Optimization Approaches to Decision Making on Long-Term Cleanup and Site Restoration Following a Nuclear or Radiological Terrorism Incident

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INTRODUCTION

Potential radiological consequences that could result from terrorist acts are of great concern to both national security and public welfare, particularly for acts involving Radiological Dispersal Devices (RDD) or Improvised Nuclear Devices (IND). Accordingly, a series of relevant planning guidance documents has been developed by federal agencies, such as the U.S. Department of Homeland Security (DHS) through its authority under the Homeland Security Act of 2002, and are currently incorporated in the National Response Framework (NRF). While the initial planning effort has focused predominantly on protecting against or responding to activities related to the early (i.e., emergency) phase of an event for both first responders and the affected public populations, guidance on the late-phase recovery effort (i.e., activities leading to the eventual reoccupation of the contaminated areas) has not been adequately developed. One major consideration for developing such guidance is the need to encompass a potential array of seemingly limitless scenarios, ranging from a minor incident that causes only some “disruption” from an RDD, to a potentially severe incident causing “mass destruction,” such as the damage that could be caused by an IND.

Regardless of the scenario, one common long-term concern is the potentially widespread radioactive contamination of either private or public property (particularly in highly populated metropolitan areas) that would require an extensive mitigation effort.[1] Two major factors, among others, would likely weigh heavily in the decision-making process: the large cost implications and the stakeholder acceptance of the cleanup goals, especially if a long time is required for site recovery.[2] The challenge to develop suitable guidance for late-phase recovery efforts will therefore be influenced by these, as well as other, considerations in subsequent deliberations surrounding related issues.[3]

A REVIEW OF HISTORICAL RADIOLOGICAL EVENTS

Although there have been events involving the use of radioactive materials for malicious intent in recent history, they have been isolated incidents and few in number, and have had limited impact on society.[4] It is thus useful to evaluate past radiological events that have caused significant releases, such as accidents involving nuclear facility operations or management of radioactive sources. Such events include accidents involving (1) nuclear power-generating facilities, (2) military and defense operations, and (3) radiation sources and transport.[5] These events cover a wide spectrum in level of severity, ranging from limited environmental impacts or human trauma to significant casualties and environmental contamination. The lessons learned and experiences gained from past accident events can serve as valuable input in formulating a meaningful response to similar radiological issues in terrorist incidents involving RDD or IND.

Radiological events can cause varying degrees of harm to humans as well as the environment. To help characterize and communicate the significance of these events, the International Atomic Energy Agency, together with the Organization for Cooperation and Economic Development's Nuclear Energy Agency, has published the international nuclear and radiological event scale (INES).[6] The scale was designed to emulate such representations as the Richter or Celsius scales for earthquakes or temperature, respectively, and offer a better understanding of the magnitude of the potential impact. The INES scale comprises seven levels of severity (from low to high):

Level 1, Anomaly;
Level 2, Incident;
Level 3, Serious Incident;
Level 4, Accident with Local Consequences;
Level 5, Accident with Wider Consequences;
Level 6, Serious Accident; and
Level 7, Major Accident.

Events that are without safety significance are called "deviations" and are classified as Below Scale (or Level Zero). Three major descriptors are used to gauge severity for nuclear facilities: impact on people and environment, impact on radiological barriers and control, and impact on defense-in-depth (the latter two apply only to nuclear facilities). Accordingly, for any significant concern about radioactive release and subsequent contamination of the environment, the possible events would register a severity scale of at least Level 5 (i.e., releases that would require implementation of planned countermeasures) or beyond. Some of the more serious events (i.e., Level 5 through 7) that attracted considerable attentions worldwide in recent history are the following.

1. *Accident at Three Mile Island Unit 2, Dauphin County, Pennsylvania, March 1979.*[7] Considered the worst accident ever in the U.S. commercial nuclear power industry, it released about 13 million curies of radioactive gases (i.e., relatively harmless noble gases) but only 20 curies of iodine-131 (I-131) to the environment. Radioactive contamination was largely limited to the facility and its confines. It has been designated as an INES Level 5 accident (accident with wider consequences).[8] As a precautionary measure, pregnant women and preschool-age children within a five-mile radius of the Three Mile Island facility were advised to evacuate, and about 140,000 residents voluntarily evacuated within days. Although the accident did not cause any significant impact on people and environment (only about one estimated long-term cancer fatality due to offsite releases), it did lead to significant damage to the reactor core. Since there was no contamination to public land as a result, the recovery activity was limited largely to the cleanup of the facility itself, which took several years and cost about U.S. $975 million.
2. *The Chernobyl Accident, Pripyat, Ukraine (Former Soviet Union) April 1986.*[9] Likely the worst nuclear power plant accident in history worldwide,

the Chernobyl accident resulted in a widespread release of radioactive materials following a massive nuclear explosion that destroyed reactor Number 4. The accident released an estimated total of 380 million curies of radioactive material into the environment (including 49 million curies of I-131 and 2.3 million curies of Cesium-137 (Cs-137)).[10] The accident led to fifty-six direct deaths (many of those were attributed to radiation exposure) and an estimated 4,000 long-term cancer deaths.[11] An estimated 336,000 people were evacuated within an extended "exclusion zone" of 4,300 square kilometers.[12] An estimated 2.6 million km^2 of agricultural land was affected, with extensive contamination of the environment and the ecosystem.[13] The release affected parts of the western former Soviet Union, Eastern Europe, Western Europe, North Europe, and also other parts of the world. Potential costs of the cleanup effort cannot be readily measured, although the initial estimate for Belarus alone in a thirty-year program to rehabilitate the affected areas was about U.S. $235 billion (thirty-two times the Ukraine's annual budget at the time of the accident).[14] As such, the accident has been characterized as INES Level 7 (i.e., a major accident), because it resulted in "a major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures."[15]

