Management of Ionizing Radiation Injuries and Illnesses, Part 2: Nontherapeutic Radiologic/Nuclear Incidents

Doran M. Christensen, DO; Steven J. Parillo, DO; Erik S. Glassman, EMT-P, MS;
and Stephen L. Sugarman, MS

In the second of 5 articles on the management of injuries and illnesses caused by ionizing radiation, the authors discuss nontherapeutic radiologic/nuclear incidents: use of a radiologic exposure device, use of a radiologic dispersal device, nuclear power plant safety failure, and detonation of an improvised nuclear device. The present article focuses on how such incidents—whether involving deliberate or accidental methods of radiation exposure—produce casualties and how physicians need to understand the pathologic process of injuries caused by these incidents. To identify the diagnoses associated with nontherapeutic exposure in time to improve morbidity and mortality, physicians must maintain a high index of suspicion when faced with a specific constellation of symptoms. In some scenarios, the sheer number of uninjured, unaffected persons who might present to health care institutions or professionals may be overwhelming. Public health and safety issues may seriously disrupt the ability to respond to and recover from a radiologic and nuclear incident, especially a nuclear detonation.

J Am Osteopath Assoc. 2014;114(5):383-389
doi:10.7556/jaoa.2014.075

From the Radiation Emergency Assistance Center/Training Site at the Oak Ridge Institute for Science and Education for the US Department of Energy at Oak Ridge, Tennessee (Dr Christensen and Mr Sugarman); the Division of Emergency Medical Services and Disaster Medicine at Einstein Medical Center in Philadelphia, Pennsylvania (Dr Parrillo); and the National Security and Emergency Management Programs at the Oak Ridge Institute for Science and Education for the US Department of Energy in Arlington, Virginia (Mr Glassman).

Financial Disclosures: None reported.

Support: This work was partly performed under Contract # DE-AC05-06OR23100 between Oak Ridge Associated Universities and the US Department of Energy.

Address correspondence to Erik S. Glassman, EMT-P, MS, Oak Ridge Institute for Science and Education, 4301 Wilson Blvd, Suite 300, Arlington, VA 22202-1867.

E-mail: erik.glassman@orise.orau.gov

Submitted April 30, 2013; final revision received July 25, 2013; accepted August 16, 2013.

Between 1983 and 2002, there were 36,110 bombing incidents in the United States involving the detonation of an improvised explosive device (IED).[1] Some of these incidents involved a malicious or terrorist detonation, but none had a radiologic/nuclear (R/N) component. However, the history of terrorism threats in the United States and abroad—in Moscow in 1995 (when Chechen rebels threatened to use a "dirty bomb" to force Russia to withdraw from Chechnya's borders)[2] and in Chicago in 2002 (when Jose Padilla was detained while allegedly planning to build and detonate such a bomb in a US city)[3]—necessitates planning and preparing for ionizing radiation injuries and illnesses. Although they will always be fewer than the number of non–R/N incidents, IEDs that are enhanced with radioactive material could nonetheless be used. The grave consequences of such a low-probability incident underscore the need for advance planning and preparation.

Most health care professionals (eg, physicians, nurse practitioners, physician assistants) have never diagnosed or managed an ionizing radiation injury. (Injuries related to therapeutic uses of ionizing radiation are probably common, but they may not be reported or considered as radiation injuries.) Moreover, the symptoms of ionizing radiation injuries and illnesses overlap with other diseases. When making a differential diagnosis, a health care professional naturally considers more common conditions first, bypassing rarer conditions such as ionizing radiation injuries and illnesses. If an incident occurs and ionizing radiation is not included in the differential diagnosis, it is unlikely that the correct diagnosis will be made initially.

An adverse scenario may occur once an incident becomes known as (or is perceived to be) radiation-related: many people who are not ill or injured will present to health care institutions and professionals for medical evaluations, thus impairing the overall ability of the health care system to respond. Many of those with minimal injuries will present to primary care physicians, instead of the hospital, for evaluation—thus, all physicians should have awareness of key topics in this field. If an incident is known to involve radioactive materials, properly trained health care professionals can respond appropriately and effectively.

For the current article, we focus on 4 key methods of nontherapeutic—whether malicious or accidental—exposure to ionizing radiation and potential patient care considerations for each method.

