination**	**Performance[a] Fixed Contamination**	**Types of Substrate**	**Initial Cost[a]**	**Product Rate[a]**	**Decon Item in Place[a]**	**Availability[a]**
Carbon Dioxide Pellet Blasting	H	M-L	Metal, wood, plastic concrete	H	L	Y	H
Water Blasting	H	M	All	M	H	Y	H
Scabbling	H	H	Primarily concrete, metal	L	H	Y	H
Spalling	H	H	Concrete	L	H	Y	H
Abrasive Grit	H	H	All	M	H	Y	H
Grinding	H	H	All	L	L	Y	H
Milling	H	H	All	M	L	N	H
Vibratory Finishing	H	H	Primarily Metal	L	L	N	H
Hand Scrubbing	H	M	All	L	M	Y	H
Strippable Coatings	M	L	All	L	L	Y	H
Vacuuming	H	L	All	L	H	Y	H
Ultrasonic Cleaning	H	H	Primarily metal	L	L	N	H
Turbulator	H	M	Metal, plastics	L	L	N	H
Plasma Cleaning	H	M	Primarily metal	H	L	N	M
Light Ablation	H	M	Metal, concrete	H	L	N	M
Electrokinetic	H	M	Primarily concrete	M	L	Y	M

[a] **All factors** are subjective and may change based on application or specific equipment, but should be nearly those quoted here.
Performance factors are based on relative reported cleaning of these methods; High is typically over about 90%, Medium is about 70% and Low is less than %70.
Cost is based on initial cost of equipment, High is over about $100,000, Medium is over about $50,000 and Low is less than $50,000.
Production rate is based on a significantly higher or lower rate than 30 sq. ft. per hour.
Decontaminate in place is based on the whether an item can be decontaminated externally without removal.
Availability is based on whether a vendor is currently marketing this equipment or process

The NHSRC/DCMD has organized its RDD decontamination R&D efforts according to a multi-year plan which addresses several specific areas. These are:

(1) Identification and evaluation of radiological decontamination technologies with priority given to currently available methods already used in radiological applications,

(2) Identification and evaluation of currently available non-radiological technologies which may be adapted for radiological use, and

(3) Identification and development of innovative technologies to meet identified urban radiological clean up needs,

(4) Foundational research to better understand the interaction of contaminants with urban substrates,

(5) Research to better understand contamination movement (such as aerosol movement, resuspension, and tracking), and

(6) Predictive modeling and decision support software tools for RDD clean up and recovery.

Two projects have been initiated in support of the first research area. One project consists of a survey of existing radiological decontamination technologies and vendors which included contacting these vendors and requesting current technical information. This information was collected in a decontamination technology database, accessible through an existing EPA program called the Remediation Technology Ready Reference (RTRR). This effort is ongoing and is intended to become a support tool for decontamination field operations personnel, such as the National Decontamination Team (NDT) and the EPA On-scene Coordinators (OSCs), and will be accessible via the Internet. An additional technology identification effort included a Sources Sought Notice, published in the internet FedBizOpps, which sought to identify commercially available technologies potentially applicable to urban RDD decontamination needs.

A second project being pursued within this first research area, called the RDD Rapid Decon project, was initiated to perform decontamination technology performance testing and evaluation. This project seeks to (1) establish decontamination performance evaluation criteria and a testing methodology, (2) execute performance testing of candidate decontamination technologies, and (3) demonstrate a suite of the most effective technologies in a full scale mock-up of an urban RDD setting, including providing an opportunity for operator training, interaction with field personnel (NDT and OSC personnel and others), and lessons learned. Though the initial testing will be performed in a laboratory setting, the test environment will replicate a near “full scale” urban environment, i.e. the equipment and test platform will be designed to replicate as closely as possible an actual urban RDD site. This test environment will employ the same contaminants expected to be encountered after an actual dirty bomb attack using building materials which accurately replicate those found in an urban environment.

In support of the basic research areas, several projects are underway or in the planning stages. One project underway involves a study of the behavior of CsCl particles as they interact with concrete, limestone, and brick, and how those interactions change over time, accounting for relative humidity and rain events. Other studies being initiated or proposed and awaiting funding examine particle transport phenomena such as infiltration into indoor environments, and resuspension and “tracking” of contaminants, such as due to pedestrian and vehicular movement during evacuation and during decontamination field operations. Finally, DCMD has proposed an RDD Decontamination Waste Estimator tool for use by recovery planners and on site decision makers based on existing 3-dimensional computer modeling capabilities, RDD impacts modules, and decontamination options analyses.

CONCLUSION

A large amount of radiological decontamination experience and expertise exists within government, industry, and academia based on more than fifty years of managing legacy radiological contamination. Some of this experience and expertise is directly applicable to the problem of cleanup after an urban dirty bomb event. However, radiological decontamination technologies, processes, and expertise currently available to address dirty bomb recovery are conspicuously inadequate – they are too slow, too expensive, and are either too destructive or are not effective at decontaminating the urban surfaces sufficiently to meet typical requirements for reoccupation and re-use. Many Federal agencies have recognized these deficiencies and have taken steps to address them, but these efforts lack the interagency coordination and cooperation required to maximize progress, reduce duplication, and ensure adequate attention is paid to important issues. For its part, the USEPA, National Homeland Security Research Center, has targeted specific science and technology shortfalls and has undertaken research and development projects to address them. NHSRC welcomes cooperative relationships with other government, industrial, and academic counterparts to help solve these problems and more effectively prepare for the eventuality of recovering from an urban dirty bomb.

REFERENCES

1. DHS, 2004, *National Response Plan, Nuclear/Radiological Incident Annex*, December.
2. DHS, Draft 2005, *National Disaster Planning Scenarios*, April.
3. Federal Register, Vol. 71, No. 1/Tuesday, January 3, 2006, page 174.x, EPA, 2006, *Preparedness Directorate: Protective Action Guides for Radiological Dispersion Device (RDD) and Improvised Nuclear Device (IND) Incidents, Draft*, For interim use and comment; January.
4. EPA, 1992, *Manual of Protective Action Guides and Protective Actions for Nuclear Events*, 400-R-92-001, May.
5. EPA, 1996, *Technology Screening Guide for Radiologically Contaminated Sites*, EPA 402-R-96-017, November.
6. EPA, 2006, *Technology Reference Guide for Radioactively Contaminated Surfaces*. EPA-402-R-06-003, March.
7. Decontamination Technologies, 2005 RDD Workshop, unpublished proceedings, ANL, 2005.