EMERGENCY RESPONSE GUIDANCE FOR THE FIRST 48 HOURS AFTER THE OUTDOOR DETONATION OF AN EXPLOSIVE RADIOLOGICAL DISPERSAL DEVICE

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Abstract—**Strategies and decisions to protect emergency responders, the public, and critical infrastructure against the effects of a radiological dispersal device detonated outdoors must be made in the planning stage, not in the early period just after an attack. This contrasts with planning for small-scale types of radiological or nuclear emergencies, or for a large-scale nuclear-power-type accident that evolves over many hours or days before radioactivity is released to the environment, such that its effects can be prospectively modeled and analyzed. By the time it is known an attack has occurred, most likely there will have been casualties, all the radioactive material will have been released, plume growth will be progressing, and there will be no time left for evaluating possible countermeasures. This paper offers guidance to planners, first responders, and senior decision makers to assist them in developing strategies for protective actions and operational procedures for the first 48 hours after an explosive radiological dispersal device has been detonated.**
Health Phys. 90(4):377–385; 2006

Key words: emergency planning; terrorism; aerosols; emergencies, radiological

INTRODUCTION

For more than twenty years, Sandia National Laboratories has conducted experiments on the aerosolization of radiological dispersal devices (RDDs). Their results and findings on the associated hazards have been published so that governmental authorities, such as emergency planners, first responders, and senior decision-makers can refer to this scientific literature to justify the technical basis for RDD emergency plans and procedures (Harper et al. 2006). The tenets of this research are summarized below as a background for this paper.

Over 500 explosive experiments were undertaken with more than 20 materials and 85 device geometries to determine the aerosol physics that are representative of what might occur from the detonation of an actual device. The tests were conducted in two chambers: an air-supported hemisphere with a volume of approximately 1,000 m^3 (Fig. 1), and a stainless-steel-lined, freestanding steel container of approximately 50 m^3 (Fig. 2). These chambers can accommodate 0.23 and 0.06 kg of explosive, respectively. In these experiments, the quantities of material used to simulate the radioactive material, the shock physics, and the aerosol physics are representative of what might occur in the detonation of an actual device. The chambers are large enough so that almost all of the aerosol generated remains in the air and is not deposited on the walls of the chamber following an explosive shot. The containments are small enough so that detectable quantities of the aerosol can be collected. The steel chamber is used when complete recovery of the larger fragmented material is desired, or if the quantities of aerosol anticipated would not be detectable in the larger volume of the air-supported building. Table 1 summarizes the tests performed with the materials of interest or with chemical surrogates. Harper et al. discussed the physics of aerosolization that can occur under many conditions and related the physical forms of the radioactive material to how the material might be dispersed. The aerosolization data were incorporated into the Explosive Release Atmospheric Dispersion (ERAD) effects model (Boughton and DeLaurentis 1992) to assess the relative consequences of different scenarios. ERAD is a first-principle buoyant rise model (designed to simulate the buoyant rise after an explosion), coupled with a Lagrangian probabilistic dispersion model (an appropriate method to simulate a plume composed of pure particulate matter). The results from ERAD, combined with health effects models and population data, then can be employed to assess impacts to personnel and

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(*Manuscript received* 23 *August* 2005; *revised manuscript received* 18 *October* 2005, *accepted* 30 *December* 2005)

0017-9078/06/0

Fig. 1. 1000 m^3 explosive aerosolization chamber with a capacity of 0.23 kg of high explosive (Harper et al. 2006).

Fig. 2. Aerosolization chamber—stainless-steel chamber with a capacity of 0.06 kg of high explosive (Harper et al. 2006).

the environment. These data were used in studies to assess the sensitivity of potential health effects to the size of the radiological source, the physical form of the source, the nuclide, and the dispersal device design; Table 2 gives examples of sources that represent the largest sources that could be obtained by most terrorist organizations. The sizes of the sources selected for the study do not represent absolute physical maximums of the material that could be obtained and do not represent the most likely sizes that might be seen in an RDD (Harper et al. 2006).

The sensitivity calculations were performed for eight high-priority radioactive materials, selected based on their potential to cause health effects, along with their global availability through their widespread use, storage, and production. Note that the International Atomic Energy Agency identified other radionuclides beyond these eight that are of concern (IAEA 2004); however, their

Table 1. Materials, physical forms, and number of devices tested to determine aerosolization properties (Harper et al. 2006).

