Special Contribution

Explosions and Radioactive Material:

A Primer for Responders

Jeffrey W. Runge, MD, Brooke R. Buddemeier

Abstract

A comprehensive primer on the threat posed by radiological dispersion devices, or "dirty bombs," and the management challenges for first responders is presented. The discussion is scenario-driven, presenting guidance for medical responders as to triage and treatment priorities in the face of radiation risk. Key questions are posed that present the need for operational and tactical planning, equipping, and training around this scenario. Decontamination priorities and potential medical management are discussed for both victims and responders. **Key words:** radioactivity; explosions; blast injuries; disaster planning; terrorism; cesium isotopes

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Dr. Runge is a consultant to the private sector in biodefense, medical preparedness, and injury control. Mr. Buddemeier supports the federal government in radiological and nuclear disaster preparedness.

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Address correspondence to: Jeffrey W. Runge, MD, 8000 Greenwich Woods Drive, McLean, VA 22102-1332. e-mail: jeffreywrunge@gmail.com

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Introduction

Emergency responders, police, firefighters, and emergency medical professionals are confronted daily with people in distress from injuries, both intentional and unintentional. After years in the street or the emergency department, the wide mix of injuries and their causes take on a certain routine character, no matter how bizarre. Whenever a group of seasoned response professionals or emergency physicians get together, there is almost no scenario that one of them has not encountered. People always do the best with actions they take every day. "Practice makes perfect," whether it is a jump shot, a golf swing, or threading a 16-gauge intravenous (IV) line in a "shocky" patient. Repetition breeds perfection.

So it is no wonder that the things we fear the most are the uncommon situations that may have catastrophic results. So it is with radiological emergencies. The average field responder or emergency manager will probably never see one in a career or a lifetime. And the idea is scary. Radiation cannot be detected without special instruments, and it takes some knowledge of physics to understand how it works. But the public expects that its emergency responders "expect the unexpected" and have prepared and trained to manage even uncommon events that may threaten the health and well-being of a community.

The goal of teaching emergency medicine is to use patterns and clusters to simplify the infinite range of patients for whom its practitioners are responsible. Although multiple articles have been written and published on the subject of radiological emergencies, this article will discuss the scenario in terms of what matters most to the early responders: "What do I need to know? What do I need to do? What equipment do I need to do it?" And we should add "How is it like what I do every day?"

TERRORISM VS. RESILIENCY

Terrorism depends on the fear of the unknown. It is that fear and the surprise of the unexpected that create terror. Conversely, lack of fear and preparation for even rare or unexpected events create a resilient population. Our first responders, at the tip of the spear, need to respond fearlessly and prudently if the public is to have faith in our governmental institutions.

Given that emergency responders must maintain proficiency in managing the events they handle every day, it is difficult for busy people to devote additional time to prepare for "low-probability" events, even those that may have high consequences. Today every police officer, firefighter, and emergency medical technician (EMT) has had instruction in various scenarios involving bugs and bombs. Whether disaster training is a one-hour incident command training class or a full week dedicated to hazardous materials (hazmat) and chemical attacks, it is nevertheless difficult to internalize lessons without having had the experience. But the fact is for medical responders, handling radiological emergencies is not that much different from what they do and do well every day.

It is still important to plan and train for the differences among disaster scenarios. Much of the success of the response to the 800 injured people in the Murrah Federal Building bombing in Oklahoma City was the planning and recent homeland security preparedness training and exercising they had undertaken at the National Fire Academy just prior to the bombing.[1] Even though America had very little experience with domestic terrorism, there had been an attack on the World Trade Center in 1993 and prudent emergency managers all over our nation were preparing for the unlikely. In the wake of the September 11, 2001, attack (9/11), no one would dream of doing less.

Today we know that the enemies of the United States are willing and able to carry out attacks on our homeland. This enemy is patient and may attack when we are perceived to be most vulnerable. What is often called a "low-probability event" may not be as low as we would like to think. Many in the homeland security and emergency response communities wonder why some of those scenarios have not happened already. For example, the so-called "dirty bomb" attack is relatively simple to execute, given that radioactive material is extensively used in industry and medicine.

When the bomb goes off, it should not be a surprise. The execution of our emergency response should be as predictable as it is for a car crash on the interstate. We will know what to do, what equipment to use, and how we put our everyday skills to use. It will not be terrifying. That is resiliency.

DIRTY BOMBS: WHAT THEY ARE AND WHAT THEY ARE NOT

The term "dirty bomb" is jargon that is not well understood by the public and many in the responder community. The widely used technical term for a dirty bomb is *radiological dispersion device* (RDD). But the term "radiological dispersion device" understates the problem. A dirty bomb does more than disperse radiation. The explosion itself can cause a number of casualties, all of whom will need attention from medical responders and hospitals. The "bomb" part of a dirty bomb—blast injury, kinetic trauma from flying debris, search-and-rescue requirements—presents a more immediate threat to the health and welfare of the victims than the radiation. It is first a blast problem, with some added requirements and protocols.

Unfortunately for our times, the term *improvised explosive device* (IED) is well understood by the public. The term "improvised explosive device" often comes with modifiers, such as "vehicle-borne" (VBIED), "radio-controlled" (RCIED), including cell phone–detonated, and "victim-operated" (VOIED), or booby traps. So perhaps a more accurate, descriptive term for a dirty bomb would be "improvised explosive device with radioactive material." (One thing the world does not need is another acronym, but the need for the term IEDRM is indeed compelling.) For this discussion, when we refer to a "dirty bomb," we mean an IED with radioactive material.

