Radiological and Nuclear Terrorism: Are You Prepared?

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Another terrorist attack on our nation is virtually inevitable. Most believe that it is not a question of if but when. The form of the terrorism, the time, and the place will not be of our choosing. Radiology professionals (radiologists, technologists, radiologists' assistants, and nurses) will be involved in caring for the victims of the attack, whether the method employed is chemical, biological, radiological, or nuclear. If chemical or biological weapons are used, we must be ready to help with the diagnoses and follow-up care of these patients. Probably the greatest challenges to the radiology community will arise if the terrorist act involves a radiological or a nuclear explosive device. Understanding terrorists' goals of creating pandemonium and causing economic disruption is important. Radiology professionals need to be prepared to be resources for the medical community in providing patient care and for the community at large, especially if the terrorist attack involves detonation of a nuclear device, an attack on a nuclear power plant, or the use of a simple radiation dispersal device in a highly populated area.

Key Words: Dirty bombs, radiological terrorism, nuclear terrorism, disaster preparedness

J Am Coll Radiol 2004;1:54-58. Copyright © 2004 American College of Radiology

INTRODUCTION

The events of 9/11 underscored the country's vulnerability to a well-planned terrorist attack. We are reminded by our government and our news media on an almost weekly if not daily basis of the potential for a terrorist attack. Terrorist threats have been broadly categorized by the Federal Emergency Management Agency (FEMA) as national security emergencies to the population at large. These threats, which are posed by either hostile governments or extremists, are grouped by FEMA into broad categories. These include the simple "threat" of a terrorist act, the assassination of high-level officials, kidnappings, hijackings, cyberattacks on our nation's computer-based infrastructure, both bomb scares and actual bombings, chemical and biological attacks, and nuclear and radiological attacks [1].

The forms of terrorism that have the greatest relevance to the medical profession are chemical, biological, nuclear, and radiological attacks on large population areas, centers of governmental or military activity, or critical economical infrastructure segments such as our agricultural base and industrial infrastructure. Chemical and biological attacks can be directed at a wide range of targets. Included in the target list are people, animals, and plants—all living things. Terrorists may focus on large population areas or rural agricultural regions. Chemical and biological agents can be dispersed using a wide variety of means. Planes and boats are conventional methods of releasing biological and chemical agents, though there are many unconventional methods as well. Although the postal anthrax attacks following 9/11 are considered by many to have been an act of domestic terrorism, they are an example of terrorist innovation.

Nuclear and radiological attacks are more likely to be directed at large population areas; military installations; centers of governmental activity; and important economic, communication, and transportation centers, such as major seaports and air transportation hubs. Because of the greater technical expertise needed to make these weapons and the hazards posed by the radiation released by the radioactive material prior to detonation, dispersal methods are limited in comparison to chemical and biological threats.

Whether the threat is biological, chemical, nuclear, or radiological, physician and community preparedness will be key in responding to any of these terrorist acts. The questions that we as members of the radiology community need to know the answers to are the following:

- What steps do we need to take to help our communities become prepared in the event of a radiological or nuclear disaster?
- What actions should we take to help our hospitals prepare for dealing with the intense either real or imagined demand for medical attention that would follow a terrorist attack?
- What do radiologists as specialists and other professionals (technologists, radiologists' assistants, nurses, etc.) in the radiology community need to do to prepare for dealing with and caring for patients created by a terrorist attack on one of our communities?
- How should the radiology community respond to the results

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0091-2182/04/$30.00 • PII S1546-1440(03)00014-0

of a terrorist attack that are separate from human injury, such as cities or land contaminated by radioactivity?

RECOGNITION OF RADIOLOGICAL FINDINGS

As radiologists, we need to know the imaging findings produced by the agents used in chemical and biological attacks. Some are relatively specific, such as the hemorrhagic lymph nodes produced by the anthrax endotoxin caused by vegetative *Bacillus anthracis* [2]. The indiscriminate attacks on our society using the simple act of sending anthrax spores through the mail, though fortunately limited in scope, made an entire nation aware of our vulnerability to terrorist attacks using biological agents. Theretofore, most Americans considered mail delivered by the US Postal Service as safe. They did not seriously consider that the mail could be used as a weapon to attack us with biological agents. Widespread fear and public uncertainty were created. An entire Senate office building was closed for several weeks. Other government buildings, including post offices, were closed. The resultant economic impact for the post-9/11 anthrax incident on the Postal Service was $1.65 billion [3].