Material	Physical form	Number of devices
Ag	Metal	17
Bi	Metal	3
Ta	Metal	1
Al	Metal	5
Stainless steel	Metal	2
Cu	Metal	2
Co	Metal	1
Mo	Metal	1
Pb	Metal	1
U	Metal	1
Ir	Metal	3
$SrTiO_3$	Ceramic (3 densities)	8
CeO_2	Ceramic (2 densities)	7
Tb/Pd	Cermet[a]	1
Co	Liquid	2
CsCl	Liquid[b]	6
$BaSO_4$	Slurry	1
MnO_2	Ceramic powder	4
UO_2	Ceramic powder	1
CeO_2	Ceramic powder	7
CeO_2	Pressed powder	3
CsCl	Powdered salt	7
$BaSO_4$	Powdered salt	2

[a] A physical mixture of ceramic and metals.
[b] Several different relative humidity and temperature combinations were investigated.

use in an RDD was deemed to be less effective and less probable than the nuclides selected. Based on the sensitivity studies, Harper et al. concluded that the primary exposure pathways for RDDs are groundshine, inhalation, and deposition on the skin, hair, and clothes. The relative importance of these pathways depends on the material and the geometry of the device. For example, cobalt metal is primarily a problem from localized groundshine, strontium titanate is principally an inhalation problem, while cesium chloride could be either one, depending on the design of the device. Table 3 summarizes these effects and hazard boundary analyses. The hazard boundaries were defined from the effects of the most conservative devices and scenarios.

PURPOSE AND SCOPE

The purpose of this paper is to apply the data described above in one specific application, an outdoor explosive aerosolization and dispersion of radioactive material, and to more specifically detail a set of practical guidance for the user community, i.e., planners, police, firefighters, hazardous materials technicians, and emergency medical technicians, who must enter the contaminated area to rescue injured victims, and protect critical infrastructure. It also is pertinent to Emergency Operations Center (EOC) crisis managers who will recommend protective actions to senior decision makers. While the guidance discussed in this paper is appropriate for the probable effects of an explosive RDD, it recognizes that there are some scenarios that exceed the hazard boundaries assumed in this paper, but are much less likely to occur, i.e., RDD geometries that are of "sophisticated engineering with a very large source" as defined by Harper et al. (2006). A "very large source" is significantly larger than 370 TBq (10,000 Ci).

The guidance offered also acknowledges that this situation is unlike routine conditions envisioned for an archetypical hazardous-materials emergency involving radioactive material, such as a vehicular accident. In contrast, it assumes this could be an extreme emergency, mass casualties and fire may be involved, panic may result, and critical infrastructure (electric and gas utilities, communications) is imperiled thereby worsening the crisis and putting many more people at risk of injury or inhibiting the responders. Furthermore, there is no time to analyze the state of the environment and the magnitude of hazards that are already present before taking action. Given this set of direful circumstances, most of the initial decisions on emergency-phase protective actions must be made prior to an attack and codified in first responders' operational procedures; also, such personnel must be trained before the event takes place.

Development of the guidance

The goal of this research is to provide (science-based response) recommendations to the U.S. Department of Homeland Security (DHS) to consider for use in community preparedness activities. These recommendations are being developed and are not official DHS policy.

As part of the research and development process, over two hundred potential users of the paper reviewed its tenets to assess their application in actual practice, and also to offer their expertise in optimizing the recommendations. With the help and guidance of local New York State, New York City, and New Jersey State regional authorities, focus groups of relevant professional disciplines were identified. These groups met in the New York-New Jersey region around New York City. Representatives from State and Federal and local government agencies, academia, and the private sector were invited, and the sessions were organized as follows:

- Fire/hazmat;
- Health/hospitals;
- Law enforcement;
- Private sector; and
- Senior decision makers.

By reaching out to many different potential users and user groups, the process encompassed a wide range of professional disciplines and evoked their respective

Table 2. Summary of sensitivity studies performed to assess the impacts of radiological dispersal devices and determine hazard boundaries (Harper et al. 2006).