What a dirty bomb is *not* is a nuclear device. The radioactive material involved does not, in any way, enhance the kinetics of the explosion; it does not cause atoms to split, it does not make a brighter flash or a bigger boom. It is also *not* a nuclear power accident, around which much of the nation's planning and radiological incident management have been built. A dirty bomb would not kill any more people acutely than would be killed by an IED without the radioactive material. The use of radioactive material in the bomb makes treating victims slightly more complex because of their external and possibly internal contamination. It may slow down response because of responders' discomfort with radiation or lack of preparation for dealing with potential contamination. Depending on the isotope, the radioactive material can also cause an environmental disaster for a city and the businesses and homes affected by the contamination, resulting in long-term evacuation. For that reason, RDDs have popularly been referred to as "weapons of mass disruption." The destruction may be well localized, but the disruption of our daily lives—the economic consequences and the loss of confidence in our security—could have long-term effects.

What makes a bomb "dirty"? Any common industrial or medical source for radiation may be used to "dirty" a conventional explosive. Radiation sources are used for medical diagnostics and therapeutics and for multiple industrial applications. Although the sale and distribution of radioactive material are regulated by the federal government, there have been many open press reports of stolen radioactive material. In 1998, for example, 19 sources of cesium-137 (Cs-137) disappeared from a radiation therapy unit in North Carolina and were never located.[2] In Volgograd, Russia, smugglers stole containers of Cs-137 from an oil refinery to sell on the black market.[3]

The cesium-137 isotope (Cs-137) is most commonly used for a dirty bomb scenario for the purposes of planning, training, and exercising, including the federal government's Top Officials Exercise 4 in October 2007. Cs-137 is an isotope commonly used in medical applications, such as radiation therapy or irradiation of blood products.[4] Although Cs-137 sources are most often encapsulated in stainless steel, the material itself is often found as a powder (cesium chloride). With a half-life of up to 30 years, it could contaminate the environment for generations if steps are not taken to recover the area.

Isotopes of other elements are also in wide industrial use, such as americium, cobalt, iridium, and strontium, any of them causing similar contamination effects. Any of these is potentially available to a terrorist. Each of them has its own set of unique characteristics, but the initial protocols of the responders would not differ regardless of the isotope in the bomb. According to the National Research Council, "out of the thousands of manufactured radionuclides, americium-241, cesium-137, cobalt-60, and iridium-192 account for nearly all (99 percent) of the sealed sources that present the highest security risk for the United States. Of the radionuclides mentioned above, cesium-137 in the form of cesium chloride is a greater concern than other radiation sources based on its dispersibility and presence in population centers across the country."[5] So for the sake of keeping this discussion simple, we will use the scenario of an IED with Cs-137.

The source of Cs-137 available in medical equipment is about the size of a soup can, so one could easily be incorporated into a backpack or a VBIED. There are certainly hazards inherent in the handling of the source that may result in injury or death, but this may not be a barrier for an enemy willing to use people for suicide missions. Although some knowledge of the source material properties is needed, any perceived lack of technical capability of the handlers is not a limiting factor.

Scenario

It is an autumn day with a clear blue sky and a light breeze; temperature is in the 50s (Fahrenheit). A husband and wife enter the "International Destinations" line at a crowded international airport at 3:00 pm, the busiest time of the day. They have several large pieces of luggage on an airport trolley. As they work their way through the line, they find themselves surrounded by thousands of would-be travelers in the long airport atrium checking in, getting boarding passes, and queuing up to go through security.

"Attention all units: Major explosion reported at International Airport. All available units, be en route. Mutual aid requested. Stand by for further."

You happen to be riding back to your station from the hospital and are only 5 miles from the International Airport. You arrive at the airport to see the façade of the building leveled for a width of about 75 yards. Flames and smoke are obscuring the central part of the damaged area and the air is filled with dust for hundreds of yards around. You note deceased victims, body parts, and clothing strewn among the debris. There are people running from the scene toward your truck, many of whom are wounded and burned.

What is Your First Course of Action and How Are Subsequent Courses of Action Determined?

The purpose of this paper is not to review all the tenets of disaster medicine. Every professional provider should be certified in the National Incident Management System (NIMS) and facile with incident command principles, and confident that those principles will be adhered to during an incident. Online training in NIMS is available through the Federal Emergency Management Agency.[6]

The local disaster plan should have a predesignated incident commander and a safety officer who can direct protective actions for responders and victims. Most large jurisdictions have a mobile command post that would be established as the emergency operations center (EOC) is being set up. What makes all this work is *situational awareness.* For responders first on scene, the importance of providing situational awareness to decision makers cannot be overestimated, nor can the value of staying informed and maintaining your own situational awareness.

What Are Your Priorities?

Every provider is trained in the principle "First, do not become a victim." The first job is to figure out quickly how to work safely in a hazardous environment. You will have placed your vehicle and equipment out of harm's way at a safe distance upwind of the blast scene. You have no reason to believe that the dust contains anything but the usual blast debris, but since you do not know the contents—asbestos, organic matter, concrete, and dust are all possibilities—you should use respiratory protection for yourself in addition to your gloves and turnout gear. Supplied-air suits are not necessary unless dictated by other, nonradiological hazards, but everyone should have access to an air-filtering respirator or even a particulate mask.

