Though an RDD would pose big challenges, solid plans — backed up by training — should cut the situation down to something manageable.

Dirty bombs, practical plans

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Washington, D.C.–area responders at a day-long October 2004 mass-casualty exercise based on an RDD scenario faced dozens of victims scattered across a site contaminated by a car bomb that had been laced with radioactive material. Gauging the site and victims' radiation levels was the firefighters' first step.

The United States has recognized that a class of weapons known as radiation dispersal devices, or "dirty bombs," poses a grave threat to ourselves and to the European Union.

Dirty bombs use a conventional explosive, such as a car bomb, to disperse radioactive materials in a populated district to cause great economic and social disruption disproportionate to the actual radiological effects and well beyond the physical destruction from the conventional bomb components. Although tens to hundreds of people could die from the conventional blast, few would die from the radiological effects.

Unfortunately, with no precedents, we are struggling with generalizations and how to prepare and respond to the first RDD event. What follows is one of many recent attempts at structuring the problem and providing guidelines that are still fluid.

Rules of thumb

The challenge to training anyone outside the fields of radiation, radiochemistry and nuclear science is to provide enough information to be useful without creating confusion. First responders know all too well how dangerous it is to oversimplify, but since it isn't possible to make all responders radiochemists or health physicists, some simplifying concepts are in order.

- The logistical difficulty in successfully carrying out a significant dirty bomb attack would be roughly the same as that of the 9-11 attacks.
- The likeliest device will be a cesium-137 chloride (Cs-137Cl) car bomb, and the level of response and danger to responders would be of the order of a 20-alarm fire.
- Defining the hot zone is the most important first response, and a simple alarming dosimeter is the most useful piece of equipment for a dirty bomb attack.
- Following protocols, it's difficult to obtain a significant radiation dose in the first hours of response to an attack.
- The greater the dispersion, the greater the affected area, but the lower the dose.
- The scene will be a war zone, not a Superfund site.
- It will be possible to quickly triage most victims without significant harm to the responders.
- Individuals with no significant physical injuries should not be significantly contaminated.
- While not effective against gamma radiation, a firefighter's personal protective equipment (turnouts, gloves, goggles and respirator) will provide complete protection against alpha and beta radiation, and almost complete protection against ingestion and inhalation of radioactive material dispersed by the attack, including gamma-emitting material.
- Removing clothing and washing with soap and water is effective at removing radioactive contamination.

The greater their training and experience with radioactive materials, the better able responders will be to evaluate the usefulness of such generalizations.

The radiation threat

RDDs could take many forms, from containers of radioactive materials wrapped with conventional explosives to manual dispersion of fine powders into the environment. Large RDD attacks could cause widespread fear, immediate death and long-term increases in cancer incidence, long-term loss of property use, disruption of services, and costly remediation of property and facilities.

Because the general public is so frightened about anything radioactive, fear must be anticipated even if there is no real health threat from the radioactive component. Even a phantom RDD, where no radioactive material was used, but an implication or anonymous tip indicates there was, could still cause considerable fear with large economic consequences.

The serious radiological threats come from large RDDs containing thousands to hundreds of thousands of curies of activity, which could cause significant and lasting health and contamination problems. Although many variables would determine the effectiveness of an RDD attack, the key factor is the quantity and type of radiological source material dispersed.

Though it has been difficult to quantify, worldwide there are about 10,000 sources that exceed 1,000 curies, and perhaps a thousand that exceed 100,000 curies. Briefly, the differences in sources relate to their specific activity (the type and amount of radiation emitted) and their chemical and physical forms (whether powder, non-metallic solid or metal).

Gamma (γ) radiation can penetrate great distances and, depending on the energies, requires shielding of about 18cm (7 inches) of lead or 3 feet of reinforced concrete. Beta (β) radiation can penetrate only a short distance, and a firefighter's PPE can block much of the dose. Alpha (α) radiation is the least penetrating of all and can be stopped by a piece of paper or ordinary clothing. (For a review of radiation basics, units and other references, see "Rad concepts," July 2005.)

The most important pathway of accumulating dose from alpha or beta sources is ingestion or inhalation, where the emitter is directly adjacent to tissue for long periods of time. For gamma sources, mere proximity is all that is required for significant doses.

For purposes of RDD planning, isotopes of plutonium (Pu), americium (Am) and uranium (U) are primarily alpha emitters, cobalt (Co)-60 and Cs-137 are gamma emitters, and strontium (Sr)-90 is a beta emitter. Co-60 usually occurs as a metal (either pellets or small rods), Cs-137 as a powder, Sr-90 as a ceramic, and Pu, Am and U as various oxides, salts and non-metallic solids.

