

# Understanding Radiologic and Nuclear Terrorism as Public Health Threats: Preparedness and Response Perspectives\*

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Terrorism dates back to antiquity, but our understanding of it as a public health threat is still in its nascent stages. Focusing on radiation and nuclear terrorism, we apply a public health perspective to explore relevant physical health and psychosocial impacts, the evolving national response infrastructure created to address terrorism, and the potential roles of nuclear medicine professionals in preparing for and responding to radiologic and nuclear terrorism.

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**U**nderstanding terrorism begins with defining it—a complex task in itself. “Terrorism” has had >100 definitions, each varying in inclusion or exclusion of certain motivating factors, means of attack, and targeted groups or individuals (1). The U.S. federal government itself has several working definitions of terrorism, whose general themes include a calculated, unlawful use of violence to intimidate or coerce populations or governments (2–4).

A brief overview of relevant historical events can aid in our understanding of radiologic and nuclear terrorism threats. In 1987, a nonterrorism-related radiologic emergency in Brazil involved health effects and radioactive material mirroring what might be expected in a radiation terrorism scenario. In this incident, a group of men seeking scrap metal dismantled an abandoned teletherapy unit at the Goiana Institute of Radiotherapy, exposing the unit’s platinum core containing <sup>137</sup>Cs (5). The purchaser of this scrap

metal then unknowingly distributed the radioactive material among relatives, friends, and children, resulting in contamination of 249 people and 4 deaths (5). The well-documented physical, economic, and psychosocial impacts on the area were significant (5).

More recently, threats of radiologic terrorism from al Qaeda were raised in 2002 when 31-y-old Jose Padilla was detained on suspicion that he intended to deploy a radiologic dispersal device (RDD) in the United States (5); detailed plans for RDDs were uncovered after the destruction of an al Qaeda training camp in Afghanistan.

Development of nuclear weapons began in the 1940s (6). In 1941, the British began a nuclear weapons’ research program (6). Fearing German production of nuclear weapons during World War II, the United States and allied nations joined efforts and the Manhattan Project began (6). In 1945, the United States dropped an atomic bomb on Hiroshima, Japan, and created the world’s first radiologic public health emergency, resulting in 60,000–70,000 immediate deaths (6). When this failed to persuade the Japanese to surrender, the United States dropped a second bomb on Nagasaki, Japan, 3 d later, resulting in another 40,000 deaths. The Japanese surrendered within 5 h of the second bomb. Within 5 y, an estimated 340,000 Japanese, mostly civilians, had died as a result of the 2 bombs (7).

In 1949, the Cold War began with the Soviet Union’s first nuclear test (6). The United Kingdom, France, and China also joined the United States in nuclear weapons’ testing (6). Since 1949, approximately 2,000 nuclear test explosions have taken place around the world (6).

The 1968 Treaty on the Non-Proliferation of Nuclear Weapons sought to promote nuclear disarmament and prevent the development of additional nuclear weapons and the spread of nuclear weapons’ technology (6). At present, 187 countries have signed the treaty (6). However, several countries continue to have active nuclear weapons’ programs, and the concern exists that terrorist organizations have or may obtain nuclear weapons (6).

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## RADIOLOGIC TERRORISM SCENARIOS

Terrorist acts or threats involving radioactive materials are broadly categorized into radiologic events, which involve the nonnuclear release of radioactive materials, and nuclear events involving nuclear weapons.

Radiologic terrorism events include, for example, radiation sources intentionally hidden in public places (sometimes referred to as “radiologic exposure devices” or REDs); RDDs; attacks on nuclear facilities or radioactive materials in transit on trucks and trains that result in intentional release of radioactive materials; and detonation of malfunctioning nuclear weapons that result in no nuclear yield (8,9). The most common type of RDD is the “dirty bomb”; this type of RDD employs conventional explosives to disperse radioactive materials. Other RDD dispersal methods may include techniques such as an aerosol or spray (6,8,9).