Nuclide	Primary radiation type (half-life)	Primary form	Size of source for calculation, in GBq (Ci)	Application that forms the basis for size of source
^{90}Sr	Beta (28.6 y)	Ceramic ($SrTiO_3$)	1.11×10^7 GBq (300,000 Ci)	Large radioisotopic thermal generator (RTG) (Russian IehU-1)
^{137}Cs	Beta + ^{137}Ba Gamma (30.17 y)	Salt (CsCl)	7.4×10^6 GBq (200,000 Ci)	Irradiator
^{60}Co	Beta, Gamma (5.27 y)	Metal	1.11×10^7 GBq (300,000 Ci)	Irradiator
^{238}Pu	Alpha (87.75 y)	Ceramic (PuO_2)	4.92×10^6 GBq (133,000 Ci)	RTG used for the Cassini Saturn space probe
^{241}Am	Alpha (432.2 y)	Pressed ceramic powder (AmO_2)	7.4×10^2 GBq (20 Ci)	Single well-logging source
^{252}Cf	Alpha (2.64 y)	Ceramic (Cf_2O_3)	7.4×10^2 GBq (20 Ci)	Several neutron-radiography or well-logging sources
^{192}Ir	Beta, Gamma (74.02 d)	Metal	3.7×10^4 GBq (1000 Ci)	Multiple industrial radiography units
^{226}Ra	Alpha (1,600 y)	Salt ($RaSO_4$)	3.7×10^3 GBq (100 Ci)	Old medical therapy sources

Table 3. Range of specified hazard boundaries from point of release based on a realistic scenario analysis. Hazard boundaries with zero values mean that the selected dose limit was not observed for any scenarios (Harper et al. 2006).

		Realistic RDD hazard boundaries for varying device designs		
Selected dose limit	Significance of selected dose limit	Intermediate size source	Very large source	Very large source, sophisticated engineering
Groundshine dose of 1 Gy (100 rad), 24-h exposure assumed	Acute groundshine threshold—lower level where deterministic effects might be seen	0	~300 m	~300 m
Inhalation dose of 2.7 Gy (270 rad) to the lung (30-d committed dose)	Threshold dose for acute pneumonitis from inhalation	0	0	~2 km
Lifetime inhalation dose of 1 Sv (100 rem) (50-y committed dose)	Threshold dose for chronic radiation sickness. Chronic radiation sickness is defined as a clinical syndrome that develops in the case of long-term radiation exposure to cumulative doses of more than 0.7 to 1.5 Gy (70 to 150 rad) (Gusev et al. 2001)	0	0	~7 km
50 mSv (5 rem) groundshine dose (5-h exposure assumed)	Level at which emergency personnel can work unrestricted for 5 h	~100 m	~600 m	~600 m
10 times the annual limit of intake	Using Prussian Blue for a cesium internal uptake, or DTPA for a transuranic internal dose is highly recommended	0	0	<10 km
500 mSv (50 rem) (50-y committed dose)	Evacuation is suggested	<150 m	<1 km	~15 km
50 mSv (5 rem) (50-y committed dose)	Sheltering is suggested	<600 m	<3.3 km	<100 km
10 mSv (1 rem) (50-y committed dose)	EPA suggests initiating protective actions	2 km	~10 km	>100 km
20 mSv (2 rem) in one y—derived deposition limit	EPA prescribes relocation	8 km	~100 km	>100 km

skills and experience. Since these people are the eventual users, this approach provided an opportunity for them to contribute to how the scientific data and concepts were melded into a pragmatic tool that would best fit their needs. As a result of this strategy, the focus groups made significant constructive criticisms that were incorporated into the end product. The following were most significant concerns voiced by the focus groups:

- The optimization of the size of the initial evacuation zone;
- The strategy to apply sheltering and evacuation;
- The status of buildings' ventilation systems (i.e., should they be turned off?); and
- The management and triage of large numbers of evacuees who might be contaminated, or "the worried well."