Methods of Exposure

An R/N incident involves exposure by any of the following methods:

- radiologic exposure device (RED)
- radiologic dispersal device (RDD)
- nuclear power plant safety failure
- detonation of an improvised nuclear device (IND)

Each method has unique characteristics, ranges of effects, and potential for causing injuries and illnesses. Knowledge of each method of radiologic exposure will aid health care professionals in envisioning potential R/N incident scenarios, in making hazard-specific preincident plans, and in predicting potential injury patterns. In addition, an understanding of incident characteristics is essential to protect all those who may be called upon to take care of patients.

Radiologic Exposure Device

An RED is a sealed, hidden method of delivery that gradually exposes a person to ionizing radiation without his or her knowledge. If unsealed, an RED would be considered an RDD, and thus be capable of causing contamination. Because it is surreptitiously placed, an RED could cause serious illness and injury to any number of persons,[4,5] sow confusion about the radiation's source, and delay notification of the health care community.

Injury expression is based on the radiation dose received, whether accidental or intentional, and the placement and type of radiation source. Although an RED causes damage by means of exposure to ionizing radiation, the element within the RED that releases radiation does not undergo nuclear fission (splitting of atoms) or fusion (joining of atoms). Patients may present with the following conditions: cutaneous radiation syndrome (CRS), cutaneous syndrome, damage to subcutaneous tissues (acute local radiation injury), or acute radiation syndrome (ARS). With CRS, deposition of ionizing radiation energy sufficient to damage the epidermis or dermis may result in sloughing or desquamation of the outer layer of skin. Details specific to the injuries will be discussed in parts 3, 4, and 5 of our series.[6-8]

Two Cases of RED Interaction

In 1999, a welder in Yanango, Peru, unwittingly placed a 37-Ci (1.37 TBq) iridium-192 (^{192}Ir, Ir-192) industrial radiography source in a trouser pocket, where it resided for several hours.[9] The case was one of the more serious on record in which injury to skin and underlying tissues did not result in a fatality. He did not learn that the device was a radioactive source for hours, leading to his right lateral thigh absorbing a substantial dose of radiation. This exposure led to necrosis of skin, subcutaneous tissues, and bone. The radiation dose affected the marrow centers, causing the hematopoietic subsyndrome of ARS. Some months later, he underwent amputation of his right lower extremity followed by a hemipelvectomy.

In 2008, the Radiation Emergency Assistance Center/Training Site received a call from a teletherapy engineer who knowingly had exposure to his left index finger while changing out cobalt-60 (^{60}Co, Co-60) sources for a teletherapy device in São Paolo, Brazil (*Figure 1*). His exposure lasted a few seconds; however, the ^{60}Co source had an activity level of 1400 Ci (5180 PBq). With a γ constant of 13 R/h cm^2/mCi , the dose rates from a source of this magnitude would be extremely high. Clinically, the dose to his finger was at least 2000 rad (20 Gy). Fifteen months later, the patient experienced a minor trauma to the finger. Though slight, the trauma was sufficient to cause a reoccurrence of the injury. He underwent an amputation at the carpophalangeal joint 7 months after that.

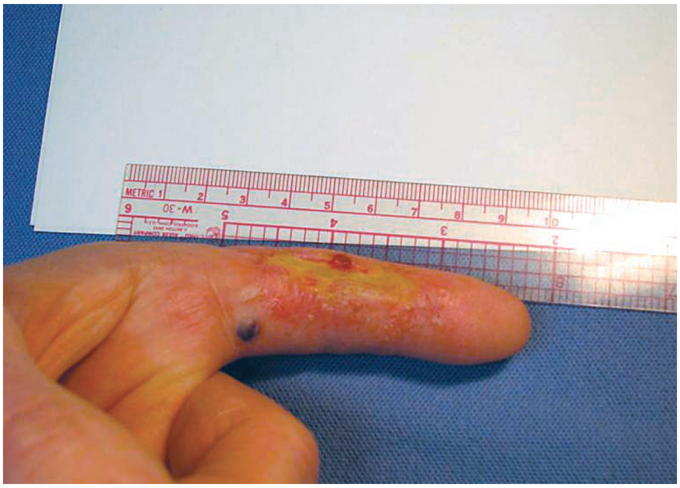

Figure 1.
The left index finger of an engineer who knowingly had exposure to radiation while changing out cobalt-60 (^{60}Co) sources for a teletherapy device. The exposure lasted a few seconds, but the source had an activity level of 1400 Ci (5180 PBq). Clinically, the dose to his finger was at least 2000 rad (20 Gy). He eventually underwent an amputation at the carpophalangeal joint.