Nuclear events involve the use of nuclear weapons, devices that use fission or fusion reactions to produce destructive energy in pulses or waves of heat, electromagnetic energy, air pressure, and radiation (6). Nuclear weapons are described by their potential yield or the energy released in their detonation, measured in kilotons (kT). A 1-kT nuclear device, for example, refers to the approximate equivalent explosive yield from 1 metric ton of the chemical explosive trinitrotoluene. Weapons that are capable of producing 0.01–10 kT are considered low yield (8). For several reasons, including the high-level security of intact high-yield weapons and extreme sophistication needed to construct high-yield weapons, low-yield weapons are considered much more likely to be used by terrorist organizations (8,10). Although these weapons are called low yield, even the lowest-yield weapon, 0.01 kT, would have an explosive impact greater than the Oklahoma City bombing in 1995 (8). The nuclear weapons detonated at Hiroshima and Nagasaki had a yield of 15 and 21 kT, respectively (7).

RDDs are said to be the most likely radiation weapons because of their relatively simple technology and the widespread use of RDD-adaptable radioactive materials in medicine, scientific research, and industries, such as civil engineering, petroleum engineering, aeronautics, and radiothermal energy generation (9,11). Such sources of radioactive material often have little security and may be small and portable (12).

Some important radionuclides that may be used in RDDs, their sources, and maximum radioactivity for the source are listed in Table 1 (11–14). Although virtually any radionuclide could be used in an RDD, most experts consider those listed in Table 1 as the most likely candidates for RDDs because of their relative ease of access compared with other radionuclides.

The type of radionuclide used in RDDs is critical because this influences dispersion (due to the physical and chemical characteristics of the source containing a specific radionuclide), risks (based on type of emissions and available activity), and later mitigation. Discussions are currently under way about changing the chemical form of larger sources (such as used in irradiators) so that these will pose less of a hazard if used for RDDs.

RDD events may result in physical injuries, variable radiation contamination, and psychologic trauma to a population. The severity of physical injuries depends on the nature of the explosives used, and the extent of contamination depends on the degree to which the radioactive material is dispersed. Dispersal is dependent on the physical and chemical form of the radioactive material, the explosives, and the atmospheric conditions (15). Smaller particles are more easily dispersed but more difficult to make (12). More explosive will disperse the material further (12). Higher winds would distribute the material more widely, and wind direction would determine where contamination occurred (12). Rain or snow would more quickly remove the material from the air, but concentrate it in water sources (12). Greater dispersal results in a larger area of contamination, whereas less dispersion might result in higher levels of radiation exposure for those exposed (12).

In spite of the common concern about radiation contamination, the blast- and radiation-related physical health consequences from an RDD would likely be limited to a maximum area of a few city blocks, and the most significant contributor to injury and mortality will be the blast rather than the radiation itself (15); any victim close enough to receive an acute lethal radiation dose would likely have been killed by the explosion itself (8). In an RDD event scenario, it has been estimated that, for most people directly involved, the exposure would have an estimated lifetime health risk comparable to that from smoking 5

**TABLE 1**  
Important Radionuclides in RDDs, the Source, and Maximum Radioactivity for the Source

Radionuclide	Source	Maximum radioactivity for source	
		Becquerels	Curies
$^{60}\text{Co}$	Medical therapeutics, industrial radiography, and food irradiation	$3.7 \times 10^{15}$ – $2.96 \times 10^{17}$	100,000–8,000,000
$^{137}\text{Cs}$	Medical diagnostics and therapeutics, blood irradiation to kill antibodies before transfusion, industrial radiography, and food irradiation	$3.7 \times 10^{14}$ – $9.25 \times 10^{15}$	10,000–250,000
$^{192}\text{Ir}$	Medical therapeutics and industrial radiography	$3.7 \times 10^{13}$	1,000
$^{241}\text{Am}$	Industrial radiography	$7.4 \times 10^{11}$	20

Data are from (11–14).

packages of cigarettes or the accident risk of taking a hike (16). For example, we modeled a dirty bomb explosion in Baltimore, based on National Planning Scenario 11, which involves 85.1 TBq (2,300 Ci) of  $^{137}\text{Cs}$  and 1,364 kg (3,000 lb) of ammonium nitrate/fuel oil as an improvised explosive. In our modeling, the 0.01-Sv (1 rem) total dose region was a cigar-shaped area extending only several blocks downwind from the explosion and was only about 1 block wide. It is possible, but unlikely, for some victims to survive the blast and receive high doses; imbedded radioactive source fragment from the RDD may have high specific activity and associated high dose rates.