3. *Cesium Source Accident, Goiania, Brazil, September 1987.* [16] Perhaps the worst accident involving radioactive sources, this was the result of an inadvertent scavenging of a radioactive medical teletherapy (radiotherapy using external radiation beams) source (containing Cs-137) in an abandoned hospital. Since the accident was not recognized for several days, it was allowed to propagate further. It thus resulted in four deaths and injuries to several other people due to radiation exposure. In addition, part of the city was contaminated and required an extensive decontamination and remediation effort lasting several months, largely due to the lack of preparedness and specific guidance in responding to an unprecedented incident. A total of 1,200 curies of Cs-137 was accounted for in the contamination (out of a total of 1,375 curies in the original cesium chloride source), with an estimated contamination area reaching 1 km^2.[17] Although the total final cost for the cleanup effort is not known, it is believed to be substantial. The accident has been designated as an INES Level 5 accident (accident with wider consequences).

These examples also offer a useful glimpse into the potential severity levels for an RDD or IND incident, with a full blown RDD incident possibly at Level 5 (widespread contamination) and the IND incident at Level 6 or 7 (potential for causing major destruction). Of course, events of smaller scale could also occur and may result in only localized damage and have a more limited impact. However, regardless of the specific situation, each event would cause considerable disruption and possible trauma to the affected society in the short term, and present an expensive and long-lasting recovery challenge.

RESPONSE AND PROTECTIVE ACTIONS GUIDANCE

Protective Actions and Guidelines

In the United States, federal agencies have been planning responses to nuclear emergencies for decades.[18] Historically the planning has focused primarily on emergencies involving accidental releases of radioactive materials, such as from nuclear power plants. The Environmental Protection Agency (EPA) first developed a Protective Actions Guide (PAG) manual in 1975. Following the Three Mile Island accident in 1979, President Carter issued an executive order establishing the Federal Emergency Management Agency (FEMA) as the lead agency coordinator for the nation's radiological emergency response and preparedness. Under the arrangement, EPA was assigned the task of establishing PAGs for radiological response planning, and it issued the *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents* with input from other federal agencies.[19]

Following the terrorism acts of September 11, 2001, DHS was created by the Homeland Security Act of 2002, which consolidated twenty-two agencies (including FEMA) into one single federal agency. DHS has a threefold mission: to lead the unified national effort to secure America; to prevent and deter terrorist attacks and protect against and respond to threats and hazards to the nation; and to secure the nation's borders while welcoming lawful immigrants, visitors, and trade.[20] The Top Official (TOPOFF) exercise, also directed by Congress in response to the September 11, 2001 terrorist attacks, was designed to strengthen the nation's capacity to prevent, protect against, respond to, and recover from large-scale terrorist attacks involving weapons of mass destruction (WMD).

In response to this directive, DHS has conducted two exercises for attacks by RDD. In 2003, the TOPOFF 2 exercise was conducted to simulate a terrorist attack involving an RDD in Seattle, Washington. In the TOPOFF 4 exercise of 2007, simulation of a full-scale response to multifaceted threats was conducted – a coordinated attack in Oregon, Arizona, and the U.S. Territory of Guam. The TOPOFF 4 exercise was based on the National Planning Scenarios,[21] designed for integrating federal, state and local partners in emergency planning (among the fifteen listed scenarios, Scenario 11 addresses a radiological attack by an RDD; the scenarios are now collapsed into a total of eight, with all chemical-related scenarios in one single core scenario, which is further differentiated by chemical agents in appropriate annexes per the Homeland Security Council). These exercises addressed policy and strategic issues involved in mobilizing prevention and response systems, and they challenged the ability of top officials to maintain a common set of operational goals during an incident of national significance. Following the TOPOFF exercises, the lessons learned were incorporated by DHS officials into the National Response Plan (NRP), which was later updated and then superseded by the current NRF in 2008. Both the NRP and the NRF were designed to provide guiding principles for a unified national response to disasters and emergencies.

In an effort to provide guidance for responding to terrorist events involving RDD or IND, DHS established an interagency working group in 2003, the Consequence

Management, Site Restoration/Cleanup and Decontamination Subgroup (of the Working Group on RDD Preparedness) to address the need for unified federal guidance on RDD-related issues, with participation from eight other federal agencies. Following several years of deliberation, the guidance entitled *Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents*, was issued in 2008.[22] The guidance provides PAG to support decisions on actions to be undertaken to protect the general public and emergency workers. The guidance includes information and regulations published by the EPA,[23] which has incorporated relevant recommendations from the Food and Drug Administration (FDA) and the Occupational Safety and Health Administration (OSHA).