Radiologic Dispersal Device

An RDD is any device—either unsealed or detonated—that is used to spread radioactive materials. Although an RDD is commonly thought of as an explosive device, or *dirty bomb*, the device does not need to explode[4,10] to spread radiologic material into the environment. A nonexplosive RDD could directly contaminate humans, but it could also cause environmental contamination that could in turn contaminate humans.[11] Unlike an RED (which is by definition not a contaminant), an RDD contaminates and could potentially cause blast injury. An RDD may be implanted in a facility ventilation system or a fumigation system. In Iraq and Afghanistan, nonradiologic IEDs are detonated almost every day and cause numerous deaths and disfigurements; the addition of radioactive material to such devices would cause further injury, external or internal contamination, and panic. Persons near the epicenter of an explosion of a dirty bomb will sustain physical trauma, including thermal burns and embedded foreign bodies such as radioactive shrapnel.

The amount and type of explosive material would determine the level of physical damage from an RDD. Removal of foreign bodies would require that health care professionals wear appropriate personal protective equipment and have access to radiation monitoring equipment, including ring dosimeters for health care professionals who have to remove radioactive shrapnel. A patient may be contaminated via inhalation or wounds, which would require additional medical countermeasures such as chelators (eg, diethylene-triamine-pentacetic acid, or DTPA). It should be noted that injuries and illnesses caused by RDDs are radiation related and are not caused by a “nuclear” reaction (fission or splitting of atoms).

Nuclear Power Plant Safety Failure

Nuclear power plants use the energy created by the fissioning of atomic nuclei—often referred to as the splitting of the atom—to generate electricity (*Figure 2*). In nuclear power, the heat generated during fission converts water to steam, which then drives electricity-generating turbines. Water is continually circulated through the reactor core via coolant pumps to control temperatures. The loss of power to coolant pumps or other interruptions of cooling capabilities to the reactors can cause the reactor core to overheat. This process is known as a *loss-of-coolant accident* (LOCA).[12] During a LOCA, the radioactive core can become molten, hence the term