Therefore, from a public health perspective, the RDD is much more of a psychologic weapon than a physical weapon for an affected community. For this reason, RDDs are often referred to as Weapons of Mass Disruption. After an event, public fear and panic could disrupt social order and overwhelm emergency response and medical systems. Depending on the location of an event, extended clean-up and site restoration could disrupt commerce and transportation. On the basis of the responses by the public and relevant officials, the degree of social disruption will influence whether RDD might continue to be used as a terrorism modality. We consider the psychosocial effects of terrorism, especially radiologic terrorism, to be so important from a public health perspective that we consider such effects separately.

## NUCLEAR TERRORISM SCENARIOS

Nuclear facilities, including nuclear reactors and fuel storage depots, are potential terrorist targets (8). Modern commercial nuclear reactors are well secured and protected, contained by walls of steel and concrete that are several meters thick. These barriers prevent dispersal of radioactive material should "melt down" from the heat produced by the radioactive fission products occur. The barrier secondarily protects the reactor from air or other outside explosive attack, and even high-level explosives would be unlikely to significantly penetrate the protective barrier. In 1988, an unmanned airplane was flown at 480 miles per hour into a 3.6-m test wall. The plane penetrated only a few centimeters (17).

Only a reactor that is being refueled, with its containment structure open, would be at risk for releasing radioactive material into the surrounding environment (8). However, in this scenario the reactor would be shut down, and much less radioactive material would be present compared with active operation (since fission products quickly decay to low levels during shutdown). The Nuclear Regulatory Commission has stated that the likelihood of a direct attack on a reactor, resulting in both direct damage to the reactor and the release of radioactive materials, is low (18). If a terrorist attack on a nuclear facility were able to penetrate a reactor and breach containment, release of radioactive material and subsequent health effects would likely be

on a smaller scale than Chernobyl, because efficient and effective dispersal of source materials requires an explosion with significant energy (8). Depending on the nature of the explosives used and material attacked, the area at risk for health effects would range from a few city blocks to several miles (8).

Nuclear facility fuel storage depots are less well protected than nuclear reactors, but spent fuel contains much less radioactive material (8). A terrorist attack on spent fuel would be unlikely to expose a population to significant amounts of radiation (15). However, as with an RDD, though the mortality and level of radiation exposure resulting from a terrorist attack on a nuclear facility would be relatively low, the psychologic impact, even of an unsuccessful attack, might be severe. An analysis of the Three Mile Island incident has demonstrated that mental health issues were one of the main public health consequences of the event (6).

A low-yield, crude nuclear bomb, or improvised nuclear device constructed by a terrorist organization, might contain weapons-grade plutonium, reactor-grade plutonium, or highly-enriched uranium (HEU) and might be either a gun-type or an implosion-type device (8,10). Because of presumed easier access to HEU and the relative simplicity of a gun-type device, a HEU gun-type device is considered the nuclear weapon most likely to be developed by a terrorist group (10).

The successful use of a nuclear weapon by terrorists would require significant technical and financial resources for planning; access to fissile material; expertise to construct a weapon; the ability to covertly transport and place the weapon; and the motive, will, and ability to detonate the weapon without detection (8,10).

A weapon constructed de novo by a terrorist group would likely be much larger than a stolen weapon and would, therefore, be easier to detect. Weapons with increasing nuclear yield potential would be larger and more detectable, not only because of size but also because of increasing radiation signature (8).

Detonation of a nuclear weapon, resulting in an initial air blast and the release of radiation, produces pressure and heat waves causing the greatest amount of destruction. Radiation from the first minute after detonation, or initial radiation, accounts for only about 5% of the total energy release, whereas the fallout from longer-lived radionuclides, or residual radiation, represents only an additional 10% of the total energy (19).

## EXPOSURES

Only ionizing radiation and the electromagnetic and particulate forms of ionizing radiation that have health consequences—x-rays,  $\gamma$ -rays,  $\alpha$ -particles,  $\beta$ -particles, and neutrons—are concerns for radiologic terrorism.