The DHS PAG guidance on RDD and IND events generally follows the existing EPA PAG Manual for nuclear accidents. That is, the response is divided into three distinctive, yet somewhat overlapping, phases of an event. The *early phase* (or emergency phase) is the period at the beginning of the incident when immediate decisions for effective protective actions are required and when actual field measurement data are expected to be unavailable. It is generally associated with the initial plume passage and with short-term exposures. Priority is given to provide lifesaving and first-aid actions to protect public health and welfare. Response measures include such actions as sheltering or evacuation of the public, as well as decontamination and administering prophylactic drugs. The period of this phase may last from hours to a few days.[24]

The *intermediate phase*, which follows the early phase, is usually assumed to begin after the sources and releases are brought under control and field measurement data have become available for decision-making. The objective of the response is to prevent or avoid prolonged radiation exposure to the public. A high priority is given to such actions as restoring critical infrastructure or relocating the general public. The intermediate phase may last for weeks or months.[25]

The *late phase* (or recovery phase), which follows the intermediate phase, represents the stage at which residual radiation levels from the event are reduced to acceptable levels, allowing a return to a state of normality, which may last for many years following the event occurrence. The PAG issued by DHS contain specific dose limits for response actions in both early and intermediate phases, but do not recommend specific dose limits for the late phase. Instead, the PAG recommends the late-phase cleanup be achieved through a "site-specific optimization process." It states, "Because of the extremely broad range of potential impacts that may occur from RDD or IND…a pre-established numerical cleanup guideline is not recommended as the best serving the needs of decision makers in the late phase."[26]

Scope of Response and Responsibility

Responsibility for responding to RDD or IND incidents is currently specified under the NRF. The framework identifies the key response principles, as well as the roles of officials that organize responses ranging from local to regional to national levels.[27] The scope and responsibilities of federal support are further prescribed under the Emergency Support Functions (ESF) within the NRF; fifteen support functions are established for all FEMA-managed incidents have been identified with responsible federal agencies (in collaboration with state and local governments cooperating with them): (1) transportation,; (2) communication; (3) public works and engineering; (4)

firefighting; (5) emergency management; (6) mass care, emergency assistance, housing, and human services; (7) logistics management and resource support; (8) public health and medical services; (9) search and rescue; (10) oil and hazardous materials response; (11) agriculture and natural resources; (12) energy; (13) public safety and security; (14) long-term community recovery; and (15) external affairs.

For the late-phase recovery issues specifically, the primary responsibility for radiological cleanup falls under ESF no. 10 (oil and hazardous materials response) with EPA as the lead coordinating agency. For issues related to long-term cleanup, and depending on specific contamination situations, it is likely that the effort may also overlap other support functions that are led by other agencies (such as ESF 14 on long-term recovery led by DHS/FEMA), which would entail close coordination among these agencies in a particular response.

LATE-PHASE RECOVERY GUIDANCE AND CONSIDERATIONS

Cleanup Guidance

Late-phase recovery response has been recognized as an integral and important component of a national response to radiological incidents, but specific federal guidance has been lacking.[28] The DHS PAG guidance of 2008 represents the first prescribed by a federal agency on events involving terrorism. However, as noted above, in lieu of a specific PAG (such as a predetermined dose criterion for cleanup), a process was prescribed for deriving a long-term cleanup plan. It involves a site-specific "optimization" process, intended to bring a balanced approach to determining the appropriate cleanup criteria for the contaminated area. One key reason that no specific level was recommended for late-phase recovery is that the potential impacts of RDD or IND incidents vary widely from minor to severe, so it would not be practical to use predetermined criteria for the cleanup and site restoration efforts.

This is an important departure from the conventional statutory cleanup processes, which have established specific cleanup guidelines based either on radiation dose or health risk levels.[29] Nevertheless, any criterion chosen from the optimization process will still include consideration of existing federal statutory requirements on environmental cleanup (such as the EPA Superfund Program and the U.S. Nuclear Regulatory Commission's [NRC] rule on license termination), along with other national and international recommendations.[30] The final cleanup will likely be decided by a host of relevant variables to be taken into consideration, such as the extent and type of contamination, human and environmental health protection, technological feasibility, and costs, among others. The deliberation on cleanup goals and criteria will be conducted by a designated Planning Section Unit under the emergency management structure by incorporating appropriate technical entities and stakeholders in the decision-making process.

Discussed in the following section are the fundamental approach and key elements to be considered for developing the optimization process.

Optimization Process and Considerations

For late-phase response (i.e., long-term cleanup), the guidance prescribes a process for deriving a long-term plan, in lieu of a predetermined cleanup level, in which site-specific situations are properly balanced. This approach entails a site-specific optimization process for determining the appropriate cleanup criteria for the contaminated area. For example, cleaning up an extensively contaminated urban area (as one might postulate for an RDD or IND event) would entail considerable complex deliberations compared to cleaning up a contaminated industrial site (as often encountered in EPA Superfund activities). Among other things, there would be an overwhelming desire for the affected community (both for businesses as well as the general public) to return to its normal routines following a radiological event (from a highly interrupted state due to initial evacuation or subsequent relocation). This effort would necessarily entail considerations far beyond the scope that is currently encompassed in the Superfund cleanup process. The cleanup process pertaining to the event would thus warrant more flexible considerations and would take the form of a multifaceted approach, that is, the optimization process. Compared to either early- or intermediate-phase responses, the decision makers would have more time to deliberate on the late-phase recovery issues.

The primary goal of optimization is to establish societal objectives that include possible future land uses, cleanup options and approaches, technical feasibility, costs, cost-effectiveness, infrastructures, local economy, and ultimately public acceptance. For example, a small-scale incident (such as confined within a city block) may receive an expedited cleanup effort (using a simple, pre-determined approach), while an incident causing extensive contamination (e.g., affecting tens of city blocks in a major urban area) may warrant considerable effort (e.g., in terms of costs and time), thus influencing the decision on the final cleanup criteria.