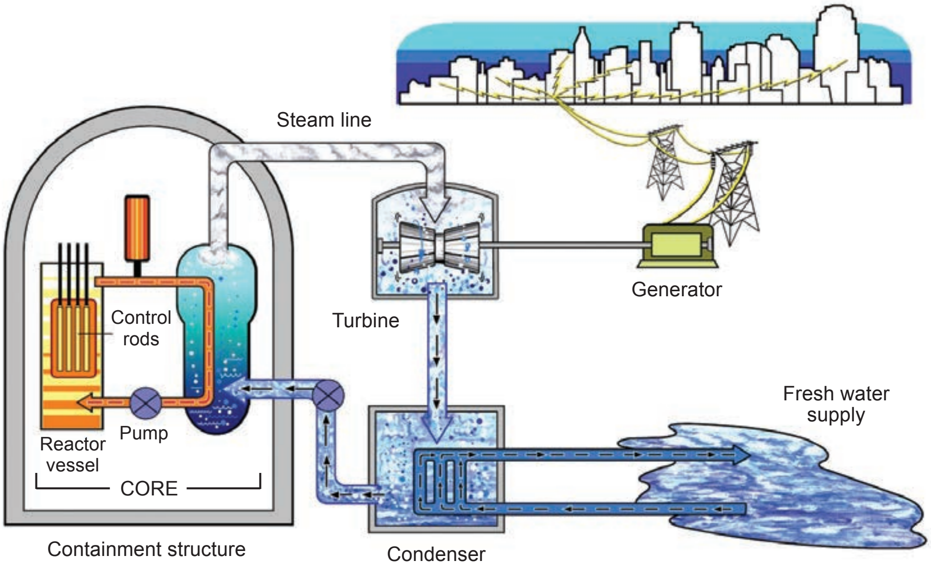

Figure 2.
How nuclear power plants use the energy created by the fissioning of atomic nuclei (ie, splitting of the atom) to generate electricity. The core is the nuclear fuel or fissile material that rests in the reactor vessel. Control rods are used to affect the rate of the nuclear reaction and thus the heat and electricity generated. The heat generated during fission converts water to steam, which is then used to drive electricity-generating turbines. Water is continually circulated through the reactor core via coolant pumps to control temperatures. The loss of power to coolant pumps—or other interruptions of cooling capabilities to the reactors—cause the reactor core to overheat, resulting in a *loss-of-coolant accident*.[12] Without the cooling capability, the radioactive core can become molten, hence the term *meltdown*. A meltdown may involve radioactive materials from the reactor vessel or the containment building (left).

meltdown. Further, a LOCA may result in a release of radioactive materials from the reactor vessel or the containment building (*Figure 2*).

In March 2011, an earthquake on the floor of the Pacific Ocean caused a 13- to 15-m tsunami, which hit the shore at Fukushima, Japan, where a nuclear power plant was situated. Thousands of people were evacuated because of radiologic concerns associated with the crippled plant. Predictably, radioactive materials released from the damaged reactor(s) received much hype in the media and heightened public concern about exposure to radioactive contamination. The emphasis on radiologic concerns overshadowed the deaths and the displacement of tens of thousands of people from the effects of the tsunami. The Fukushima disaster was highly unusual and was the first time that such a serious situation at a nuclear power plant was triggered by an environmental disaster.[13]

Improvised Nuclear Device

An IND is an illicit nuclear weapon bought or stolen from a nuclear state. A terrorist group may fabricate INDs from the following illegally obtained materials: a fissile nuclear weapon (which produces a nuclear explosion), components of such a weapon, or nonweaponized nuclear material (plutonium or highly enriched uranium). An IND is also likely to be constructed by personnel who are less skilled in handling nuclear material than workers from nuclear processing facilities in officially recognized nuclear weapons states.

It was not until 2004 that the US Department of Homeland Security's Federal Emergency Management Agency (FEMA) published the *National Response Plan*, now called the *National Response Framework*,[14] which outlined the federal response to national R/N incidents. In 2005, 15 all-hazard national planning scenarios were developed for incident-specific response planning. The first of these scenarios describes a 10-kT IND detonation. In response to this scenario, FEMA began to plan and prepare for response to a detonation of an IND. The National Incident Management System and the Incident Command System[15]—both entities implemented by FEMA—are considered effective means to respond and recover from the detonation of a small nuclear weapon.

Compared with an RDD—which may explode but does not involve fusion or fission—an IND incorporates fissile materials and thus would cause massive physical damage to a community and considerable psychological devastation to its population, regardless of size. In 2009, the National Security Staff released the first edition of *Planning Guidance for Response to a Nuclear Detonation*,[16] which categorized the devastation, types of physical damage, and types of human injuries on the basis of distance from the detonation epicenter in zones. The second edition of *Guidance*,[17] released in June 2010, updated recommendations and guidelines based on intensive modeling efforts to further quantify the effects of a nuclear detonation in an urban US city. The second edition further refines the following definitions of the proposed damage zones:

- **Severe damage:** the area closest to the epicenter of the IND detonation
- **Moderate damage:** the affected area adjacent to the severe-damage zone
- **Light damage:** the affected area furthest away from the epicenter
- **Dangerous fallout:** a variable area that is determined by the scattering of radiologic material

The presumed "safe" and "dangerous" distances away from the epicenter vary from scenario to scenario in modeling efforts and would be made after the fact by the incident commander based on types of damage found on the ground. Zone determinations are made on the basis of the following criteria: (1) the yield of the weapon, (2) whether the detonation occurred above or at ground level, and (3) the topographic features of the terrain and its structures.

Severe-Damage Zone

According to modeling results, the severe-damage zone would sustain the combined effects of the blast, thermal pulse, and prompt radiation and would have few intact buildings and very few survivors. Further away, some buildings may remain intact if their construction is sufficiently durable. Because infrastructure damage in this zone will cause debris and make the streets impassible for responders, most life-saving and rescue operations will occur outside this zone.