Although the public generally thinks of plutonium and enriched uranium when hearing the word "radioactive," these are not considered RDD materials of choice, because they're primarily alpha emitters, are costly, cannot be obtained in large amounts, are well tracked and secured, and are more useful to terrorists in the production of actual nuclear weapons than in being wasted in an RDD. In this sense, Cs-137Cl powder is much more effective as an RDD material.

Although the inclusion of any radioactivity, no matter how small, in a dirty bomb will cause disruption at some level, the real health and economic threat resides in large sources, because even after dispersion over many city blocks, the radioactivity would be above public health limits and have to be remediated before normal activities could resume.

As an example, a 25-gram Cs-137 source (about 2,200 curies) is lethal after about one hour of exposure at one meter, a dose of about 1,000 rem/hr or 10 Sv/hr. However, that source is not lethal if uniformly spread over 10 by 10 city blocks (dose less than 1 rem/yr), since the surface area in a 10- by 10-block area in downtown Manhattan, for example, is more than 1 billion square feet. On the other hand, a 2.5kg Cs-137 source (about 220,000 curies) that's used in large irradiation units would be well above public health limits even spread out over those same 100 city blocks.

Risk, perception and education

Because risk is based on a combination of probability and damage, it's next to impossible to estimate risk for a highly improbable event, like 9-11 or a large dirty bomb attack, one that has a huge effect but only happens once in a great while, if at all.

In fact, how we respond to the first event has as much to do with the probability of it occurring again, as it does with the logistical difficulty of pulling it off in the first place. As an example, if a dirty bomb attack shuts down Manhattan for one year with an economic impact of $400 billion in clean-up and lost business, which would be deemed a great success by the perpetrators, then the likelihood is much greater of a second attack elsewhere. On the other hand, if we are even somewhat prepared, respond well in the week following the event and keep the cost below $500 million, then we have presumably decreased the likelihood of a second attack.

It is essential that the responder community

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Seattle Fire Department hazmat technicians conduct initial radiological surveillance during the TOPOFF 2 exercise in 2003.

understands the problem and has an effective response plan that is executable. It is also critical that our society continue rational discussions of risk on a national level without sensationalizing particular scenarios beyond their actual likelihood.

Learning to evaluate the scene of a car bomb is just one of many tasks covered in dirty bomb training, which combines material from RadWorker II, NIMS/ICS and Modular Emergency Response Radiological Transportation Training.

Radiological risks are the most obvious subject of sensationalism. Knowledge about radiation and its effects is not intuitive, is not generally taught in school and is not generally understood by society. In recent surveys of perceived risks, Americans were asked to rank various activities such as smoking, consuming alcohol, driving, working in the fossil-fuel industry, working in the construction industry and working in the nuclear power industry. Almost every respondent ranked working in the nuclear power industry as either the most dangerous, or second most dangerous, activity.

In reality, in the last five years, no one has died in the nuclear power industry, whereas more than 700,000 Americans have died from smoking and more than 200,000 from car accidents. This misperception of how dangerous radiation is constitutes the number-one issue concerning the effectiveness of a dirty bomb, because how responders and the public respond to a dirty bomb attack will determine whether the attack is successful.

Therefore, short of a multi-year national public education initiative on radiation, how can we prepare and respond to this type of attack? The answer is to develop a simplified, practical guidance for responding to a radiological attack that does not depend on in-depth understanding of radiation, that dispels the fear that comes from misperceptions, and that fits into the National Incident Management System/Incident Command System framework so that it can actually be implemented during a crisis.

At the same time, we must provide enough resources in the form of training, documents, Web sites and expert consultation that responders can, if desired, obtain a greater depth of understanding over time.

Training for responders

Many training programs exist for the first responder with respect to radiological incidents. Because a dirty bomb attack is closer to a radwaste spill than to any other event, these training programs have logically adapted the RadWorker II programs that have been used for decades to train radiation workers in the nuclear, clean-up and

A comprehensive dirty bomb training course

At the Carlsbad Environmental Monitoring and Research Center, New Mexico State University's College of Engineering offers a three-day dirty bomb course for first responders that provides two college credits, 3.5 continuing-education credits and 18 credits through the Continuing Education Coordinating Board for Emergency Medical Services.