Initial radiation results almost entirely from the nuclear processes occurring at detonation (20), producing  $\alpha$ - and  $\beta$ -particles as well as  $\gamma$ -rays and neutrons. The  $\gamma$ -rays and

neutrons, however, are of greater consequence because of their ability to travel greater distances (21).

For the initial radiation exposure, conventional time, distance, and shielding principles apply, although the inverse-square relationship for distance does not always completely apply because of the complex atmospheric, mixed radiation field created initially after detonation (8).

As a result, absorbed dose often increases at a much greater rate as "ground zero" is approached (8).

In addition, unlike RDDs, where the amount of radioactive material released is directly proportional to the amount of radioactive material in the bomb, the amount of initial radiation produced from detonation of a nuclear weapon does not increase linearly with the yield of the weapon (20). However, initial blast and thermal effects do increase proportionally, and as the weapon size increases they play a much greater role in initial health effects than initial radiation (20).

Residual radiation can be either fission products of  $\beta$ -particles and  $\gamma$ -waves, which produce the greatest levels of ionizing radiation, or unfissioned plutonium or uranium, which decays as  $\alpha$ -particles (8,20).

The fallout pattern from a ground-level nuclear explosion, the most likely scenario for a terrorist nuclear incident, would depend on the weapon yield, the height of the burst, and the meteorologic conditions (8). The greater the nuclear yield and the height of the burst, the greater the distance the fallout will travel. Wind direction determines the area that will be affected, and wind speed can increase the fallout area (20). Rain and snow can accelerate fallout locally (20).

## HEALTH EFFECTS

We assume that readers of *The Journal of Nuclear Medicine* are well aware of the health effects of ionizing radiation; thus, we only briefly review these effects here.

There are 2 basic models for understanding the health effects of ionizing radiation. The deterministic model states that as the dose of radiation increases, the severity of a given health effect increases (22,23). According to the deterministic model, there is a threshold of radiation dose below which a given health effect will not occur and above which a given health effect will occur (23). All health effects of ionizing radiation, with the exception of cancer and genetic effects, follow the deterministic model (23). Examples of deterministic effects include bone marrow suppression, cataract formation, and fertility impairment (22).

Unlike all of the other health effects of ionizing radiation, cancer follows the random or "stochastic" model (23). The stochastic model states that as the dose of ionizing radiation increases, the risk (not the severity) of cancer increases (22,23). In contrast to the deterministic model, the stochastic model does not have a threshold, and there is no such thing as "zero risk" of cancer from a given dose of ionizing radiation.

Radiation injury occurs through ionization of water molecules leading to the production of free radicals, which directly cause organelle and cellular damage (9). Ionization can also break covalent bonds in macromolecules such as proteins and DNA and lead to changes in the biologic or chemical function, particularly when cellular repair mechanisms are ineffective (9,24).

In acute injury, the risk of cellular damage is proportional to the total absorbed dose, becoming clinically apparent in organ malfunction or failure when significant numbers of cells have been damaged (24). Rapidly dividing cells, such as intestinal mucosal cells and blood-producing cells, are the most susceptible (24).

Cutaneous radiation injuries (CRI), occurring from direct contact with radioactive material in doses as low as 2 Gy (200 rad), follow the deterministic model (24,25).

Unlike thermal burns, where tissue injury is quickly apparent, CRI findings are delayed (24,25). Early signs and symptoms (within hours) include itching, tingling, and transient skin reddening or swelling. This is followed by a symptom-free latent period of days to weeks, and then, depending on the dose, by intense skin reddening, blistering, peeling, and ulceration that may occur in several waves (25). In cases of high-dose exposures, irreversible tissue damage may occur and result in permanent hair loss, damaged sebaceous and sweat glands, tissue atrophy and fibrosis, alterations in skin pigmentation, and tissue necrosis (25).

When acute whole-body exposure to high doses of penetrating radiation occurs, acute radiation syndrome (ARS) may result (26). ARS is the manifestation of radiation-induced cellular death and deficiency in hematopoietic, gastrointestinal, and neurovascular tissue (22,26). Damage to these tissues results in clinical presentations termed the hematopoietic, gastrointestinal, and neurovascular (or cerebrovascular) syndrome, respectively.