The optimization approach is also exemplified in the selection of appropriate decontamination technology. A recent report by the U.S. Government Accountability Office (GAO) cites the importance of developing guidance for identifying cleanup methods.[31] The report pointed out that by not selecting appropriate cleanup technology, the decontamination effort may generate waste types that are more difficult to remove, thereby creating more wastes for disposal. For example, washing Cs-137-contaminated concrete walls with water may inadvertently enhance chemical affinity of the contaminant to the concrete surface, thus potentially increasing the quantity of waste generated (due to the need for additional decontamination efforts), in addition to creating secondary waste water streams. Or, applying chemical agents for decontamination may increase decontamination efficiency but also help generate mixed wastes (i.e., waste containing both hazardous chemicals and radioactive materials) that would increase costs for waste treatment and disposal. Thus a careful evaluation on the availability, effectiveness, and potential costs would necessarily entail a full understanding of the performance of a particular cleanup technology under consideration.

The concept of optimization has been advocated by international and national regulatory and advisory bodies, and is also commonly practiced by all levels of government in decision-making processes. The International Commission on Radiological Protection (ICRP) has prescribed basic principles for protection against radiation.[32] Of particular relevance is the fact that ICRP has advocated use of the principle of optimization of protection, which maintains that the likelihood of exposure, the number of people exposed, and the magnitude of individual doses "…should all be kept as low as reasonably achievable, taking into account economic and societal factors." This objective is commonly referred to as the ALARA (as low as reasonably achievable) Principle and has been affirmed by the National Council on Radiation Protection and Measurements (NCRP).[33] The ALARA Principle has thus been a requirement in all existing regulations for control of radiation exposures, including the statutes on cleanup of nuclear facilities. A "graded" approach recommended by the Presidential-Congressional Commission on Risk Assessment and Risk Management for environmental health risk management is also consistent with the optimization process and ALARA Principle.[34] The graded approach is directly applicable to the highly varied situations that are both event- and site-specific in cases involving RDD or IND. Implementation of the cleanup decision thus requires input from all relevant stakeholders, taking into account a broad set of long-term objectives.

Based on the above discussion, a number of areas have been identified as important for future development considerations. Such issues span from formulating applicable national policies, to advancing research and development in characterizing decontamination and cleanup technologies, improving understanding and ascertaining potential radiological impacts and implications, and finally, to developing effective decision-making processes and opportunities for stakeholder involvement. These are further discussed in the following sections.

NEED FOR FURTHER DEVELOPMENT

While the late-phase guidance developed by DHS offers a logical framework for the optimization process, it still lacks specificity and technical substance on how to reach cleanup decisions. In particular, given that the complexity of a cleanup is highly dependent on site-specific factors, several issues particularly critical to the decision-making process require more in-depth consideration; for example, (1) how to characterize the governing cleanup principles, (2) how to factor in event conditions and other relevant parameters, (3) how to identify and prioritize options, and (4) how to achieve consensus between stakeholders and decision makers. A host of relevant issues need to be fully evaluated in order to facilitate decision making, ranging from policy assessments, to a basic scientific understanding of cleanup technologies and their limitations, to public relationships and communication.[35] In fact, some of these problems have begun to surface in recent TOPOFF exercises.[36]

Formulating Appropriate National Policies

Although the scope and responsibility of the national response to events are well structured and prescribed under the NRF, individual policies that govern the operation of the responsible agencies in late-phase recovery have yet to be fully evaluated. The potential lack of coherent policies will likely hinder decision-making deliberations and therefore the efforts associated with site cleanup and restoration.[37] Since we have little experience in addressing major radiological terrorism incidents, an evaluation of the relevancy and applicability of existing policies is warranted. Important issues are property condemnation and economic assistance for the affected individuals and areas, waste storage and disposal, and recovery of critical infrastructure and facilities such as government buildings, major transportation arteries, and hospitals.[38]

Two policies that need to be determined are disposal of the radioactive waste created during cleanup and the finality of cleanup objectives. With regard to radioactive waste disposal, decisions must be made about the disposal location and required acceptance criteria. Large volumes of very low-level contaminated radioactive waste (LLW) could be generated. Valuable lessons have been learned from past nuclear events, discussed earlier in this paper, where the decontamination activities involved mainly the removal of contaminated soils and dismantling of the houses that were deemed unsafe for dwelling. For example, in the event involving a cesium source in Goiania, Brazil (1987), the stored low-level waste (based on an ad hoc standard of 2 mSv/h dose rate) from the cleanup activities reached a total of 3,500 m^3 (with a radioactive content of 1,375 Ci), which included contaminated soils, debris, and other materials.[39] A temporary waste storage was used as a staging location (it was unclear where the waste was ultimately disposed of, as there was not an available disposal site at the time of the incident).

This issue leads to consideration of expanding the current regulatory definition of LLW in the U.S. (substantially large amounts of LLW would be generated according to the current regulatory definition that contains no lower cut-off limits for radioactivity; in the Goiania case that limit was set at 2 nCi/g) and the possibility of using appropriate waste disposal sites (including existing commercial or government-owned radioactive disposal sites or alternative sites, such as local landfills for lower activity wastes).[40] Currently, there is an acute shortage of LLW disposal options in the nation. According to the Health Physics Society, "…the current shortfalls…are not attributable to any deficiencies in science or technology, but rather to the failure to garner the political resolve required to implement the Low-Level Waste Policy Act of 1980 (LLWPA)…as directed by Congress."[41] It would be prudent to identify and resolve such policy-related issues ahead of time. Toward this end, certain policies may need to be established in the process, including the possibility of invoking Presidential Executive Orders to expedite the disposal process (such as at DOE disposal facilities) as an emergency measure. Such policy issues warrant further deliberation and planning.