DISCUSSION

High zone, medium zone, and low zone: definitions/evacuation during the emergency phase[‡]

The area impacted during the emergency phase by an explosive RDD where acute health effects are possible, as well as lesser affected areas that have levels of contamination that meet or exceed the criteria of 10–50 mSv for evacuation (U.S. EPA 1992), can be assumed to be bounded within a 500 m radius (Harper et al. 2006) and might be considerably smaller, depending on the amount of radioactivity in the weapon and the kinetics of the explosive. Accordingly:

a. If there is no knowledge of the size of the initial radiological source, or if it is known (from law-enforcement intelligence sources earlier) that the device contained a very large radiological source—greater than 370 Tbq (10,000 Ci)—establish a high zone boundary at 500 m in all directions from ground zero. Do not decide anything based on the perceived wind direction, especially in an urban setting where the wind field can be very complex. This boundary definition is consistent for both alpha and beta-gamma emitters;
b. Evacuate the high zone to control the dose to the population therein. Control access to the high zone to limit the number of non-contaminated persons entering the most contaminated area and exclude nonessential people;
c. Confirm the outer boundary of the high zone when the actual 10 mSv h^{-1} line is determined from instrument readings. In most cases, this will be much closer to the source than 500 m;
d. Define the outer boundary of the high zone at 10 mSv hr^{-1} because this has the advantage of establishing the point where emergency personnel can stay, unrestricted, for 4–5 h without exceeding 50 mSv from external exposure, unless a more pragmatic location further away reduces the dose rate to As Low As Reasonably Achievable (ALARA). But, for saving lives and protecting critical infrastructure, 10 mSv h^{-1} is an acceptable radiation level if occupancy near this boundary is necessary for the first few hours of the crisis. (Note: Even though the outer boundary of the high zone is recommended at the 10 mSv h^{-1} boundary, ballistic fragments or isolated high spots that greatly exceed 10 mSv h^{-1} could be located inside or outside the zone. For example, ^{60}Co in metallic form tends to fracture into large pieces and partially aerosolize (Harper et al. 2006);
e. If it is known (from prior law-enforcement intelligence) that the source is smaller than 370 Tbq (10,000 Ci), establish the initial high zone boundary at 250 m without waiting for measurements from instrumentation;
f. Once the high zone is defined, establish the outer boundary of the medium zone where the radiation level is in the range of 0.01–0.1 mSv h^{-1}. Definition of this boundary with this range gives first responders flexibility to set up the outer boundary of the medium zone at the most pragmatic locations, rather than being tied to an explicit exposure rate, i.e., 0.02 mSv h^{-1}. The inner boundary of the medium zone, $<$10 mSv h^{-1}, is the outer boundary of the high zone. The low zone is defined outside of the outer boundary of the medium zone such that occupancy time is unrestricted for the first responders;
g. Normally, establish the command post in the low zone upwind from ground zero or where the radiation or contamination level is less than 0.01–0.1 mSv hr^{-1}, or at 1,000 counts min^{-1} at 3 cm above the ground on a pancake type Geiger-Meuller type probe for a beta-gamma emitter, or 10 counts min^{-1} at 1–2 cm above the ground with a 100 cm^2 alpha probe. If geographical circumstances do not permit this from a practical standpoint, the alternative recommendation is to choose the location based on levels of ground contamination that limits the impact to personnel and equipment. This selected place might have dose rates up to 0.2 mSv h^{-1}, or 10,000 counts min^{-1} at 3 cm above the ground on a pancake-type Geiger-Mueller-type probe for a beta-gamma emitter, or 100 counts min^{-1} at 1–2 cm above the ground with a 100 cm^2 alpha probe.
h. As soon as possible, ensure that first responders promptly measure and record exposure rates to determine and map the rough profile of the groundshine and mark hot and cold spots. The latter will assist first responders to control their own exposure in the first critical hours; the former is the most critical piece of information that the local EOC will need to begin to assess the order-of-magnitude of the overall event;
i. Expect that the EOC will likely redefine the size of the evacuation zone after ground deposition is mapped over the 12–36 h after the event. This will probably occur after the outside emergency response personnel and resources arrive in the 12–24 h timeframe in accordance with the National Response Plan (U.S. DHS 2004). Radiation levels as high as 50 μSv h^{-1} and total dose equivalents of 20 mSv in the first year (exclusive of the first 4 d of exposure) could require a secondary evacuation order in accord with the U.S. Environmental Protection Agency's guidance for the

[‡] The terms high, medium, and low are generic ones. Some emergency planners use, equivalently, hot, warm, and cold, or control zones.

intermediate phase (U.S. EPA 1992). This impact is possible out to several kilometers from the point of release in some cases, but, regardless, it is likely to occur at some distance beyond the high zone defined for the emergency phase conditions; and

j. Based on the actual experience after the attacks on the World Trade Center, expect an orderly mass self-evacuation.[§] With that assumption, preplanning should channel self-evacuees to avoid their crossing the High Zone and to guide them along designated evacuation routes to predetermined exit points far away from ground zero.