CEMRC is a 26,000-square-foot radiochemistry facility that includes environmental and radiochemistry laboratories, a plutonium-uranium laboratory, an in vivo bioassay facility, mobile laboratories, field programs and computing operations. The course includes approximately equal time in classroom, laboratory and field exercises in areas including:

- the basic concepts of radiation physics and chemistry,
- biological effects of radiation,
- hazard recognition,
- characteristics of a dirty bomb: the source and the explosives,
- initial response actions,
- incident control and command,
- prehospital practices,
- handling the "walking worried" and the terrified,
- situation board drills,
- radiological survey instrumentation and dosimetry devices,
- DHS guidelines for RDD events and what that means to first responders,
- clean-up and ways to mitigate the effects of dirty bombs,
- site forensics and preservation of evidence,
- decontamination, disposal and documentation, and
- when to return to work and living spaces after a dirty bomb attack

What differentiates this course from most is the inclusion of first responders on the faculty, including fire chiefs, state police detectives, National Guard Civil Support Team personnel, EMTs and forensic scientists, as well as radiochemists and health physicists.

This course is not necessarily meant for advanced radiation event responders, such as the National Guard CSTs or Department of Energy Radiological Assistance Program teams that will arrive to assist local responders within 12 hours of the event. Rather, it's intended to provide local responders with enough information to provide incident control and command, determine the effected areas, address immediate concerns such as fire and priority rescue, aid citizens and medical personnel, provide support to the CSTs and RAP teams once they arrive, and generally keep disorder to a minimum.

This last point is critical. If the responders first on the scene do not understand what a dirty bomb attack entails, that uncertainty will be communicated to the civilians in the area and attempts to contain the situation and the contamination may fail. Because there are more than 200,000 first responders in the top 100 target areas in the United States, many such training programs are needed.

disposal industries.

However, the first responder is not a radworker and doesn't need most of the information in these training programs. What is needed is a combination and streamlining of three types of training: RadWorker II, NIMS/ICS and Modular Emergency Response Radiological Transportation Training, which was developed as part of the U.S. Department of Energy's Transportation Emergency Preparedness Program <www.teppinfo.com>. MERRTT is the only nationally recognized first responder training for handling radiological transportation incidents.

(For an example of such a training program, see the sidebar at left.)

Response guidelines

So what can emergency responders do? The following summarizes a simplified guidance. (Variations exist and some form will be standardized in the near future.)

- Assume that all explosions, particularly car bombs, could be dirty.
- If no dose or activity readings are available, set up a working hot zone inner boundary at 500 meters from ground zero. If readings are available, set the hot zone inner boundary as 1 rem/hr and the hot zone outer boundary as 0.1 rem/hr. Within this zone, essential personnel can operate for several hours without accumulating a significant dose. Exact adherence may not be feasible because of logistical or geometric issues, and plus or minus a factor of two in dose units is expected. If this zone is very large, it can be subdivided into smaller working zones to allow longer working times in various areas.
- All personnel in the hot zone should wear full PPE. If this is not available, improvise by breathing through cloth and covering all exposed skin, until evacuated from the hot zone or full PPE can be obtained. Remove improvised breathing covering after 30 minutes, however, as the plume will have dissipated, and continued use could increase exposure from any trapped radioactive material.
- When it is determined that the situation is radiological, immediately alert the appropriate secondary response teams, such as Civil Support Teams, the Department of Energy Radiological Assistance Program and the FBI, as advised in the unified command protocols for your region.
- Set the outer boundary of the affected area as 1-10 mrem/hr, as circumstances dictate.
- Occupancy time outside the hot zone, but within the affected area, is basically unrestricted for essential personnel for the duration of the initial response (up to days).
- Establish incident command upwind of ground zero at the closest point outside the hot zone.
- Evacuate everyone from the affected area and exclude non-essential personnel thereafter. Expect self-evacuation for large affected populations of uninjured people and provide them with designated safe routes out of the affected area. Try to establish quick dose-rate screening, or radiological monitors, to identify those few needing decontamination, but do not attempt mass decon. Instead, advise most to go home, remove and bag external clothing before entering their residences, shower with warm water and soap, and not use hair conditioner, hair color or other fixative hygiene products. After emergency response is over, attempt to survey bagged clothing of those persons who think they were contaminated.
- Do not decontaminate vehicles or structures during the initial response phase and do not try to contain contaminated water, but allow — or even encourage — it to enter the municipal drainage system.
- Establish decontamination areas for heavily contaminated individuals, for example if there is obvious surface radioactive material or if they are heavily injured from the blast. Provide those who have heavy external contamination of the upper body with follow-up exams to determine possible contaminant inhalation or ingestion. Countermeasures such as administering Prussian blue should be evaluated promptly.
- Separate those people needing immediate medical attention and remove outer garments, survey for surface contamination, decon if necessary and possible, and evacuate. Be sure to inform the receiving medical facility that the person has little or no surface contamination, or they may deny admittance.