ARS also follows the deterministic model and occurs only above a threshold dose of about 0.7 Gy of penetrating radiation (26). With increasing doses, onset of the syndrome is more rapid, and the ARS is more severe and includes an increasing number of tissue types (22). In practice, it is difficult to specify meaningful threshold doses and dose ranges for each syndrome (because of individual variations in susceptibility), but we will make an attempt here.

As with CRI, onset of ARS is delayed after exposure (22). ARS is described in 4 stages: the prodromal stage, the latent stage, the manifest illness stage, and recovery or death. The prodromal stage occurs as early as minutes after exposure and lasts for up to several days (26). During this time, nausea, vomiting, anorexia, and, depending on dose, diarrhea occur. In the latent stage, the patient will feel generally well for hours to days (26). Timing and duration of the latent stage is also variable and dose dependent (22). The manifest illness stage occurs next, and the type of illness depends on the dose received and the type of syndrome, or syndromes, that occurs (26).

At doses in the range of 0.7–10 Gy, the full hematopoietic syndrome occurs (26). Bone marrow depression leads to reduced white blood cell and platelet counts, with subsequent hemorrhage and infection (24). Patients exposed to lower doses recover over periods of weeks to a year (26). At doses above 1.2 Gy, the mortality rate for the hematopoietic syndrome increases, and the 60-d median lethal dose ( $LD_{50}$ ) is 2.5–5 Gy (26).

At doses greater than 10 Gy (though known to occur at doses as low as 6 Gy), the gastrointestinal syndrome occurs as a result of intestinal mucosal stem cell death (26). This leads to fluid and electrolyte imbalance, dehydration, shock, and hemorrhage. The mortality rate associated with the gastrointestinal syndrome is extremely high (22). At even higher doses (>20 Gy), the neurovascular syndrome occurs. Damage to neurovascular tissue leads to hypotension, cerebral edema, seizures, and invariable death, often within 3 d of exposure (22).

Death due to the hematopoietic syndrome occurs within a few months of exposure (26). Patients who develop the gastrointestinal or neurovascular syndromes almost invariably die (26). In the case of the gastrointestinal syndrome death usually occurs within 2 wk, and in the neurovascular syndrome death occurs within 3 d (26).

Delayed health effects of ionizing radiation include cancer, genetic effects, cataracts, and growth and mental retardation of the developing fetus. Many types of cancer have been linked to ionizing radiation exposure, with the incidence of cancer modified by the dose rate, total dose of radiation, and the quality (relative biological effectiveness) of the radiation. As radiation-induced cancer follows the stochastic model, there is assumed to be no dose threshold, and the severity of cancer is not dose related. The latency period for cancer development after radiation exposure is long, on the scale of years, but variable by type of cancer. The minimum latency for radiation-induced leukemia is 2–3 y, for bone tumors it is 3–4 y, for thyroid cancer it is 4–5 y, and for solid organ tumors it is 10 y. Latency, especially for solid organ tumors, can be as long as 50 y or more (8,27).

Persons with a history of exposure to ionizing radiation may have an excess lifetime risk of cancer, but in many cases this excess risk is quite small (27). For example, in a group of 10,000 people, approximately 2,000 would die of cancer in the absence of radiation exposure (23). If this population is exposed to a dose of 0.01 Sv (1 rem), perhaps from a dirty bomb, that number would increase by only 5 or 6 (28).

The other delayed health effects of exposure to ionizing radiation, cataract formation and mutations leading to birth defects (teratogenicity), follow the deterministic model of exposure. Cataract formation begins sometime between 6 mo and several years after eye irradiation (20). The exposure threshold for cataract formation is approximately 2 Sv (200 rem) (20). Mutations leading to birth defects can occur when a fetus is exposed to ionizing radiation (23). An

exposure threshold for radiation-induced birth defects is not firmly established but is estimated to be 0.1 Gy in the maximally vulnerable time of gestation, 8–15 wk. Birth defects include smaller head or brain size, poorly formed eyes, abnormally slow growth, and mental retardation (23).