Pre-designate several exits/triage/decontamination points to quickly channel evacuees

Triage and decontamination strategies should be developed separately from those used for chemical and biological agents. For the more probable scenarios, expect that the victims' clothes or bodies will not be dangerously contaminated, nor will they have inhaled enough radioactivity to cause acute health effects. This is in contrast to chemical or biological agents where the material still present on the victims could be immediately dangerous to them or others with whom they will subsequently have contact upon returning home or elsewhere.

While medically significant levels of contamination are not expected in the general population of uninjured contaminated persons, a small subgroup of high zone evacuees or some of the injured/contaminated victims possibly will need prompt decontamination due to potential acute effects from high skin contamination, and/or medical intervention to mitigate an inhalation exposure that could lead to acute health effects, i.e., acute pneumonitis may result from an alpha emitter, or hematopoietic syndrome from ^{137}Cs:

a. If possible, pre-plan to triage those who need decontamination at exits as far away from contaminated areas as practical;
b. Pre-position radiological monitors at exits; and
c. Assure that exit points are in areas of relatively low background, less than or equal to twice background, or at most, approximately 0.5 μSv h^{-1}.

Decontamination

Do not plan to perform mass decontamination if the number of evacuees is very large. For example, in New York City on 11 September 2001, approximately two million people self-evacuated:[§]

a. Allow personnel to go home and tell them to remove and bag their external garments before entering the dwelling. Few, if any, particles will penetrate outside clothing, especially if it is not summertime. Garments and jackets serve as effective protection from radioactive particulates;
b. Advise the persons who were contaminated, or think they may have been, to take a shower with warm water and mild soap, gently wash the exposed skin as practical (head, hair, hands), and to not use hair conditioner, which may fix the contamination;
c. Survey the bagged clothing after the emergency phase with support of outside emergency resources who will arrive during and after the intermediate phase;
d. Do not plan to decontaminate motor vehicles in the emergency phase; and
e. Do not waste effort trying to contain contaminated wash water (U.S. EPA 1992).

Triage

High external or internal doses and their associated acute radiation effects are unlikely for RDDs that incorporate only ^{241}Am, ^{252}Cf, ^{192}Ir, or ^{226}Ra because, typically, these materials are not available in the range of 4–40 TBq (kilocurie magnitude), such as other forms of radioactive materials commonly used in industry, research, and medicine, i.e., ^{60}Co, ^{90}Sr, and ^{137}Cs. Because of the associated high security and the lack of use in routine commerce and industry, the availability of a large enough quantity of ^{238}Pu or ^{239}Pu to produce a event comparable to one with 370 TBq (10,000 Ci) or greater of a beta-gamma emitter is considered improbable compared to one using ^{60}Co, ^{90}Sr, or ^{137}Cs.

First, separate those people who need medical consideration from those who do not (as practical). Assume that a person is not likely to have received a significant dose from inhalation without presenting gross external contamination at triage. Separate from all others those persons with upper body contamination, particularly of the shoulder, head, and hair. Assume that individuals with contamination only on lower portion of the body crossed the contaminated zone but were not exposed to the passing plume and did not inhale high airborne radioactivity concentrations. People with significant upper body contamination may require evaluation for follow-up medical treatment because they may have inhaled excess amounts of radioactive material. With help from the media, the EOC can seek those persons who were outdoors in the high zone, determined by its actual radiological footprint, but were not seen at a triage station. These two subgroups of people need to be evaluated promptly; they probably do not pose an urgent medical emergency, but should be treated as a medical

[§] Sheehan M. Private communication, Deputy Commissioner New York City Police Department, New York, NY, 2004.

priority. Countermeasures such as Prussian Blue need to be administered promptly, but not within a highly urgent timeframe as the medical situation is serious but not immediately dangerous to life.