With regard to the finality of the cleanup, it will be important to evaluate the cleanup requirements in existence now and to determine how to ensure that a site will not be subject to further cleanup actions in the future. An optimization process cannot be created without a comprehensive understanding and full resolution of these and other potential policy issues.

Advancing Research and Development

A large amount of experience and knowledge has been gained over the past few decades from cleanup activities conducted under various statutory requirements (including EPA Superfund cleanup activity, DOE efforts to remediate its former nuclear weapons complex, and NRC efforts to decommission its licensed facilities). However, as discussed earlier, significant differences do exist; thus the direct applicability of such experiences to RDD- or IND-related incidents must be thoroughly investigated.

First on the list of concerns is the characterization of contamination. Current cleanup efforts tend to focus on alleviating the long-term contamination of groundwater (by emphasizing the subsurface transport) due to existing conditions such as subsurface contamination. On the other hand, the situation in an RDD or IND incident would primarily involve aboveground contamination and subsequent transport in the environment. Because of the relatively high mobility of many contaminants, factors that could influence redistribution of contamination are ground-to-air resuspension, particle-size distributions, human disturbance, and adverse weather conditions (i.e., weather effects on the characteristics and transport of contaminants). Analysis of these factors will entail applications of, and possibly changes to, current models of contaminant dispersion in order to adequately characterize the possible exposure scenarios in RDD and IND incidents.

Second, current knowledge of cleanup technology is generally limited to contamination of confined industrial areas, but not the wide-area contamination in a heavily populated metropolitan area that might occur in an RDD or IND incident. Examples for these specific applications do not exist today, as relevant events have not occurred. Yet one can get a glimpse of the potential magnitude of effort involved by examining the activities that have taken place following a major nuclear accident. In the case of the Chernobyl accident, for example, several different kinds of decontamination techniques were used.[42] These included flushing of buildings and paving, digging up and removing of soils, plowing of fields, and chemically treating building materials. A comparison of the effectiveness of these techniques for urban settings reveals large variations.[43] For example, while washing down the road (for dry deposition) was identified as being effective, the same technique was found to be ineffective for decontamination of building walls.

The variations under these circumstances have yet to be fully researched, verified and documented. In the aforementioned GAO report,[44] it was pointed out that current research efforts have focused mainly on predicting the effects of radiation release through simulation, small-scale testing, and theory, otherwise lacking full-scale field testing and verification. The report also calls for more research in developing standardized guidance for technology deployment and for cost-effective guidance on the efficacy and effectiveness of cleanup technology. The availability and applicability of such information needs to be well developed, compiled, and documented.

Third, the basic understanding of the fate and transport of radionuclides in the environment must be strengthened, particularly with regard to the modern urban environment. Examples include the surface water runoff from rain or washing from decontamination activities into drinking water or sewage systems, and the development of effective containment and treatment downstream from the event. More research is needed to provide such information in predicting the movement of contaminants in an urban environment that would serve to guide an effective response in the recovery phase activities. As in the case of technology discussed above, current knowledge in this subject area has not been specific to urban settings.

In summary, extensive scientific endeavors are needed to investigate the interrelated "real world" issues, rather than simply focusing on a single physical phenomenon. These efforts would include (1) tracking the movement of radionuclides in the environment (e.g., from the streets to transportation systems to the drinking water or sewage systems in an urban environment); (2) the continued propagation of such contamination beyond the area of deposition; and (3) the accumulation of radionuclides, such as those that might be encountered in an urban environment and that must be removed prior to reoccupation. A well-developed body of technology that is specifically applicable to event situations in urban settings would greatly help in formulating a sound cleanup strategy and thereby facilitate rapid recovery.

Improving Understanding of Potential Impacts and Implications

The important decisions leading to a long-term cleanup strategy would necessarily be risk-informed and aimed at achieving optimization. According to DHS guidance, the optimization process should include "potential future land uses, technical feasibility, costs, cost-effectiveness, and public acceptability." The DHS guidance further states that "Broadly speaking, optimization is a flexible, multi-attribute decision process that seeks to weigh many factors."[45] While many consider RDD as "weapons of mass disruption" (even if they lack significant destructive force, they have a great potential to spread radioactive contamination), the exact magnitude of their potential impacts on society has yet to be assessed with certainty because of the large variability in possible scenarios.[46] The potential impacts of IND incidents are even less certain,[47] although they would likely be of greater magnitude than those of RDD incidents, potentially causing some casualties as well as widespread, substantial, long-term contamination. Above all, inaccurate predictions of potential effects could adversely influence nuclear terrorism preparedness, leading to erroneous decisions.[48]

Aside from the potential impacts on human health, emphasis must be placed on characterizing the potential economic losses and the possible recovery costs (relatively large costs may be involved if a key metropolitan district is affected)[49] that an RDD or IND incident may inflict on society — a challenge for which a substantial DHS-supported research effort has been undertaken and for which further assessments are still needed.[50] Additionally, the potential psychological impact on society is another factor that has to be fully understood and characterized.[51] Other impacts also remain uncertain, including future land use options, waste generation and disposal, available cleanup technologies and approaches, public acceptability, and potential coverage of cleanup costs through insurance policies held by private property owners.[52]

The long-term cleanup would entail extensive input and evaluation in the context of optimizing site cleanup and restoration in the aftermath of an RDD or IND incident. Many of these issues are exemplified by, and have been manifested in, the major radiological accidents discussed earlier (specifically the radioactive source accident at Goiania and the reactor accident at Chernobyl).