You will undoubtedly begin to try to help as many people as you can as resources make their way to the scene. You will have already considered setting up triage collection points well away from the danger zone. You will use your supplies as you need them on the most seriously injured but salvageable victims. You will recruit lay people to help you with basic first aid—maintaining patent airways, stopping bleeding with pressure, and keeping people as warm as they can until more help arrives.

What Skills and Equipment do You Need to Manage Multiple Patients with Burns, Penetrating Trauma, Deafness, Blindness, and Blast Injury?

Although explosions of the magnitude in this scenario are uncommon in the United States, they are not rare around the world. There have been mass-casualty bombings in Madrid, London, Tel Aviv, and Mumbai since 2004. In a post-9/11 environment, the principles of blast injury recognition and treatment from high explosives should be part of every responder's basic curriculum. Low-yield bombs and industrial explosions are far more common and may present similar injury patterns to this scenario, depending on a victim's location relative to the blast. The Centers for Disease Control and Prevention (CDC) and the American College of Emergency Physicians have made a brief course in blast injuries available online.[7]

Scenario Continued

The fire services have their equipment approaching the buildings to fight the fire when you hear over the radio "Attention, radiation hazard has been detected. Repeat...."

Does This Change Your Priorities?

Does This Change What You do to Protect Your Health and Safety?

How Does This Change Your Triage and Treatment of Patients?

What Does This Mean For Scene Control?

Do You Have Everything You Need at the Local Level to Manage This Scenario?

This announcement from incident command has just turned an extremely challenging scenario for a trained responder professional into a much more complex one. It just changed from a large volume of patients of the type you care for every day into a first-time experience. There is no time to pull the training manual off of the shelf.

But this added information need not paralyze the response. The priorities you had before the announcement have not changed: *Help as many people as you can with the resources you have, and do not become a victim.* The principles of disaster field triage remain the same, but in this case, no one can be dismissed as "well" and allowed to leave the scene without decontamination or explicit instructions on self-decontamination.

It is useful to review certain points that are worth remembering to guide responders' judgment during this scenario:

- In this scenario of debris contamination, simply removing their outer clothing reduces their dose by 90%.[8]
- It is extremely unlikely that any victim would have a high enough level of contamination to prevent rescuers from tending to high-priority injuries, especially if caregivers are using barrier skin and eye protection and respiratory protection.
- In the rare instance that shrapnel from the radioactive source becomes embedded in a patient, the source could present a hazard to the victim and caregivers with prolonged contact.[9]
- Caregivers and other responders in the proximity of the blast zone should use radiation detection equipment to identify hazard zones and track exposure.
- After a patient is stabilized, and as resources and time permit, efforts should be made to reduce or contain external contamination before transferring the patient to the next point of care.
- Simple techniques for removing clothing and decontaminating skin can further reduce small contamination risks to caregivers and the environment.
- The use of standard personal protective equipment (PPE) provides caregivers sufficient protection from contamination.
- People who have been exposed to radiation do not become radioactive or contaminated. They present no potential for harm to caregivers.

Does This Change Your Priorities?

While the additional factor of radiological contamination does not *change* your treatment priorities, it *adds* a layer of protocol to an already complex situation. A key premise is that radiation is not a medical emergency. Treatment priorities at the scene and in the emergency department do not change because of the presence of radiation. There are additional considerations for *contamination*, but treatment priorities do not change.[10] A consensus position developed by the Health Physics Society in 2004 states that "Lifesaving actions and actions to secure the area of a radiological terrorist event from further terrorist activities should take precedence over radiological considerations following a radiological terrorist event..." such as an IED with Cs-137.[11] The background information for that position makes the case that it is "extremely unlikely that [an RDD] can disperse sufficient radioactive material for the resulting air and ground contamination to pose an immediate personnel health hazard to people in the area or first responders."[12] That does not mean that the risks of radiation can be ignored. Rather, simple interventions with the patient and protection for caregivers are indicated.

Does This Change What You do to Protect Your Health and Safety?

In preparing to intervene with victims of a blast, you will already have donned PPE or turnout gear. Because of dust and debris, you will already have employed respiratory protection with a barrier mask or air-purifying respirator, such as N95. This equipment is generally all you need to prevent significant contamination of response personnel in the wake of an IED with radioactive material. Supplied air respirators (Level A or B) are not necessary and may hamper patient treatment. You should also not eat or drink in the area of dust and debris, not always easy on a 90°F day in turnout gear, and try to get away from the immediate scene to maintain hydration. While the use of a mask is prudent, most of the potentially contaminated dust and smoke will clear from the air fairly quickly, often before responders arrive.[13,14] Thus, the respiratory precautions you would take for working in non-radioactive dust and debris are sufficient.

Caregivers may have concerns about treating people who have ingested or inhaled or are contaminated with a significant amount of radioactive material. Experience shows us that there is no appreciable risk from caring for patients who have received doses of radiation, including those who are internally or externally contaminated. While internally and externally contaminated patients may cross-contaminate or excrete the radioactive material in their body fluids, the universal precautions used for infection control are all that is necessary to protect health care workers from radioactive material uptake.