Nuclear detonation can also result in blast and thermal injuries. The air blast of nuclear explosion produces injuries directly and indirectly through blast wind (20). Direct injuries occur in persons closest to the point of detonation (8,20). Rapid compression and decompression result in transmission of pressure waves through tissue at bone/muscle and air/tissue interfaces. The lungs and intestines are particularly susceptible. Indirect blast wind drag forces (produced by rapid and forceful pressure changes in the air at ground level) can cause injuries at greater distances and in a nuclear event will be responsible for more casualties than the direct blast wave (20). Blast winds can exceed the force of the strongest hurricane winds and cause missile, blunt trauma, and crush injuries (20).

Detonation of a nuclear weapon produces a fireball with temperatures in excess of millions of degrees Kelvin (20). The light from this can cause temporary or permanent flash blindness while the thermal energy causes burns. All objects in the immediate vicinity of the detonation will be incinerated, but at greater distances, the type and degree of burn will depend on the duration of the thermal pulse and the amount of energy per square centimeter, clothing, and other factors (20). The thermal energy from a nuclear blast can travel great distances, particularly in the case of large weapons. A 1-kT weapon will produce thermal burns with 50% mortality at 610 m from the detonation site (8). A 10-kT weapon will produce burns with the same mortality rate at 1,800 m (8).

The role of initial thermal radiation versus ionizing radiation in causing casualties is variable with weapon size. In small nuclear explosions, a person in sight of the explosion might receive nonlethal thermal burns but a fatal dose of radiation (8). For weapons of around 1 kT, thermal burns are as likely as ionizing radiation to produce fatalities (8). For weapons of 10 kT and greater, thermal burns will cause fatalities at much greater distances than initial ionizing radiation (8,20).

## PUBLIC HEALTH RESPONSE AND MEDICAL MANAGEMENT

The response to a radiologic terrorist event will involve multiple disciplines from all levels of government, including emergency medical systems, fire, law enforcement, radiation experts, hazardous material (HazMat) teams, public health officials, and health care providers.

Using an RDD as an example, crisis management at the scene would begin with first responders equipped with dosimeters. If they detected higher-than-expected levels of radiation, a team of radiation experts and HazMat personnel would determine the radionuclides involved and their amounts. This team, in concert with the state environmental

department, would estimate the doses and geographic distribution of the radioactive “plume.” On the basis of these assessments, public health and public safety officials would guide the community on whether to shelter in place or evacuate (or selectively evacuate), factoring in considerations of time, distance, and shielding.

Medical management of a radiologic explosive event would begin in the field with triage of casualties, with first aid and resuscitation as the initial intervention. For a detailed list of the steps involved in the medical management of a radiologic explosive event, the reader is referred to the article on this subject by Koenig et al. (24).

Both the injured and noninjured would require external decontamination by trained, personally protected personnel. The first step in external decontamination, also the most effective step, is to remove and double bag clothing for future exposure analysis, followed by washing the head and hands or full showering, depending on exposure (8).

Internal decontamination uses dilution, purging, diuretics, and laxatives to facilitate excretion and reduce incorporation of radionuclides (8). Specific protocols for internal decontamination are radionuclide specific and are beyond the scope of this document. An excellent reference for decontamination drugs was published by Marcus (29).

Assessing patients for ARS involves symptom evaluation (nausea, vomiting, anorexia, diarrhea) and serial analysis for lymphocyte count, as both the rate and the degree of decrease of lymphocytes are dose dependent and can be used to estimate the absorbed dose (8,26). In a patient with no other injuries, a 50% drop in lymphocyte count and a total count of  $<1 \times 10^3 \mu\text{L}^{-1}$  within 24–48 h indicates at least a moderate dose of acute radiation, although this is less reliable for patients with other injuries because burns and trauma can also cause lowering of the lymphocyte count (8).

Management of ARS patients depends on the dose of radiation received. Patients can be managed as outpatients for a dose of 1–2 Gy, are hospitalized and receive various interventions for 2–8 Gy, and typically receive comfort care only for doses greater than 8 Gy (9). Management may include neutropenic isolation precautions, antibiotic prophylaxis, aggressive hydration and electrolyte replacement, transfusion with irradiated blood products and platelets, sucralfate or prostaglandin therapy to prevent gastrointestinal hemorrhage, and parenteral nutrition (8,9). Of note, in the post-Chernobyl era, cytokine therapy is recognized as the preferred alternative to allogeneic bone marrow transplantation, as the latter has rarely been effective in treatment of severe ARS (30).