Economic modeling by Kaufmann et al [4], of the Centers for Disease Control and Prevention (CDC) in Atlanta, attempted to understand and quantify the economic impact of using three of the classic biological warfare agents (*B. anthracis, Brucella melitensis,* and *Francisella tularensis*) released as aerosols in a suburb of a major city. Their model showed that in addition to the pandemonium created, the economic impact of a bioterrorist attack could range from an estimated $477.7 million per 100,000 persons exposed (*B. melitensis* scenario) to $26.2 billion per 100,000 persons exposed (anthrax scenario). These data were based on 1996-1997 dollars [4].

Chemical agents such as aerosolized ricin (castor bean toxin), blistering agents such as phosgene and mustard gas, poisons such as cyanide, and nerve agents such as sarin and tabun may be dispersed in a variety of ways. The most common anticipated method is by airplane, though these agents also can be dispersed by controlled release in a dense populated area. The sarin (neurotoxin) attack in a Japanese subway a few years back was an example of a controlled-release attack [5]. Unlike biological agents, most chemical agents, in general, have more immediate effects. Although these agents are generally lethal, they are difficult to deliver in concentrations that will produce widespread mortality. Additionally, many of these agents require production using complex manufacturing processes. Unfortunately, some agents can be “homemade” [6].

Chemical agents have few if any pathognomonic findings. Those that are inhaled produce pulmonary edema. Inhaled ricin produces an intense pulmonary edema in about 18 hours [7]. Ingested agents affect the gastrointestinal mucosa, producing gastrointestinal bleeding, vomiting, and diarrhea. It is expected that in any future terrorist incident, the chemical agent will usually be identified early in the process, allowing time for quick research into the specific imaging findings for each specific agent.

It is difficult to get specific information from the government concerning the probability or predictions of which form(s) of terrorism experts believe is most likely. However, the intense focus of the government on variola major (smallpox), a highly contagious pathogen, probably gives us a significant clue about the government’s thoughts. A study by the RAND Center for Domestic and International Health Security revealed the vulnerability of the unvaccinated population to a smallpox attack in an airport [8].

Smallpox belongs to the most virulent category (category A) of critical biological agents, according to a report from the CDC Strategic Planning Workgroup released April 21, 2000 [9]. Category A agents are easily transmitted from person to person and produce a high mortality rate and social chaos. They require special medical action by the community. Other agents in this category are anthrax, plague, botulism, tularemia, and the Ebola filovirus. Our very recent experience with severe acute respiratory syndrome (SARS) underscores this concern. Only a very few terrorist vectors (perhaps only one) in a busy airport could potentially create a worldwide epidemic when the pathogen is as easily transmitted from human to human as is smallpox.

In the specific case of smallpox, it is important to remember that although release by a terrorist vector may have a significant psychological effect on the populace, once detected, there is ample time for vaccination if personnel have been prepared and smallpox vaccine is available.

RADIOLOGICAL AND NUCLEAR TERRORISM

In the event of a nuclear or radiological terrorist event, radiologists will be looked to for expertise in the medical community, especially in the decontamination of the exposed and contaminated patients; the identification and management of patients with significant radiation exposure; and dealing with large, potentially overwhelming numbers of frightened patients.

There are three basic scenarios for acute, high-dose radiation terrorist incidents. The first is a true nuclear detonation producing mass destruction, prompt radiation, and fallout from the fission products. The second is a failed nuclear detonation, in which nuclear material is formed into a critical mass releasing large amounts of γ and neutron radiation as well as fission by-products, but the material does not stay at critical mass long enough to create an actual nuclear explosion. Last, a radiation dispersal device (RDD) can be exploded to disperse highly radioactive material of sufficient quantity to potentially produce acute radiation injuries [7].

I have already mentioned the difficulty in obtaining classified information to better understand the threats that are out there. One of the more recent comprehensive analyses of the threat of a nuclear attack was by *New York Times* reporter Bill Keller, entitled “Nuclear Nightmares”, in the *New York Times Magazine* [10]. In his article, Mr. Keller provided an in-depth look into the threats of a terrorist organization either obtaining an actual nuclear device or manufacturing a homemade nuclear device. He also examined other aspects of radiological terrorism, such as RDDs and terrorism directed toward nuclear power plants.

A true nuclear explosion would most likely occur from the use of a stolen nuclear weapon. Our military has long had concerns about the security of nuclear weapons in certain countries outside of the United States, particularly Russia and the former Soviet satellite republics [10]. One does not have to detail the devastation that the detonation of a single nuclear weapon would have in terms of the loss of life and damage to the country and its economy and environment. The psychological damage alone to the country would be extremely traumatic. How likely is this to occur? Not very likely, according to the evidence to which we have access. However, as resources for nuclear material grow and information on how to use them spreads, the probability may increase.