This was demonstrated during three different examples of caring for contaminated patients. In the case of the Alexander Litvinenko poisoning in England, health care workers cared for him after he was severely contaminated internally by ingestion of polonium-210 (Po-210). His caregivers did not receive any exposures of concern, despite the fact that the victim was in the hospital for more than two weeks before the radioactive nature of the poisoning was discovered.[14]Po-210 is an alpha emitter, which can be a hazard only if it is inhaled or ingested. Thus the risk to caregivers would be only through accidental contamination and uptake from sweat, blood, urine, or feces. A more apt example for our Cs-137 scenario would be the cases of Goiânia, Brazil (discussed later in the paper), and Chernobyl, both of which involved emissions of penetrating gamma radiation. Gamma radiation can be a hazard due to direct exposure as well as cross-contamination and uptake from sweat, urine, and feces. In Goiânia, all personnel caring for the patients were monitored for radiation exposure using badges and finger dosimeters for skin contact. No one received over 0.5 rem (roentgen equivalent man) of radiation, which is 10% of the annual occupational exposure limit.[15] When workers at Chernobyl who were in the reactor area at the time of the nuclear accident were decontaminated, the medical personnel at the site received less than 1 rem of radiation, 20% of the annual occupational exposure limit.[8]

In order to guide emergency evacuation and treatment during the acute rescue phase, zones of radiation hazards will be designated by field personnel using real-time radiation measurement devices carried by the hazmat team in every major city. Exposure and radioactivity levels of 100 mSv/h (millisieverts/hour) (10,000 mR/h [milliroentgens/hour]) or higher have the potential to produce acute radiation injury to victims and rescue personnel. This level of radiation would define an inner perimeter, called the "high-hazard zone." Activity within this area should be restricted to rapid, time-sensitive, mission-critical activities such as lifesaving[16] using "scoop and run" techniques. A larger area will be designated the "hot zone" inside a "hot line" of 0.1 mSv/h (10 mR/h).[17] Within the "hot zone," the public should be evacuated and emergency workers' time in the area should be minimized, and they should follow appropriate personal protection guidelines. Within the hot zone, but outside the high-hazard zone, a responder may work for several hours or more without exceeding federal guidelines for occupational exposure for rescuers. Outside the outer boundary of the hot zone, there are no time restrictions on personnel to stay and work.

Since you are a first responder to the scene, there will not have been an established zone of safety defined, but science has provided a rule of thumb. Hundreds of studies in real blasts and modeling have been performed by the Sandia National Laboratory in order to provide estimates of the effects of such a bomb.[13] Based on these studies, when the size of the radiological source is unknown, the edge of the high-hazard zone should be temporarily set at 500 meters. When radiation readings are taken, the borders of these zones will likely contract, so it may be possible to get closer to reach more victims with equipment and people.

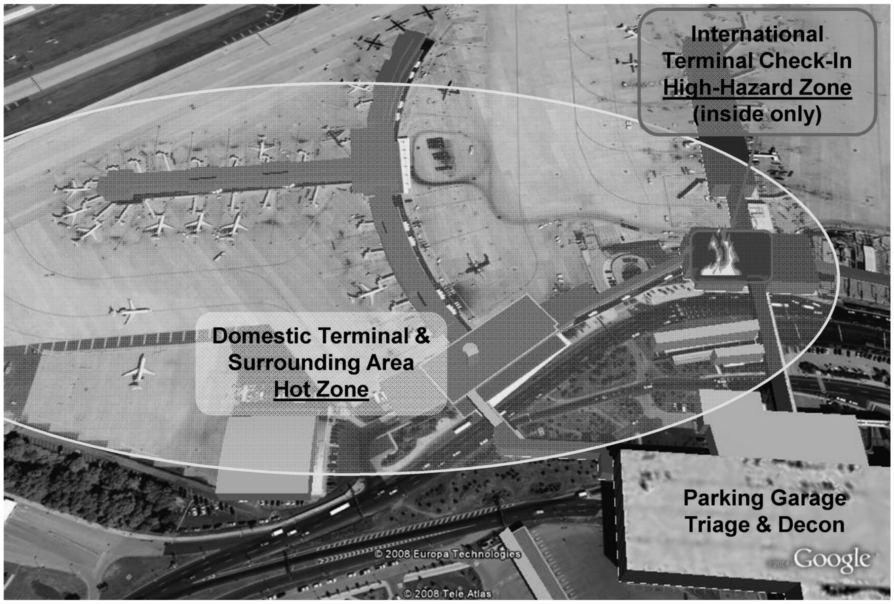

FIGURE 1. Examples of zones in the scenario discussed: Red indicates the high-hazard zone. Yellow indicates the hot zone. Ample opportunities for staging, triage, collection, and decontamination exist outside the hot-zone boundary. (Graphic from Google Earth used under its "fair use" policy.)

Scenario Continued

For our airport terminal scenario, the high-hazard zone (Fig. 1). *was confined to the international terminal check-in indoor atrium area. Although the windows were blown out (causing significant glass projectile injury), the inner boundary exposure rates of 100 mSv/h (10,000 mR/h) were not detected outside the structure. Initial casualty collection points were fortuitously staged outside the building because of structural stability and falling glass concerns, but there are still several hundred people in the building, many of whom are injured.*

The hot zone, defined by the 0.1-mSv/h (10-mR/h) hot line, is more extensive and extends a kilometer downwind and encompasses the nearby domestic terminal containing approximately 10,000 people.