Diagnosis of CRI is based on signs and symptoms (early itching, tingling, and transient skin reddening or swelling). Early management may include antihistamines, antiitch preparations and corticosteroids to minimize itching, antibiotic prophylaxis, topical antimicrobial and antiinflammatory agents, wound cleansing and removal of dead tissue, and pain management (25).

The medical issues after a dirty bomb event include acute and delayed issues. In addition to the usual medical problems after a bomb attack (shrapnel injuries and burns), other acute medical issues include acute radiation syndromes and internal contamination. Delayed health effects, as discussed, include cancer. There are both acute and delayed health effects on the developing fetus from in utero radiation exposure.

Guidelines for long-term management, particularly cancer screening, of patients with a history of radiation exposure are not well established. Cancer risk is dose dependent, and persons with a greater exposure history have a greater need to be evaluated, but screening is not effective for all cancers (8). In addition, there is no need to screen until the end of the known latent period for a given radiation-induced cancer (8). Most states already have cancer surveillance and registry systems in place as part of their public health services.

The response to a nuclear event would be managed similarly, though the scope of the event would be of a greater scale with vastly greater numbers of patients with traumatic injuries and burns. In addition, more public health and medical response infrastructure would likely be lost, further complicating response and recovery.

## THE TERROR OF TERRORISM

The psychologic impacts and goals of the terrorist represent common threads among different definitions of terrorism. In fact, psychologic terror is the primary objective of terrorist acts. Therefore, it makes sense to consider the psychosocial aspects of terror along with the physical aspects.

Radiation is an especially powerful terrorism weapon because it instills considerable fear. In this regard, in a classic article on risk perception, Slovic identified 2 clusters of factors that increase fear: “threat,” which includes such characteristics of the risk as uncontrollable, potentially fatal, and not easily reduced adverse outcomes; and “observability,” which includes inability to sense exposure and delayed effects (31). Radiation has characteristics that fall squarely in line with Slovic’s factors. It is physically imperceptible, requiring sophisticated monitoring equipment for detection; its carcinogenic potential includes a long latent period; exposure—especially from a terrorist act—is involuntary; and such exposure is potentially fatal.

The mental health consequences of a terrorism attack include effects on those victims directly impacted by the event, as well as the fear, terror, and demoralization transmitted to those not directly affected by the event. The latter phenomenon is referred to as “psychological contagion” and has been found to be important in communities exposed to terrorism (32). Many experts have noted that an act of terrorism can be expected to create many more psychologic casualties than physical casualties (33–35). The Institute of Medicine expects an estimated 4 psychologic

casualties for every physical casualty, a ratio observed in recent terrorism attacks (33).

Most terrorism survivors are normal people facing extraordinary circumstances and in nondisaster times would be quite able to manage their own lives. However, their usual individual and societal support systems may be compromised after a terrorist attack. Unable to access traditional emotional and financial resources, some survivors can develop long-term mental health problems that can occur after a long latency period (36). For a description of these long-term mental health consequences of terrorism, the reader is referred to Bass et al. (36).

Those in the helping professions who are called to respond to a disaster, especially an act of terrorism, are also vulnerable to the short- and long-term mental health consequences (36). In addition to first responders and workers in the helping professions, other populations especially vulnerable to the mental health consequences of terrorism include families with children, the elderly, those with chronic mental illness, and rural residents. These groups are at risk because they may already be experiencing psychosocial, medical, or financial difficulties that would be compounded by a terrorism event (37,38).

One of the best techniques to fight the “terror” of terrorism is to integrate excellent crisis communication into every disaster response plan created, beginning far in advance of any event.

## CRISIS COMMUNICATION

In a crisis, “how” information is communicated to the public is as important as “what” information is communicated. By communicating in a manner that is clear, empathic, consistent, and meaningful to the public, important information can be provided that could help citizens take appropriate steps to protect themselves from harm (39).