Moderate-Damage Zone

Many serious injuries can be expected in the moderate-damage zone. There will be many individuals with blunt-force trauma, direct thermal burns, pattern burns from clothing that catches on fire, embedded shrapnel injuries, eye injuries from flying debris, and retinal injuries from seeing the flash of the nuclear detonation. Many individuals will not be ambulatory and may survive only if they can be transported to a hospital that is still capable of providing health care. The bulk of initial response efforts should be directed to the moderate-damage zone because the most individuals that will benefit from the provision of immediate medical care will be located here.

Light-Damage Zone

Most casualties in the light-damage zone will survive the damage and destruction from the IND detonation. Many of the injured will be ambulatory and may be capable of reaching medical care at a health care institution. Most will survive without direct treatment at a facility. Survivors may have embedded glass or other shrapnel from broken windows or light infrastructure damage. Some may have eye injuries from foreign bodies or flash injuries from seeing the nuclear blast. Casualties from the light-damage zone can be expected to overwhelm any nearby health care institutions, highlighting the importance of pre-incident planning, which communities may undertake by consulting the latest *Guidance*.[17] In addition, communities may be unable to provide food, water, sanitation, or other services.

Dangerous-Fallout Zone

The dangerous-fallout zone includes areas in which radioactive fallout is expected to be located, whether immediately after the incident or for an extended period of time. Fallout deposited in this zone is anticipated to cause a significant level of exposure to individuals who were unable to reach a fallout shelter. Individuals outside the severe- and moderate-damage zones who are able to access a fallout shelter following an IND incident can avoid nearly all detrimental effects from airborne radiation. Therefore, in the first few hours after IND detonates, this area is where public safety officials have the opportunity to have a substantial impact on morbidity and mortality, mainly by recommending those who were in the fallout path (also known as the *fallout plume*) to shelter in place.[16] Fallout can be particularly hazardous given the more severe levels of radiation exposure that occur in this path. Sheltering in place is an effective way to avoid such exposure. In the United States, protective action guidance is provided by the Environmental Protection Agency (http://www.epa.gov/radiation/rert/pags.html#pags).

Issues With Damage Zones

Several issues arise for health care emergency planners and health care professionals in damage zones.

First, health care institutions in the severe-damage zone will not be operational, and institutions in the moderate-damage zone may also not be operational. Institutions in the light-damage zone and potential dangerous-fallout zones may be operational but may be overwhelmed by injured and the uninjured who are concerned about health issues. Second, traffic in and around passable areas can be expected to be heavy, further interfering with travel and emergency response. Third, workers may not report to work because they were directly affected by the detonation or because they fear for their safety or that of their loved ones.

Finally, a community's ability to respond and recover after an IND event depends on health care professionals to provide appropriate or timely treatment; non–health care staff (eg, workers in the janitorial, food service, laundry, supply/logistics, or pharmacy departments) to aid the health care professionals; and public service workers (eg, transportation or communications workers, firefighters, police officers, heavy equipment operators).

The landscape of care will radically change after an IND detonation. Emergency response efforts to move patients to functioning health care facilities may take hours or days. Recovery efforts will be adversely affected until medical and infrastructure needs have been sufficiently addressed. Many logistical layers of communications, transportation, and infrastructure complicate the response and recovery. Material supply to local health care institutions will inevitably be interrupted. Workers who have not reported for work may not return until they have been sufficiently assured by a credible authority that their workplaces are safe.

Conclusion

To respond effectively during an R/N incident, health care professionals should be familiar with nontherapeutic methods of radiation exposure, as well as the types of injuries and illnesses that can be caused by these methods. They should learn to include ionizing radiation in differential diagnoses if radiation is not known to be involved. Although successful management of injuries and illnesses requires aggressive and appropriate medical care, protection of responders remains the primary concern because an overwhelming number of persons may present for medical care in spite of not being injured or ill. Health care professionals will be in the best position to allocate resources according to immediate patient need.