What Precautions do You Need to Take For Your Safety?

You Are One of Few Paramedics on Scene, But Your Alarming Electronic Dosimeter (Radiation Measurement Device) Alerts You That You Have Been Exposed to 50 mSv, or 5 rem. Does This Modify The Actions You Perform or Zones You Work in?

If you are working in the hot zone, it is imperative that you have radiation monitoring equipment, especially when you are inside the inner boundary (the high-hazard zone). A radiation dose of 50 mSv, or 5 rem, is the typical occupational exposure limit for routine work. For a typical RDD, it would be unlikely to reach this level of exposure. However, the level of exposure may not be uniform within a hot zone because of bomb fragments and debris in the area of the rescue.[13] Under certain conditions, including performing lifesaving operations or critical property protection, exceeding routine exposure guidance by a factor of 5 (250 mSv, or 25 rem) or more is warranted and justified.[18] Even exposures 20 times the occupational exposure limit would not produce any short-term physical effects; however, long-term cancer risks are presumed to be dose-dependent, with higher exposures having an increased risk. Although the risk of premature death from cancer increases less than 1% for a 5-rem exposure,[19,20] that dose should be exceeded only by responders who volunteer, preferably over the age of 45 years.[21] Since the areas of exposure are not uniform and responders will probably be moving in and out of the high-hazard zone, accurate dose estimates may be difficult.

It is likely that treating all the victims, performing search and rescue, and clearing all people from the scene will take many hours or days. It is important that your agency's radiation safety officer have a method for determining when it is time for you to be replaced at the scene because of exposure thresholds and moved to work in the low zone. These data from first responders are also useful to the EOC to characterize the magnitude of the incident.[11] Many types of radiation monitoring equipment are available. The important feature for this scenario is a dosimeter with the capacity to be read on site in real time and provide alarms to avoid potential overexposure.

How Does This Change Your Triage and Treatment of Patients?

In any blast scenario with tens or hundreds of casualties, it is not appropriate to spend resources trying to treat the nearly dead or moribund. Also, if the environment is unsafe, you will attempt to move patients to a safe location before administering treatment. You will direct ambulatory victims to a collecting point where they can receive care and support. This is also the case in a blast with radiation present, but the definition of "unsafe" is a bit different.

In addition to falling debris or fire risk, this scenario may demand relocation of patients away from radioactive material deposited on the ground. Such "ground shine" risk is estimated to be the primary source of exposure, far greater than contamination on clothing or skin that would stick to patients when they are moved.[12] It is therefore a priority to relocate these people as quickly as practical to an area outside the high-hazard zone. The caveat remains that if a stabilizing intervention can save the life of a patient or prevent acute morbidity, it should be undertaken regardless of environmental or victim contamination. If a seriously injured victim is within the high-hazard inner boundary, consider the "scoop and treat" method to evacuate the patient from the highest-hazard area.[22.23] Avoid staying longer than necessary in the high-hazard zone, as the longer the responders have to stay in the immediate blast area, the less time they will be able to render assistance within the operational area.

Scenario Continued

In our airport scenario, a five-story parking garage upwind of the international terminal was outside the hot zone. Victims (both injured and uninjured) who were initially staged just outside the international terminal were moved to the parking structure.

A shelter-in-place order[15] was given by the incident commander to the members of the public within the domestic terminal. Air-handling systems were adjusted to reduce circulation of potentially contaminated air, and persons within the terminal were discouraged from leaving by airport security.

Should You Decontaminate the Victims?

Although contamination is unlikely to cause radiation injury to the victim or the responder, it will cause anxiety, and concerns over cross-contamination may delay treatment of the injured. If this number of potentially contaminated victims is small and the weather warm, then full wet decontamination may be preferable. Full decontamination may reduce the victim's anxiety and could reduce the need for cleanup of any cross-contamination outside the perimeter. However, as the number of victims grows, monitoring and decontamination capacity will quickly be exceeded, and expedited methods should be considered. These methods include the following:

1. Screening to identify those needing decontamination
2. Dry decontamination techniques
3. Self-decontamination[24]

For our airport scenario, the number of potentially contaminated victims (both injured and uninjured) could exceed easily exceed 1,000 people. With this large number of victims, alternate decontamination methods need to be considered and used to avoid wait times of more than an hour. Establish decontamination reception areas away from the immediate area that can accommodate victim modesty and warmth. The use of full, wet decontamination capabilities (if available) should be prioritized to those who may be the most significantly contaminated. Prioritization can be based on visual inspection (evidence of smoke or dust contamination) or through rapid screening surveys if radiation detection equipment is available for the task. Studies have indicated that screening individuals for prioritization can be accomplished in around 15 seconds per individual using a thin-window "pancake"-style Geiger-Müller instrument.[25]

Consider establishing community reception centers away from the scene (and not at the hospital) that can be used for follow-up monitoring and decontamination. Uninjured victims who self-evacuated may be referred to these reception centers.

- Uninjured victims can self-decontaminate; this practice involves removing the outer layer of clothing and wiping/washing any exposed skin.
- Injured victims who cannot self-decontaminate can have their clothing cut away and their exposed skin washed/wiped.