By educating the public and other professionals about the true risks from radiation exposure, radiation experts can help to reduce the public’s misunderstanding of, and consequent fear of, radiation. If the public’s perception of the risk of a situation, such as radiation exposure, is closer to the actual risk of the situation, they can make better decisions about how to protect their health and safety and that of their loved ones.

Risk communication procedures must be thoroughly integrated into agency response plans to ensure that the general public remains well informed at all phases of a terrorism event. Communication must occur throughout the planning stages before an event occurs, during an event to provide reliable and timely information about the situation, and after the event to foster as speedy a recovery as possible. By effectively and empathically communicating with the public before the next terrorism event about what might happen, what safeguards are in place to prevent terrorism events from occurring, and what plans and infrastructure are already in place to rapidly respond to the public’s needs

in the event of a terrorism attack, we can decrease the terror from a terrorism attack.

## TERRORISM PREPAREDNESS AND RESPONSE INFRASTRUCTURE

The United States’ terrorism preparedness and response infrastructure has undergone rapid expansion and evolution since the September 11, 2001, terrorist attacks. After these attacks, President George W. Bush established by executive order the Office of Homeland Security and the Homeland Security Council.

With congressional approval after a federal review of the government’s existing response infrastructure, the Homeland Security Act of 2002 established the Department of Homeland Security (DHS) in November 2002 (40). The formation of the DHS was the largest government restructuring in the United States in >50 y. The Department’s mission is to prevent terrorist attacks within the United States; reduce the vulnerability of the United States to terrorism; and minimize the damage, and assist in the recovery, from terrorist attacks that do occur within the United States (41).

In 2005, DHS Secretary Michael Chertoff led a review of the Department’s structure and functions (42). As a result of this activity, the DHS is currently undergoing reorganization but presently consists of 23 subcomponents and agencies (43).

## NATIONAL RESPONSE PLAN AND NATIONAL INCIDENT MANAGEMENT SYSTEM

Since its inception, a key priority of the DHS has been to develop a comprehensive National Response Plan (NRP). Completed in January 2005, the NRP is an all-hazards plan that establishes a single, all-inclusive framework for the management of domestic incidents (44). The plan incorporates federal, state, and local governments and all incident management disciplines (44). The NRP is supported by the National Incident Management System (NIMS), which attempts to establish consistent nationwide mechanisms for federal agencies to interact with each other and with state and local authorities. Standardized organizational structures within the NIMS, such as the Incident Command System (ICS), permit emergency managers and responders in multiple jurisdictions and disciplines to effectively coordinate an incident response (45). The NIMS was activated during the response to Hurricane Katrina in the summer and fall of 2005. The response revealed that the NIMS processes and procedures were not yet adequately diffused to all jurisdictions and professional disciplines (46).

Each local planning agency is now required to maintain a current emergency operations plan that details how the organization will operate in emergency situations. Most community planning efforts stem from local emergency planning committees (28). Some communities have also created specific terrorism committees to prepare for the

effects of terrorism. When a disaster strikes, representatives from these groups meet in a designated emergency operations center, which becomes the center of command for ICS operations. Excellent resources on radiologic terrorism preparedness and response are currently available (8,47).

## NUCLEAR MEDICINE PROFESSIONALS IN TERRORISM PREPAREDNESS AND RESPONSE

Nuclear medicine professionals have a significant role to play in terrorism preparedness and response, especially radiologic and nuclear terrorism preparedness and response. Their specific roles might include oversight of radiation plans and detection equipment, monitoring of radiation exposures, assistance with patient screening and radiation decontamination procedures, laboratory guidance for radiologic assays, medical treatment of patients with internal contamination or significant exposures, oversight of radioactive waste disposal, and risk communication guidance on radiation for first responders and the general public.

We also encourage nuclear medicine professionals to get actively involved with the first-responder community in their local area. Most municipalities do not have formally identified radiation experts, and nuclear medicine professionals can fill this need. A strong working relationship between such professionals and the public safety sector (especially fire and police) needs to be built before a terrorist event, not during it. Nuclear medicine professionals should actively seek out such collaboration and be part of planning and preparedness activities now. Given the real potential for radiation terror in the post-9/11 global environment, those trained in the science and application of radiation can play a vital role in their community's response to the physical and psychosocial impacts of such an event.

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