Past experiences and the lessons learned from them reinforce the fact that there is an urgent need to develop a sound technical basis for applying optimization processes in late-phase recovery from a major radiological or nuclear terrorism incident. Research should be continued and also further expanded in areas identified as critical to developing basis for decisions in the process that is described in the following section.

Developing Effective Decision-Making Processes and Stakeholder Involvement

It is important to recognize that the optimization process for cleanup following an RDD or IND incident would be fundamentally different from the more familiar processes employed under the current statutory cleanup requirements. Superfund, for example, requires meeting a preset cleanup criterion or risk goal together with prescribed procedures (e.g., through the remedial investigation and feasibility study, together with five years of follow-up monitoring).[53] Most of the Superfund sites are located in industrial or suburban areas. The optimization process, on the other hand, is designed to address a far more complex issue than cleanup, since its predominant objective is to achieve a timely restoration of the affected site to "normality" (a condition that allows government and its citizens to resume their daily routines) following the creation of a highly perturbed state, particularly in a heavily populated metropolitan area.

Important considerations that must therefore be factored into optimized decision-making processes are identifying and mitigating potential health risks, addressing public financial burdens, restoring key infrastructures, and resuming normal commercial activities, as well as balancing the roles and interests of affected stakeholders. However, society as a whole has little experience with such processes.[54] Clarification of, and stepwise guidance for, developing and applying optimization processes would be helpful and is clearly necessary. While existing cleanup guidance may serve as a convenient benchmark, different cleanup criteria may result from application of an optimization process. A decision on any cleanup approach, of course, must be weighed against the potentially large costs to be borne by society.

Thus, achieving "optimization" requires a transparent approach backed by a sound rationale that satisfactorily reconciles the potential constraints in balancing acceptable health and environmental risk goals with the costs involved. The development of such an optimization process would be the key to implementing the PAG guidance recommended by DHS. Toward this end, one may view the existing statutory cleanup requirements as being an integral component of the overall optimization process, one that would only distinguish the event-related conditions from those unrelated to the events (such as Superfund) in a self-consistent deliberative process. Recent activities in the decision-making process for incident response may offer further information on this complex decision process.[55] However, a systematic approach will be required to develop a comprehensive framework and a more instructive process with illustrative examples, together with a sound scientific basis and an extensive stakeholder engagement, to achieve the objective.

SUMMARY AND RECOMMENDATIONS

On the basis of these considerations, it appears that the current guidance issued by DHS presents a starting point for the long-term cleanup of sites contaminated by an RDD or IND incident. Nevertheless, further clarification and step-by-step procedural details are still required for both the development and implementation of optimization procedures for setting cleanup and site restoration goals. The most important issue to be addressed is identifying and defining the underlying elements for developing the principles and approaches in an optimization process to support the framework outlined by DHS. Further developmental work is required to support decision making, ranging from policy, to technical know-how, to impact assessments, to stakeholder interactions. For further input, some of the major issues should be vetted through a series of future emergency exercises designed to identify and resolve late-phase recovery objectives in order to obtain meaningful feedback from stakeholders.[56] To this end, the effort should be devoted to developing a systematic approach that encompasses the following areas: (1) characterization of event scenarios, (2) development of viable alternatives, (3) decision framework and process, (4) technical basis and key parameter sensitivity, (5) stakeholder engagement and involvement, and (6) event- and site-specific considerations. The GAO has called for the development of a national disaster recovery strategy;[57] the optimization process should become a centerpiece of that strategy.

In recent years, national advisory bodies such as NCRP have devoted considerable effort to developing general guidance related to homeland security. NCRP, for example, has developed a considerable body of guidance on preparing for, and responding to, RDD and IND. This guidance includes NCRP Report No.138 (2001), *Management of Terrorist Events Involving Radioactive Material*;[58] Commentary No. 19 (2005), *Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism*;[59] and Commentary No. 20 (2007), *Radiation Protection and Measurement Issues Related to Cargo Scanning with Accelerator-Produced High-Energy X Rays*.[60] NCRP is currently preparing a report, *Responding to Radiological and Nuclear Terrorism: A Guide for Decision Makers*. Another report related to environmental remediation management is NCRP Report No.146 (2004), *Approaches to Risk Management in Remediation of Radioactively Contaminated Sites*.[61] The wealth of such information forms an initial basis for formulating decision-making actions involving response to RDD- or IND-related events. However, further development of the framework and guidance is necessary, particularly regarding decisions facing the daunting tasks associated with the aftermath cleanup activities following such an event.

Thus timely development of guidance on the late-phase optimization process as espoused by DHS is very much needed by society, preferably well before any unfortunate RDD or IND terrorism incident occurs.

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[1] U.S. Government Accountability Office (GAO), "COMBATING NUCLEAR TERRORISM: Preliminary Observations on Preparedness to Recover from Possible Attacks Using Radiological or Nuclear Materials," Testimony Before the Subcommittee on Emerging Threats, Cybersecurity, and Science and Technology, Committee on Homeland Security, House of Representatives, Washington, D.C. (September 15, 2009); "Dirty Bomb: Response to Threat," *FAS Public Interest Report, Journal of the Federation of American Scientists,* Vol. 55, , No. 2, 1–10, March/April 2002.