In any case, basic triage will not change. First, separation of injured patients from uninjured but possibly contaminated victims is critical. Medical resources can then be applied to those who are injured, and a secondary triage for transport can occur. If resources are adequate, a minor-injury collection point can be established, to be staffed by responders with lower medical skills.

The collection points should have a method of decontamination for the most severe cases as well as radiological monitors at the points of egress. It would be unrealistic to believe that such a scenario would lend itself to decontamination of all persons who may have particulates on their skin or hair, even with the largest mobile decontamination units and unlimited personnel. The delay in insisting that everyone be decontaminated at the scene may present a higher risk than allowing people to decontaminate themselves at home. Moreover, with hundreds or thousands of people to control, it would be desirable to get as many uninjured people as possible out of the area to preserve medical and decontamination resources for those who are injured and need transport to medical facilities.

Among the uninjured, there are two categories of victims. The first is the group with obvious upper body contamination, especially the shoulders, head, and hair. This group requires decontamination to the extent practical prior to leaving the collection area. The second is the group that has been outdoors in the high-hazard zone but has no gross evidence of contamination. These people may have been allowed to leave the area or escaped notice and self-evacuated. Both groups are at higher risk of internal inhalational contamination and need to be evaluated for the need of follow-up medical treatment. Because of this risk of internal contamination, an onus is created for public health to communicate those risks to the public accurately after the event, but in a time-sensitive manner.

If some people were a considerable distance from the blast and their only risk is their exposure to dust, it could be prudent for incident command to instruct perimeter control to allow these people to get into their vehicles and leave the area once they have removed their outer clothing and left it behind. They should be instructed to disrobe completely before entering their home, bag their clothing for later analysis, and immediately shower and shampoo. They should use warm water, avoid abrading their skin, and avoid hair conditioners, which may adhere to the radioactive debris.[13] The drainage effluent from the shower presents no measurable hazard.[20] They should avoid the use of their vehicle and leave their clothes bagged and stored away from occupants of the home until health officials have evaluated it for radioactivity in the days or weeks that follow.

A summary of priorities is presented in Table 1.

Scenario Continued

Your community's hazmat team is setting up their personnel decontamination capability in the ground floor of the parking structure. This has the capability for dual (male and female) personal decontamination shower corridors, each of which can process 100 ambulatory people per hour. The showers have the capability to run warm water, which will be important on this cool autumn day. There are enough blankets and modesty clothing for 500 people.

Transportation staging for medical emergencies is also established in the ground floor of the parking garage.

For our scenario, there are approximately 150 injured victims, 20 of them severely injured. Most of the injured appear to have been near the detonation. Another 2,500 uninjured victims are gathered in the parking structure; the levels of visual contamination on these victims vary from very dirty to apparently unscathed.

It is estimated that several thousand more international terminal victims left (or are leaving) the scene. The domestic terminal population is still sheltering in place, although some are leaving the building despite the shelter-in-place order.

How Would You Optimize/Prioritize the Use of the Decontamination Resources?

How Would You Manage the Contaminated Injured?

What Does This Mean for Scene Control?

The added complication of radioactive contamination presents additional requirements for security. Most law enforcement agencies are well trained in and experienced with control of a crime scene, which this scenario certainly is. They may not be as adept at scene perimeter control when there are hundreds or thousands of victims evacuating a scene. Some will run from the area and some will stay behind to help their neighbors, coworkers, or strangers. Unlike the World Trade Center experience on 9/11 in which thousands of people walked home directly from the scene, contaminated victims should not leave the area without consideration of contamination issues; however, force should not be used to contain potentially contaminated victims. Potential or actual radioactive contamination is **not life threatening** and does **not warrant quarantine** protocols. Deadly force should never be used to contain contaminated victims.

Experience from the Madrid and the London bombings presents some interesting lessons in field triage. First, there is no way a limited number of responders can perform effective triage. You do only what you can do, but you should also know what to expect. Some bystanders will run for their lives, but others will perform evacuation without direction. They may carry people from the scene or load them into private vehicles. People who self-evacuate with or without injured people in tow will find their way to the closest hospital, which may not be the most appropriate hospital. The one certainty is that they will beat the ambulances to the hospital and will overwhelm existing resources, effectively blocking the way for the more severely injured.[26]

Ideally, law enforcement will be prepared for this and will control the perimeter to funnel people into collection points. If the perimeter is set outside the hot zone after the dust plume has settled, workers with skin and respiratory protection have no significant risk from radiation exposure. Once radiation readings have been taken and the EOC has mapped the ground contamination, the perimeter may be moved forward and collection points established closer to the scene.

TABLE 1. Summary of Priorities

Within the treatment area:
1. Prevent contamination of rescuers—skin, eye, and respiratory protection, activate radiation detection and monitoring equipment.
2. Assess victims—moribund, treatable or ambulatory.
3. Move everyone who is treatable or ambulatory as quickly as possible to a location >500 yards from the blast or outside the hot zone (if established).
4. If victims are treatable or ambulatory, remove their outer clothing and leave it in a pile.
5. Stabilize injuries according to normal protocols.
6. Move or direct victims to collection points, even if they have no sign of injury.
At the collection points:
1. Decontaminate to the extent practical *without delaying transport or definitive care of high-priority patients.*
2. Establish patient logs with contact information.
3. Treat minor injuries.
4. If decontamination facilities are not present, instruct ambulatory victims on home decontamination and follow-up.