What about a homemade nuclear device? The issue here would not be the importation of a stolen nuclear weapon but the assembly in the United States of a nuclear weapon from component parts. In an analysis presented to the Fourth International Chemical and Biological Medical Treatment Symposium, Bernard Anet termed these *improvised nuclear devices* (INDs) [11]. Both Keller and Anet pointed out that their analyses indicated that IND assembly is beyond the scope of an individual terrorist. Keller quoted former United Nations weapons inspector David Albright: "You can do it in facilities that look like barns, garages, with simple machine tools. You can do it with 10 to 15 people, not all Ph.D.'s, but some engineers, technicians. Our judgement is that a gun-type device is well within the capability of a terrorist organization" [10]. Carnegie Endowment senior associate Rose Gottemoeller indicated in her testimony to the House Subcommittee on National Security that the principal barrier to fashioning a gun-type or Hiroshima-style nuclear device is in obtaining a large amount of weapons-grade nuclear material, such as highly enriched uranium or plutonium [12].

The technical challenges of crafting a successful IND are great. Even greater is the challenge of obtaining sufficient quantities of nuclear material for the device without detection. An IND may produce a nuclear explosion. If mistakes are made in assembling the device or if the crafting of the device does not meet the degree of precision required, the IND might simply create a nuclear detonation or critical mass but not the colossal associated nuclear explosion. To obtain a nuclear explosion, the nuclear material must remain together long enough to produce the intense neutron flux that produces the explosion. Given all of the obstacles faced in the production of an IND, the consensus is that the probability of construction is extremely low [10-12].

In any analysis of radiological terrorism, consideration should be given to attacks on nuclear power plant facilities. This possibility is very real, but the probability is quite low for several reasons [10-12]. First, unlike many civilian industrial facilities, nuclear power plants operationally are protected by complex power plant design safeguards and redundancies in power plant safety systems [11]. Numerous protective measures prevent the release of radioactive material into the environment. Second, extensive security measures designed to thwart terrorist attacks exist at all these facilities. They are often likened to military fortresses. Third, all nuclear material is safeguarded according to federally set guidelines and guidelines set by the International Atomic Energy Agency. Last, all of the material in a power plant is highly radioactive. Handling this material is complex and difficult.

In an attack from the air, breaching a power plant's containment vessels with a jetliner would be much more difficult than hitting the World Trade Center or the Pentagon with the same aircraft. Aircraft smaller than a large jetliner would not pose a threat to containment vessel integrity [10,11]. A successful direct ground attack would be even more difficult to pull off. Local authorities and the military train frequently to be prepared for such an attack. Still, the probabilities for any of these forms of attacks are not zero.

Last, there is the possibility of the detonation of an RDD [10-13]. Technologically, an RDD is the simplest device to assemble, making the probability of deployment the highest of all the threats so far considered. The greatest technological challenge of assembling an RDD is handling the radioactive material [11]. The greater the mass of radioactive material incorporated in a device, the greater the hazard presented to those handling that material.

In his testimony before the Senate Foreign Relations committee, Dr. Henry Kelly described three scenarios [13]. The first scenario modeled an RDD using a pea-sized source of ^{137}Ce dispersed by 10 pounds of TNT at Union Station in Washington, DC. The source is similar to that discovered in February 2002 in a discarded piece of industrial equipment at a North Carolina scrap metal processing plant. The second modeled an RDD explosion using a ^{60}Co pencil in Battery Park at the southern end of Manhattan. These ^{60}Co pencils, 1 inch in diameter and 1 ft long, are used to sterilize food in processing plants across the country. The third model employed a small source of ^{241}Am, similar to americium sources found in oil well surveying equipment. This material was modeled being spread from the detonation of 1 lb of TNT at Times Square in New York. Both ^{137}Ce and ^{60}Co are high-energy γ emitters. ^{241}Am is an α particle emitter [13].

In all three case studies, the only immediate projected injuries occurred as a direct result of the explosive detonation. The greatest problem created by the RDDs was the decontamination of the affected buildings and areas contaminated by the devices. In the ^{60}Co scenario, the largest radiation source of the three, the level of contamination was great, with a large area of Manhattan contaminated to levels that significantly exceed current US Environmental Protection Agency (EPA) guidelines. When compared with the radiation levels created by the Russian Chernobyl disaster, the property left "as is," without decontamination, a significant area of Manhattan would be permanently closed to routine access (Fig. 1).