[2] Current statutory cleanup activities in the U.S. include the Superfund cleanup overseen by the Environmental Protection Agency, decommissioning of the nuclear facilities licensed by the Nuclear Regulatory Commission, and cleanup of the former nuclear weapons complex by the Department of Energy. Each of these programs has been operating in the order of multi-billions of dollars on an annual basis. The cleanup standards are currently based on radiation doses or health risks, with an aim to reach an optimal level that is deemed "as low as reasonably achievable." As such, it has become necessary for the responsible parties to closely engage the stakeholders throughout the cleanup process as a means of balancing the available budgets and achieving the cleanup goals.

[3] E. Eraker, "Cleanup After a Radiological Attack – U.S. Prepares Guidance," *The Nonproliferation Review* 11, No. 2 (Fall-Winter 2004): 167-185; B. Porfiriev, "Recovery Policy in Crisis Areas: The Risk Management Concept versus Normative and Administrative Approaches to Rehabilitation of the Radioactively Contaminated Areas in the Former Soviet Union," *Journal of Contingencies and Crisis Management* 7, Issue 2 (1999): 76–85.

[4] One confirmed case of attempted nuclear terrorism was conducted in Russia on November 23, 1995, when Chechen separatists placed a bomb containing radioactive cesium in Moscow's Ismailovsky Park. The bomb was not detonated; instead, the rebels informed a television station of its location; http://belfercenter.ksg.harvard.edu/publication/660/nuclear_terrorism.html. A. Goldfarb and M. Litvinenko, *Death of a Dissident: The Poisoning of Alexander Litvinenko and the Return of the KGB*. (New York: The Free Press, 2007). In November 2006, a former Russian Federal Security Service (FSB) officer Alexander Litvinenko was poisoned by radioactive polonium and died in London.

[5] M. Eisenbud and T. Gesell, "Experience with Radioactive Contamination Due to Accidents," chapter 12 in *Environmental Radioactivity – from Natural, Industrial, and Military Sources*, 4th ed. (Academic Press, 1997).

[6] International Atomic Energy Agency (IAEA), *INES – The International Nuclear and Radiological Event Scale*, User's Manual, 2008 ed., cosponsored by OECD/NEA (2008).

[7] J.S. Walker, *Three Mile Island: A Nuclear Crisis in Historical Perspective* (Berkeley, CA: University of California Press, 2006).

[8] IAEA, *INES*.

[9] IAEA, "Health Effects of the Chernobyl Accident and Special Care Programmes," *Chernobyl Forum Expert Group on 'Health*' (Vienna, 2006); IAEA, "Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendation to the Governments of Belarus, the Russian Federation and Ukraine," *The Chernobyl Forum: 2003–2005*, 2nd rev. ed. (Vienna, 2006); IAEA, "Environmental Consequences of the Chernobyl Accident and their Remediation: Twenty Years of Experience," *Chernobyl Forum Expert Group on 'Environment* (Vienna, 2006).

[10] M. Eisenbud and T. Gesell, "Experience with Radioactive Contamination Due to Accidents," chapter 12 in *Environmental Radioactivity – from Natural, Industrial, and Military Sources*, 4th ed. (Academic Press, 1997).

[11] IAEA, "Health Effects of the Chernobyl Accident and Special Care Programmes;" IAEA, "Chernobyl's Legacy."

[12] IAEA, "Chernobyl's Legacy;" IAEA, "Environmental Consequences of the Chernobyl Accident."

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[13] Ibid.

[14] Eisenbud and Gesell, "Experience with Radioactive Contamination Due to Accidents."

[15] IAEA, *INES.*

[16] IAEA, *The Radiological Accident in Goiania* (Vienna: IAEA, 1988).

[17] Ibid.

[18] Health Physics Society, "Background Information on 'Guidance for Protective Actions Following a Radiological Terrorism Event,'"Position Statement of the Health Physics Society (January 2004).

[19] Environmental Protection Agency (EPA), *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA 400-R-92-001 (1992). (Note: In a parallel effort to the DHS PAG guidance, the EPA is currently updating its PAG guidance for all radiological events and likely will incorporate DHS provisions on terrorism.)

[20] Information available at http://www.dhs.gov/xlibrary/assets/DHS_StratPlan_FINAL_spread.pdf.

[21] The *National Planning Scenarios* was issued under the DHS Secretary in 2006 under a directive on integrating the Federal Emergency Management Agency (FEMA) with state and local partners and national planning. The directive contains a total of fifteen all-hazard planning scenarios for use in national homeland security preparedness activities. The directive has since been updated annually.

[22] Federal Emergency Management Agency, Department of Homeland Security (FEMA), "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents," *Federal Register* 73, No. 149 (March 1, 2008): 45029–45049.

[23] EPA, *Manual of Protective Action Guides.*

[24] FEMA, "Planning Guidance for Protection and Recovery."

[25] Ibid.

[26] Ibid.

[27] Available at http://www.fema.gov/emergency/nrf/aboutNRF.htm.

[28] Eraker, "Cleanup After a Radiological Attack"; Porfiriev, "Recovery Policy in Crisis Areas"; Elcock, et al., "Establishing Remediation Levels in Response to a Radiological Dispersal Event".

[29] Current statutory cleanup activities in the U.S. include the Superfund cleanup overseen by the Environmental Protection Agency, decommissioning of the nuclear facilities licensed by the Nuclear Regulatory Commission, and cleanup of the former nuclear weapons complex by the Department of Energy. Each of these programs has been operating in the order of multi-billions of dollars on an annual basis. The cleanup standards are currently based on radiation doses or health risks, with an aim to reach an optimal level that is deemed "as low as reasonably achievable." As such, it has become necessary for the responsible parties to closely engage the stakeholders throughout the cleanup process as a means of balancing the available budgets and achieving the cleanup goals.