In reality, most cases of major bomb blasts do not result in effective and orderly scene control. Experience shows that chaotic egress of those who can run or walk will have occurred to some extent prior to the arrival of first responders. There will undoubtedly be more people fleeing the scene than can be contained. Active fires may be present in the zones with entrance and egress of people and equipment. Medical responders will need as much equipment and supplies as possible to come quickly through the perimeter. People posing as doctors and nurses will attempt to enter the scene, either to aid victims or for nefarious purposes.[27]

Law enforcement will be focused on crime scene protection protocols, which will quickly be guided by the Federal Bureau of Investigation. It would be naïve, however, to believe that such a perimeter could actually be controlled without leakage. Therefore, emergency managers will need assistance from the media in conveying accurate information to the public in order to ensure that everyone who needs evaluation and medical attention receives it.[28]

Another consideration for responders is the mass of people who may have sheltered in place inside the hot zone. Adjacent buildings may have protocols for sheltering in place that may be effective but present another set of challenges for support. Such protocols would typically call for the prompt shutdown of air-handling systems and movement of people to interior safety zones with sufficient water and food for a period of hours to days. This is important for responders to consider, as there may be calls for medical emergencies in the buildings or requests for services. Safety officials should be prepared to provide guidance to the building managers regarding environmental safety regarding air handling and safe egress.

Do You Have Everything You Need at the Local Level to Manage This Scenario?

No municipality in the nation has all the resources it needs for the scenario described. Every municipality should have plans in place for this scenario and have mutual aid agreements signed and in place with surrounding cities and counties. At the state level, all states are members of the Emergency Management Assistance Compact (EMAC), which can provide mutual aid across state lines. Federal resources are also available, but the time lines for federal assistance vary with the resource requirement. For example, the CDC coordinates the Advisory Team for Environment, Food, and Health (A-Team), which is available immediately to help guide local governments and their safety officials' protective health actions following a radiological incident. The Department of Energy maintains several teams and resources such as the regionally located Radiological Assistance Program[29] teams and the medical teams from the Radiation Emergency Assistance Center in Oak Ridge Tennessee.[30] But other hard assets such as ambulances or materiel may take hours or days to arrive.

Recognizing that federal resources may take time to mobilize, the CDC has made recommendations for EMS response for the first 72 hours of an event, following a study of the bombings in London and Madrid.[31] They include recommendations for mobilizing 50 ambulances and implementing alternative transportation for 200 people within 10 minutes after the blast as well as detailed operational plans for decontamination and transportation of victims with gross contamination.

MEDICAL MANAGEMENT OF RADIATION EXPOSURE

The same universal precautions that are used for infection control are sufficient to protect first receivers from harm in managing potentially contaminated patients.[16,32] In the scenario of an IED with radioactive material, the acute signs of exposure from high levels of radiation, such as nausea and vomiting, are not likely to be present.

You will have done your best to minimize the time your victims and you spent close to the radiation source, and to work as far away from the source as possible. You will have removed their outer clothing and, in so doing, eliminated most of their radiation exposure. You will have sent victims with gross evidence of head and neck contamination to a decontamination station. Your colleagues at the perimeter will have helped decontaminate the victims. But none of your patients will have had dosimeters on their person and, although the dose would be expected to be small, there is no way to know for sure at the scene how much radiation they received. Immediate medical intervention is not required for the treatment of external radiation exposure; however, tracking time to onset and severity of symptoms, such as nausea and vomiting, can help diagnose the severity of exposure.[33]Although many resources are available for hospital medical staff to diagnose and treat radiation-related injuries,[34,35] victim dose determination would be difficult. Only two laboratories in the United States can perform the type of retrospective dose assessment that is considered the “gold standard,” cytogenetic dosimetry.[36] Research is under way to develop more widely available, rapid, on-scene dose-assessment capabilities.[37]

Knowing which isotope is causing the contamination is less important to the field responders than to downstream management of contaminated patients. Whether the isotope is an alpha, beta, or gamma ray emitter should not change the first responders’ initial management of injuries or external decontamination. However, in the field, hazmat or radiation safety personnel with a simple Geiger-Müller counter can differentiate between alpha, beta, and gamma emitters. If the substance is a gamma emitter, such as Cs-137, teams equipped with a gamma spectrometer can evaluate the “gamma signature” unique to each isotope, providing precise identification of the radionuclide. This information can aid in managing the response in the field and in identifying appropriate medical countermeasures at the hospital.

You should also consider whether or not the responders in the area of dust and debris were also exposed through inhalation or ingestion. Masks are not 100% efficient or may not have been worn before the hazard of radioactive material was known. Many people may have found it necessary to drink water when it may not have been completely safe to do so. Fortunately for the response force, most of the potential inhalation hazard (airborne radioactive dust) will have greatly dissipated a few minutes after the explosion.[13]

In addition to external radiation exposure, our scenario with Cs-137 was chosen because the physical properties of the isotope create the need to consider ingestion and inhalation as sources of internal contamination. Those in the immediate vicinity when the blast occurred may have inhaled a significant quantity of Cs-137-laden dust. The Cs-137 deposited in the body can create a larger overall dose since the radiation exposure from this internally deposited material does not stop when the victim leaves the area or by external decontamination. Even with potentially life-threatening exposures, victims might be unaware of the degree of their exposure or the levels of internal contamination and could remain asymptomatic for days or weeks.