The acute effects of such a device would be limited. Radiologists would need to be involved in the decontamination process and would be the greatest help in assisting in the triage of those requiring medical attention. We would be important in accessing the needs of specific therapies if a large radiation dose were received.

The long-term effects of a radiological attack, however, would be the greatest. The dominant effect would probably be the psychological effects created by the latent radiation. Psychological effects are usually far greater than the real damage. Witness the nation's response to anthrax and the threat of a SARS epidemic. Additionally, there always is the fear of additional attacks on the country.

The most important role that we as radiologists can play is to help put the cancer risk created by an RDD into the proper perspective. Depending on the resource, the current overall

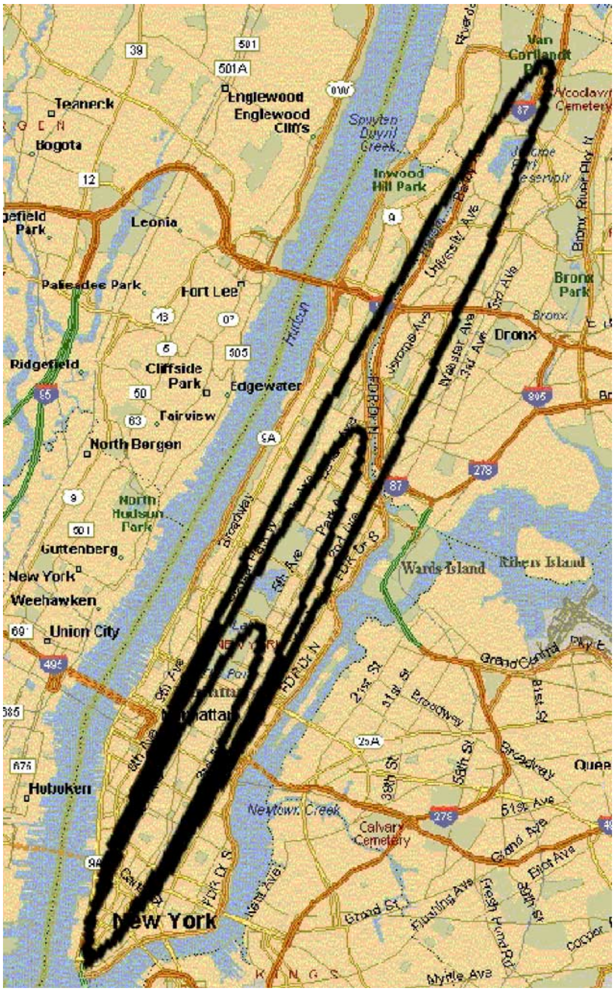

Fig. 1. Contamination due to ^{60}Co food irradiation pencil placed into a dispersal bomb in New York City: Chernobyl comparison. Inner ring: same radiation level as permanently closed zone around Chernobyl; middle ring: same radiation level as permanently controlled zone around Chernobyl; outer ring: same radiation level as periodically controlled zone around Chernobyl. [Reprinted with permission [13].

cancer risk to the general population is estimated at approximately 40%. In an example given in the Federation of American Scientists report, the increase in cancer risk to the population of Danbury, Connecticut, as the result of the residual radiation from a ^{60}Co RDD was 0.01%. Therefore, the overall increase in lifetime cancer risk in a population of 40,000 would go from 10,000 to 10,004 cases. This theoretical risk increase is dependent on the constant exposure of the population living in the region over a 40-year period (Fig. 2).

The decontamination of the more highly contaminated areas of Manhattan would be expensive. EPA guidelines are very stringent concerning the permissible levels of residual radioactivity. Princeton University physicist Dr. Robert W. Nelson indicated that the cleanup could cost $2 trillion [14]. The economic impact to the country of such a terrorist act and the subsequent cleanup would be enormous.

The hazards presented in the RDD example using americium, an α emitter, pose a different set of health hazards. Because of the short distances α particles can travel in air, these agents pose health hazards when they are inhaled or ingested. Left "as is," without decontamination, the contamination would be spread by the wind and other factors, creating opportunity for internal contamination. In the example used in the Federation of American Scientists report, the potential cleanup costs would exceed $50 billion if current EPA guidelines were followed [13].