[30] FEMA, "Planning Guidance for Protection and Recovery."

[31] GAO, "COMBATING NUCLEAR TERRORISM."

[32] International Radiological Protection Commission (ICRP), *The 2007 Recommendations of the International Commission on Radiological Protection,* Publication 103, (Vienna: ICRP, 2007).

[33] National Council on Radiation Protection and Measurements (NCRP), *Limitation of Exposure to Ionizing Radiation,* Report No. 116 (Bethesda, MD: NCRP, 1993).

[34] Presidential Commission on Risk Assessment and Risk Management, *Framework for Environmental Health Risk Management,* Vol. 1, and *Risk Assessment and Risk Management in Regulatory Decision-Making,* Vol. 2 (Washington, DC: 1997).

[35] Eraker, "Cleanup After a Nuclear Attack;" Porfiriev, "Recovery Policy in Crisis Areas;" Yassif, J., "How Well Did TOPOFF 2 Prepare Us for Mitigating the Effects of a Dirty Bomb Attack?" *FAS Public Interest Report, Journal of the Federation of American Scientists* 56, No. 2 (Summer 2003).

[36] TOPOFF 4 Long-Term Recovery Table Top Exercise (T4 LTR TTX). Sponsored by DHS, Washington, D.C., Dec. 4–5, 2007.

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[37] Eraker, "Cleanup After a Radiological Event."

[38] Yassif, "How Well Did TOPOFF 2 Prepare Us?"

[39] IAEA, *The Radiological Accident in Goiania*.

[40] According to 10 CFR Part 61 ("Licensing Requirements for Land Disposal of Low-Level Waste"), low-level waste is defined as "radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in section 11.2 (e) of the Atomic Energy Act (uranium and thorium tailings and waste)." This definition applies specifically to waste generated in a nuclear facility. For waste generated by an RDD- or IND-related event on public property, a new, uniquely explicit definition would be required.

[41] Health Physics Society, "Public Witness Testimony for the Record by the Health Physics Society to the Committee on Energy and Natural Resources, United States Senate on Low-Level Radioactive Waste Oversight," September 30, 2004, http://hps.org/govtrelations/documents/hps_testimony_senate_energy_9-29-30.pdf.

[42] R.L. Demmer, "Large Scale, Urban Decontamination; Developments, Historical Examples and Lessons Learned," WM'07 Conference, February 25 – March 1, 2007, Tucson, AZ, http://www.wmsym.org/archives/2007/pdfs/7076.pdf.

[43] Ibid.

[44] GAO, "Combating Nuclear Terrorism."

[45] FEMA, *Planning Guidance*.

[46] "Dirty Bomb: Response to Threat."

[47] In recognition of some major differences between INDs and RDDs, the DHS acknowledges its continuing effort to develop separate guidance for the high-dose-rate zones expected to result from an IND. See *Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents; Response to Comments*, available at http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&o=09000064806a62f5.

[48] Robert Harney, "Inaccurate Prediction of Nuclear Weapons Effects and Possible Adverse Influences on Nuclear Terrorism Preparedness," *Homeland Security Affairs,* Vol. V, No. 3, September 2009.

[49] "Dirty Bomb: Response to Threat;" Eraker, "Cleanup After a Radiological Attack."

[50] Economic models and assessments have been developed by organizations such as the one supported by DHS, the National Center for Risk and Economic Analysis of Terrorism Events (CRETE), at the University of Southern California, Los Angeles, CA. See the CRETE Web site at http://create.usc.edu/.

[51] Eraker, "Cleanup After a Radiological Attack."

[52] Elcock, et al., "Establishing Remediation Levels."

[53] The Superfund cleanup process is a structured process geared toward final cleanup of a contaminated site. See the EPA Web site at http://www.epa.gov/superfund/cleanup/index.htm.

[54] Eraker, "Cleanup After a Radiological Attack;" Yassif, "How Well Did TOPOFF 2 Prepare Us?"

[55] C.B. Georges, M. McGeary, and S.R. McCutchen (eds.), *Assessing Medical Preparedness to Respond to a Terrorist Nuclear Event: Workshop Report* (Washington, DC: National Academies Press, 2009); NCRP, *Management of Terrorist Events Involving Radioactive Material,* Report No. 138 (Bethesda, MD: NCRP, 2001); NCRP, *Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism,* Commentary No. 19 (Bethesda, MD: NCRP, 2005); Homeland Security Council, Interagency Policy Coordination Subcommittee for Preparedness & Response to Radiological and Nuclear Threats, Office of Science and Technology Policy, *Planning Guidance for Response to a Nuclear Detonation* (Washington, D.C., January 16, 2009).

[56] A tabletop exercise on RDD events, the "Empire 09 Emergency Management Exercise," was conducted by the U.S. Department of Energy in 2009. Another exercise, the Liberty RadEx, coordinated by EPA is being planned for early 2010, will focus on the late-phase recovery issues from an RDD event.

[57] See note 2.

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[58] NCRP, *Management of Terrorist Events*. See note 55.

[59] NCRP, *Key Elements of Preparing Emergency Responders*. See note 55.

[60] NCRP, *Radiation Protection and Measurement Issues Related to Cargo Scanning with Accelerator-Produced High-Energy X Rays*, Commentary No. 20, (Bethesda, Maryland: NCRP, 2007).

[61] NCRP, *Approaches to Risk Management in Remediation of Radioactively Contaminated Sites*, Report No. 146 (Bethesda, MD: NCRP, 2004).