Cs-137 is one example of an element that can be scavenged from the body even after internal contamination.[38] Removing the source of the radiation from the body is one type of countermeasure. Some radioactive isotopes lend themselves to binding with drugs administered intravenously or orally. In the case of Cs-137, “decorporation,” or removal from the body, is accomplished by ferric hexacyanoferrate (Prussian blue), which binds cesium in the gut. Since it works in the gut, it is administered orally, unlike chelating therapy for other elements that require IV drugs. The effectiveness of the treatment is dependent on how soon after exposure the Prussian blue is used and on the length of the treatment.[39,40] Although it can help decorporate Cs-137 even days after uptake, the earlier Prussian blue is given, the more effective it is at removing material and reducing radiation dose. If given in the first hour after contamination, enteric absorption of Cs-137 is also suppressed and is eliminated in the stool.

Previous experience with Cs-137 exposure is based on a limited number of incidents and a small number of patients for whom therapy can be individualized. The most notable example is from Goiânia, Brazil, in 1987, in which a small amount of “glowing blue” powder was looted from equipment in an abandoned health clinic. The environment in the village was severely affected, contaminating 249 people, 17 of whom suffered bone marrow suppression, four of whom died.[15] Initially, several people had incorrectly diagnosed systemic illness and others had local injury. Prussian blue was given to 46 people based on their internal burden of radiation.[41] Radiation dose reductions of 51% to 84% were reported when Prussian blue was used to treat the victims of Goiânia.[42] Based on these data, when Prussian blue is given after Cs-137 has been absorbed into the system, the expected rate of elimination of Cs-137 from the body is two or three times as fast as without the drug. Stated in terms of the “biological half-time,” the time required for one-half of the Cs-137 to be expelled from the body, Prussian blue can reduce biological half-time from about 110 days to about 30 days[43]and consequently reduce the radiation exposure by a corresponding amount.

How is the internal contamination evaluated? Traditional methods include measuring body excreta for radionuclides, including urine, feces, and nose swabs. Special facilities also exist that can detect radiation given off by the internally deposited materials; these “whole body counters” tend to be located in or near national laboratories or nuclear reactors. Needless to say, this approach may work for a few victims, but it is useless in assessing risk to hundreds or thousands of people. Methods for evaluation using filed screening techniques have been suggested[44] as well as the use of hospital nuclear imaging tools for screening,[45] but these techniques have not been adopted into widespread operational planning.

The Food and Drug Administration (FDA) recommends administering Prussian blue for removal of Cs-137 "as soon as possible after exposure. However, even when treatment cannot be started right away, patients should be given Prussian blue as soon as it becomes available because it is still effective even after time has elapsed since exposure."[46] Current therapy guidelines are based on patient-specific measurements as described above. Clinicians who suspect the presence of a condition tend to err on the side of treatment, as long as the risks and side effects are outweighed by the risks of not treating the suspected condition. Unfortunately, pharmaceutical-grade Prussian blue is not readily available in the hospital or pharmacy, as it has no other medical indications than removal of cesium or thallium from the body, a rare occurrence. As a result, clinicians do not have immediate access to Prussian blue, even for FDA-approved indications. Currently, the drug can be obtained anywhere in the United States from the Strategic National Stockpile (SNS) or from Oak Ridge Institute for Science and Education (ORISE), but it may not necessarily be acquired and administered at the treating physician's discretion. The Armed Forces Radiobiological Research Institute provides a simple, straightforward flow diagram to guide clinicians in the use of Prussian blue in the wake of an explosion with Cs-137.[47]

The need for a drug that requires timely administration but is not readily available presents a difficult public policy question as to how it should stockpiled and dispensed.[48] On one hand, acquiring the drug should not be so difficult that clinicians cannot easily prescribe the drug for their patients who are highly suspected of internal contamination and would benefit from decorporation therapy, particularly with a paucity of side effects. On the other hand, it is easy, in the wake of a dirty bomb attack, to imagine a wave of people seeking the treatment who do not need it, depleting supplies for those who do. What does seem clear is that methods should be developed and promulgated for clinicians to obtain Prussian blue rapidly, and that the scale of availability should support the treatment of hundreds to thousands of potential patients in the wake of an attack with a dirty bomb.

SUMMARY

A dirty bomb presents another level of complexity to a major blast scenario. The presence of radiation may not be evident by first responders. Any blast with dust and debris should invoke skin, eye, and respiratory protection for responders. If the presence of radiation is detected by any responder equipped with detectors, all responders should be advised to take appropriate precautions, but response activities should not cease.

There is no justification for delaying treatment of the injured because of the presence of radiological material. Agency safety officials should be present to measure radiation exposure to the responders and rotate them to the low zone when thresholds are reached. Perimeter control for both entry and egress must take into account the need for medical care, transport of people and supplies, decontamination, and victim information.

Countermeasures for reduction of exposure should be familiar to all responders. Outer clothing of any person in the high-hazard zone or exposed to dust and debris should be removed and left behind. Relocation of victims away from the high-hazard zone is priority for both the victim and the caregiver. Decontamination of the head, neck, and shoulders should be undertaken in anyone with obvious contamination. People highly suspected of receiving internal contamination should be treated with ferric hexacyanoferrate (Prussian blue) as soon as possible to reduce their overall exposure.

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