■ Begin mapping the affected area to obtain a rough dose profile of the area, marking hot and cold spots to assist in avoiding large doses during operations and to assess the magnitude of the situation.

■ Essential personnel within the affected area should record cumulative dose, if possible, and not exceed 5 rem total, unless protection of critical infrastructure is deemed imperative and no alternative exists. Do not exceed 10 rem, except to save lives and protect critical infrastructure, and do not exceed 25 rem unless the responder decides voluntarily, and with full knowledge of the risks, to save large numbers of lives and protect critical infrastructure that may harm large populations if not secured. Do not exceed 50 rem.

■ Sheltering in place is advisable only if the population ahead of the plume is aware of its radiological nature ahead, which would be unlikely in most cases. Evacuate buildings along routes away from the hot zone that have been determined to be safe.

■ It is unlikely that shutting down building ventilation systems could be accomplished fast enough to do any good, unless a networked metrodetection system is in place. In any case, modern ventilation systems will filter most radioactive particulates.

Mitigation considerations

Once an attack has happened, there are limited options for mitigation. Researchers are investigating spray-on fixatives to prevent secondary migration beyond the affected area and to make subsequent clean-up easier.

These may be ideal for the most heavily affected areas, such as the immediate blast area, and for specific source materials such as alpha-emitters, but the best option may result from the fact that $Cs^{137}Cl$ is so soluble that it can be washed off surfaces with water.

However, washdown must be done quickly and completely, within days or even hours of the event, to preclude further effects such as diffusion into building materials, secondary migration, and cumulative dose effects. Diffusion rates are primarily a function of moisture content and will depend strongly on weather conditions and the porosity of the materials.

If the weather remains dry and sunny, little diffusion will occur, but if the surfaces become wet (but not enough to wash off the cesium), or if surfaces are wet during deposition, significant diffusion can occur quickly. Cs-137 can diffuse into wet concrete more than a quarter of an inch each week, but it would not diffuse that much into granite, glass or metal even after several years, no matter what the conditions.

There's considerable debate over the washdown approach, but it's unlikely that any other strategy could be implemented rapidly enough to be affective. Although a 10- by 10-block area in downtown Manhattan has approximately a billion square feet of surface area, 100 fire hydrants operating for 24 hours would deliver about 100 million gallons of water, adequate to wash off large areas and wash most of the cesium into the stormwater drainage system, where it would be adequately diluted and deposited in areas of lesser consequence.

Alternatively, the wash water could be treated at the outflow points using inexpensive materials such as gabions of zeolitic gravel ($80/ton), which are extremely specific for cesium and other radionuclides.

It is essential that the United States respond quickly and efficiently should an RDD attack occur. Doing so will both minimize the long-term effects and decrease the likelihood of future RDD attacks.

But this can be accomplished only if emergency response agencies are well trained and have suitable plans that can be executed within a comprehensive interagency command structure. HPP

Rad resources for the responder

Many resources have appeared, particularly online, to fill gaps in knowledge on radiological terrorism for first responders.

The national laboratories provide basic radiation training and resources (such as Sandia National Lab <www.sandia.gov/mission/homeland/solutions/emergency/index.html> and the Pacific Northwest National Lab <www.hammertraining.com>) and there are many sites linked to DHS <www.dhs.gov/dhspublic> and various private and quasi-private sites such as <www.homelandresponse.org> and the Responder Knowledge Base at <www.rkb.mipt.org>.

Sites sponsored by the federal government are built specifically to serve the needs of emergency responders and contain information on currently available products, along with related information such as standards, training, and grants. The Responder Knowledge Base anticipates posting the Radiation Community Preparedness Resource (RadCPR) database, a comprehensive database on radiation and radiological incidents prepared by a team at Los Alamos National Laboratory. Because these resources consist of thousands of pages of information, they're best used periodically by first responders as ongoing education.

However, for the immediate aftermath of a radiological attack, the first responder needs a simple set of basic principles that are useful but not daunting. This approach is now being incorporated into many training programs, including the training developed at the New Mexico State University Carlsbad Environmental Monitoring and Research Center.

Finally, an excellent guide for a simplified approach recently appeared as a result of many years of experiments at Sandia (S.V. Musolino and F.T. Harper in the April 2006 issue of Health Physics, vol. 90(4), pp. 377–385).

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