Personal protective equipment (PPE) for the first responders

Because the initial plume will pass beyond the high zone in 10–15 min, most first responders will not be exposed to high airborne concentrations of particulates because they will arrive after it has passed or first encounter the plume downstream when concentrations have become diluted. Therefore, because the remaining levels of airborne radioactivity along with any additional contribution from re-suspension will be relatively low, the PPE requirements, as a minimum, are as follows:

- Uniform;
- Goggles;
- Gloves of any type; and
- Half-face air purifying respirator (APR) (most responders typically use a full-face one that affords more protection).

Supplied air respirators (Level A and B) are excessive for this level of hazard.

Improvised respiratory protection near the high zone

Improvised respiratory protection could be a beneficial ALARA technique provided that the public was informed about the practice before the event took place. Therefore, this issue represents a topic for discussion with the public in the planning stage rather than an emergency recommendation to be issued by the local health authorities. This countermeasure can be used to reduce inhalation during the approximately 10 to 15 min of the plume's passage. Using protection during this period is advised because of concerns about the ability of current technology to model urban canyon environments. Based on present knowledge, it cannot be categorically ruled out that respirable particles will not be caught for a longer time in a recirculation cell by a complex urban wind pattern,** although this is viewed as unlikely. For improvised respiratory protection, the following are recommended:

a. Cover the mouth and nose with a dry cloth or handkerchief (NCRP 2001). In some cases, wet material could actually enhance the amount of inhaled particles. For example, cesium chloride is water-soluble, and so a wet cloth could concentrate the radioactivity, as well cause labored breathing; further, there may be leakage around the edges of the damp cloth; and
b. Remove the protection 30 min after detonation.

Sheltering

Sheltering is not a critical countermeasure for an explosive scenario anywhere, although it can reduce exposure given the timing and location from ground zero. Sheltering during the passage of the plume can lower exposure, but sheltering beyond that time can entail an additional exposure when the airborne concentrations inside the buildings become higher than the outdoor concentration. Thus, this scenario could occur due to the intake by a large urban building's ventilation system of material from the passing plume, so that, afterwards, when the outdoor concentrations have significantly decreased, higher levels of particulates remain inside the building. Because it is impossible to know the actual phenomenology of the event during the phase of the plume's passage, it is exceedingly difficult to offer sound, coherent guidance on sheltering vs. evacuation. Except for people outdoors who experience the plume close to ground zero, all others who are indoors will encounter relatively low airborne concentrations, which reduces the importance of this countermeasure. Although a wide range of variability is expected, estimates suggest that the concentrations inhaled inside the building could be about 5% of those in the outside environment.[††]

Building ventilation systems

a. Ideally, the prompt shutdown/isolation of the air intake to a large urban building for 60 min post detonation would mitigate impacts to the occupants, the interior of the building, and the components of the ventilation system. For this countermeasure to be effective would require the building's operator to promptly be aware an RDD is associated with the explosion. If the building is not equipped with a radiation detector, it is not likely that the management will know there is airborne radioactivity in less than 10 min. In addition, most buildings do not have the ability to shut down an entire ventilation system with the "push of a button." Conversely, in some circumstances, the efficiencies of the filters can be significant, removing >90% of the material, depending on the particle size, the condition of the filter, and its design (U.S. DHHS 2003). In cases where the ventilation can be isolated or shut down, there is a possibility that a "chimney effect" could take place, drawing unfiltered air into the structure, a condition that would be counterproductive. Therefore, for most

** Brown M. Private communication, Los Alamos National Laboratory, Los Alamos, New Mexico, 2005.

†† Thatcher T, Delp W. Private communication, Lawrence Berkeley National Laboratory, Berkeley, California, 2005.

Table 4. Emergency dose limits (EPA 1992; NCRP 2001).