Will "it" happen? Many have gone on record, including Vice President Cheney, in stating that it is not a question of if but when [15]. Secretary of Homeland Security Tom Ridge has echoed Vice President Cheney [16]. The events of 9/11 were not predicted, and certainly the timing was not anticipated. Secretary Ridge has indicated that he is most worried by

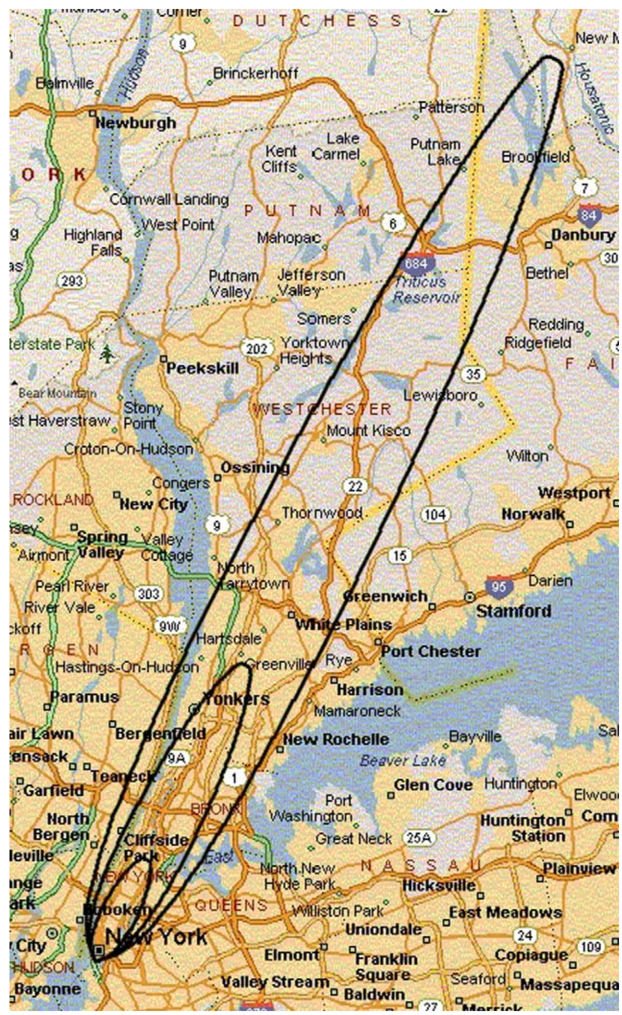

Fig. 2. Long-term contamination due to ^{60}Co food irradiation pencil placed into a dispersal bomb in New York City: US Environmental Protection Agency (EPA) standards. Inner ring: 1 cancer death per 100 people due to remaining radiation; middle ring: 1 cancer death per 1000 people due to remaining radiation; outer ring: 1 cancer death per 10,000 people due to remaining radiation. The EPA recommends decontamination or destruction. [Reprinted with permission [13].

the radiological and nuclear scenarios. The probabilities of such attacks exist. The time and place will not be of our choosing. The nation must be prepared.

As a component of the first responders in the medical community, we must ensure that our hospitals and other facilities are prepared and that we are prepared to deal with the emergency created by a nuclear terrorist attack. For this reason, the ACR has formed the Emergency Preparedness Task Force, which developed the primer *Disaster Preparedness for Radiology Professionals: Response to Radiological Terrorism* [7]. The primer goes over the 10 basics of response that you and your facilities will be required to implement. It is loaded with pertinent information that can be used to help in a response. It contains a large number of references and enumerates several Web sites that can be used as instant references. The primer is a living document. The most recent version can be found at http://www.acr.org/departments/educ/disaster_prep/disaster-planning.pdf.

SUMMARY

- The United States remains vulnerable to another terrorist attack using a variety of methods, including kidnapping, cyberattacks, chemical or biological attacks, attacks employing nuclear weapons, the attempted destruction of a nuclear power plant, or the detonation of a "dirty" bomb.
- Most believe that a terrorist attack of some form is inevitable.
- In the event of the use of a chemical or biological weapon, radiologists will be asked to image the victims of these attacks, and they should be familiar with the imaging findings in these terrorist scenarios.
- Terrorism involving radioactive material is felt to be one of the methods that has a relatively high likelihood because of the economic impact and disruption to normal daily activity.
- A thermonuclear explosion or a fizzled thermonuclear detonation will produce the most devastating impact to the nation, but the challenges in accomplishing such an explosion are extremely great. The explosion of a "dirty" bomb is technically less challenging, and therefore, the RDD scenario has generated great concern among terrorism experts.
- Radiologists and other radiology professionals must prepare themselves, their facilities, and their communities to deal with the victims and the community aftermath in the event an act of terrorism, especially an act of nuclear or radiological terrorism, occurs in their community. Wherever the terrorist act occurs, it will be local to those directly affected.

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