References

1. Kapur GB, Hutson HR, Davis MA, Rice PL. The United States twenty-year experience with bombing incidents: implications for terrorism preparedness and medical response. *J Trauma.* 2005;59(6):1436-1444.
2. Fact sheet on dirty bombs. United States Nuclear Regulatory Commission website. https://forms.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-dirty-bombs.html. Accessed April 1, 2013.
3. Chronology of events. Nova website. http://www.pbs.org/wgbh/nova/dirtybomb/chrono.html. Accessed April 1, 2013.
4. National Council on Radiation Protection and Measurements. *Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers.* Bethesda, MD: National Council on Radiation Protection and Measurements; 2010. NCRP Report 165.
5. Radiological Exposure Devices (REDs). Radiation Emergency Medical Management website. http://remm.nlm.nih.gov/red.htm. Accessed April 1, 2013.
6. Christensen DM, Livingston GK, Sugarman SL, Parrillo SJ, Glassman ES. Management of ionizing radiation injuries and illnesses, part 3: radiobiology and health effects of ionizing radiation. *J Am Osteopath Assoc.* In press.
7. Iddins CJ, Christensen DM, Parrillo SJ, Glassman ES, Goans RE. Management of ionizing radiation injuries and illnesses, part 4: cutaneous radiation syndrome and acute local radiation injury. *J Am Osteopath Assoc.* In press.
8. Christensen DM, Iddins CJ, Parrillo SJ, Glassman ES, Goans RE. Management of ionizing radiation injuries and illnesses, part 5: radiation-related diseases—acute radiation syndrome. *J Am Osteopath Assoc.* In press.
9. *The Radiological Accident in Yanango.* Vienna, Austria: International Atomic Energy Agency; 2000. http://www-pub.iaea.org/books/iaeabooks/6090/The-Radiological-Accident-in-Yanango. Accessed October 31, 2012.
10. Radiological Dispersal Devices (RDDs). Radiation Emergency Medical Management website. http://www.remm.nlm.gov/rdd.htm. Accessed April 1, 2013.
11. National Council on Radiation Protection and Measurements. *Management of Terrorist Events Involving Radioactive Material.* Bethesda, MD: National Council on Radiation Protection and Measurements; 2001. NCRP Report 138.
12. Nuclear Energy Agency. *Nuclear Fuel Behaviour in Loss-of-coolant Accident (LOCA) Conditions.* Paris, France: Organisation for Economic Co-operation and Development; 2009. NEA No. 6846. http://www.oecd-nea.org/nsd/reports/2009/nea6846_LOCA.pdf. Accessed July 21, 2013.
13. *IAEA International Fact Finding Expert Mission of the Fukushima Dai-Ichi NPP Accident Following the Great East Japan Earthquake and Tsunami.* Vienna, Austria: International Atomic Energy Agency; 2011. http://www-pub.iaea.org/MTCD/meetings/PDFplus/2011/cn200/documentation/cn200_Final-Fukushima-Mission_Report.pdf. Accessed July 20, 2013.
14. National Response Framework. Federal Emergency Management Agency website. http://www.fema.gov/national-response-framework. Accessed November 3, 2012.
15. National Incident Management System. Federal Emergency Management Agency website. http://www.fema.gov/national-incident-management-system. Accessed November 3, 2012.
16. National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats. *Planning Guidance for Response to a Nuclear Detonation.* Washington, DC: Department of Homeland Security; 2009.
17. National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats. *Planning Guidance for Response to a Nuclear Detonation.* 2nd ed. Washington, DC: Department of Homeland Security; 2010. http://www.fema.gov/media-library-data/20130726-1821-25045-3023/planning_guidance_for_response_to_a_nuclear_detonation___2nd_edition_final.pdf. Accessed Juily 21, 2013.

Radiation & Nuclear Energy: The nuclear fuel cycle does not give rise to significant radiation exposure for members of the public. Radiation is particularly associated with nuclear medicine and the use of nuclear energy, along with X-rays, is ionising radiation.Â Ionizing radiation which can damage living tissue is emitted as the unstable atoms (radionuclides) change ('decay') spontaneously to become different kinds of atoms. The principal kinds of ionizing radiation are: Alpha particles.Â (However, this is only twice a typical daily therapeutic dose applied to a very small area of the body over 4 to 6 weeks or so to kill malignant cells in cancer treatment.) 10,000 mSv short-term. Fatal within a few weeks.