Dose limit (mSv)	Activity performed	Conditions
50	All	None
100	Protecting critical infrastructure	Only on a voluntary basis where lower dose limit is not practicable
250	Lifesaving, protection of large populations (EPA 1992), or protecting critical infrastructure which, if not mitigated, could place public's health at risk	Only a voluntary basis where lower dose limit is not practicable
500	Lifesaving or protecting of large populations (NCRP 2001)	Only on a voluntary basis to personnel fully aware of the risks involved

Table 5. Dose rate recommendations for emergency conditions.[a]

Dose rate recommendations		
Personnel decontamination trigger[b]	For beta-gamma contamination, two times background with background <0.5 μSv h^{-1} (counts m^{-1} or μSv h^{-1}) For alpha contamination, any detectable activity	
Medium zone outer boundary	0.01–0.1 mSv h^{-1}	Green
High zone outer boundary	10 mSv h^{-1}	Yellow
Work in high zone	10–100 mSv h^{-1}	Yellow
Turn-around dose rate for non-life-saving	100 mSv h^{-1}	Red
Turn-around dose rate for life-saving and critical infrastructure	2 Sv h^{-1}	Red
Only volunteers fully informed of the risk may proceed	>2 Sv h^{-1}	

[a] Adapted from WMD/Non-FNF Incident Response Plan and Procedures, Rev. 1, July 2004, Washington State Department of Health, Office of Radiation Protection, Internal Document.
[b] If large a population is potentially contaminated, they should not be held up near ground zero for triage or decontamination, but rapidly evacuated to avoid dose from groundshine.

modern large buildings, intervention via the ventilation system is not likely to be an effective countermeasure; and

b. It is advisable to keep away from the contaminated filters and not access their enclosures until health authorities perform a radiological assessment.

Emergency dose and dose-rate guidelines

Table 4 shows the emergency dose limits consistent with U.S. EPA (1992), with one exception. The dose limit for persons who are properly informed of radiological risks was made consistent with NCRP (2001). Because the consequences of an RDD could be much more extensive than those of an archetypical accident with hazardous materials involving radioactive material, mass casualties may have occurred, and/or the damage and continuing degradation to critical infrastructure might have created the potential to cause more deaths; hence, there may be a need for an incident commander to exercise the option to allow a few well trained and informed first responders to accrue significant doses. Evoking this option will maximize efforts for saving lives in the first few hours of an emergency.

Table 5 gives a simple set of guidances on dose rate.[‡‡] Similar to the guidance on dose limit, the dose rates were chosen to facilitate first responders in maximizing their life-saving efforts.

CONCLUSION

The recommendations made in this document are based on source-term data that recently were made public so that planners and decision makers have peer-reviewed information on which to base policy and procedures. The information in this paper, along with the scientifically founded and realistic definitions of hazard boundaries made by Harper et al. (2006), can be employed to reduce uncertainties and unnecessary conservatism in RDD emergency-response planning. The guidance offered is based on the probable effects of an outdoor explosive RDD, recognizing, however, that less probable but possible effects could be engendered. The guidance also was based on the most probable case vs. the worst case possible. Since the existing chemical and physical forms of the eight

[‡‡] McBaugh D, Lawrence C, Schwab K, Leitch J, Poeton R. Protective action recommendations for a radiological dispersal event, Washington State Department of Health, Internal Document.

radioactive materials in Table 2 directly bear upon their aerosolization properties, reengineering the composition of sources manufactured for use in industry, research, and medicine in the future could be another effective countermeasure to reduce the overall impact of an RDD to the responders and the environment.

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Acknowledgments—The DHS Office of Science and Technology funded this work and we appreciate the support of, and guidance from, Anthony Fainberg and Brooke Buddemeier. We acknowledge the valuable contributions of New York and New Jersey officials who helped facilitate and took part in the Focus Groups held in New York City and New Jersey. This project could not have succeeded without their enthusiasm and dedication. They are Kevin Clark, New York City Office of Emergency Management; John Searing, Fire Chief, Brookhaven National Laboratory; Michael Sheehan, Deputy Commissioner Counter Terrorism Bureau, New York City Police Department; Ronald Stryker, New Jersey Domestic Security Preparedness Task Force; and Dani-Margot Zavasky, Medical Director Counter Terrorism Bureau, New York City Police Department. We extend our appreciation to Mike Brown of Los Alamos National Laboratory, and Tracy Thatcher and Woody Delp of Lawrence Berkeley National Laboratory for their valuable technical advice on urban dispersion. Beverely Simspon from the Los Alamos National Laboratory assisted and contributed to all of the Focus Group meetings. Adela Salame-Alfie of the New York State Bureau of Environmental Radiation Protection and Robert Greger of the California State Department of Health Services made helpful technical suggestions. Rita Rosen and Al Cavallo assisted with the planning and logistics for the meetings held at the Environmental Measurements Laboratory.

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