SPECIAL REPORT

Are We Prepared for Nuclear Terrorism?

Robert P. Gale, M.D., Ph.D., and James O. Armitage, M.D.

> No plan ever survives first contact with the enemy.
>
> — General Helmuth von Moltke, Prussian Army Chief of Staff

Was von Moltke right, or was Winston Churchill, who said "He who fails to plan is planning to fail"? Recent events have increased concern about the consequences of nuclear terrorism. Nuclear terrorism can take several forms, such as forceful takeover of a nuclear power facility by terrorists, targeting of a country's nuclear power facilities by terrorists or rogue states using conventional or nuclear weapons or commercial aircraft, intentional detonation of a nuclear weapon by a terrorist organization or rogue state, or the use of radiologic dispersion or exposure devices (such as radioactive material from a stolen nuclear weapon or a conventional explosive device ["dirty bomb"]) by terrorists. Our focus in this report is on preparedness in the United States, but most concepts apply to other developed and developing nations.

In 1945, the United States detonated two atomic weapons (A-bombs, or fission bombs) over Japan to end World War II. The bombs had an explosive force of approximately 13 kilotons and 22 kilotons of TNT (trinitrotoluene), respectively (approximately 50 to 100 terajoules). It is estimated that 120,000 to 250,000 persons in Hiroshima and Nagasaki died within 4 months, most of them immediately or within a few days after the explosions. Most of these deaths were caused by percussive force, projectiles, and thermal injuries from "superfires" (i.e., fires of approximately 100,000,000°C; for comparison, the surface of the sun is 6000°C), not by radiation. Nuclear fission reactions release approximately 10 million times more energy than equivalent-mass chemical explosions. However, less than 10% of the energy released by a nuclear weapon is in the form of ionizing radiation (mostly neutron and gamma [photon] radiation). Consequently, only a small fraction of the deaths after the detonation of a nuclear weapon are radiation-related.[1] In addition, although there is concern about the long-term carcinogenic effects of radiation exposure, only approximately 5% of deaths from cancer among A-bomb survivors have been attributed to radiation exposure.[2]

Since the atomic bombings in Japan, and especially during the Cold War, people have been concerned about the threat of nuclear terrorism and nuclear war. However, beginning about 40 years ago, accidents at the Three Mile Island, Chernobyl, and Fukushima nuclear power facilities heightened this fear; the fear has been compounded by several recent events, including the acquisition of nuclear weapons capability (a thermonuclear weapon [H-bomb, or fusion bomb]) by North Korea and the seeming ability of that country to target the United States with an intercontinental ballistic missile, threats to dismantle the U.S.–Iran nuclear deal (Joint Comprehensive Plan of Action), the deterioration of U.S.–Russian nuclear arms–limitation agreements, and the recent decisions by the United States and Russia to upgrade their nuclear arsenals. In this report, we consider whether it is necessary to plan for nuclear terrorism and whether such plans will be effective. We conclude that although planning is potentially useful for a small-scale nuclear terrorist event, responses to large-scale events are difficult to plan effectively. We should not expect these events to play out as planned for, and prevention is key. Because the effectiveness of any nuclear terrorism emergency plan relates predominantly to exposure circumstances, we consider several scenarios below.

NUCLEAR POWER FACILITIES

Exposure of fewer than 100 facility personnel to ionizing radiation from an incident or accident at a U.S. nuclear power facility is planned and trained for, as are measures to protect the surrounding population, including sheltering in place, evacuation (if appropriate), and distribution of iodine tablets to block uptake of radioactive iodine (reviewed by Christodouleas et al.[3]). The extent to which this is the case in all other nations with nuclear power facilities is uncertain and is affected by the level of societal development and political stability.

However, the above scenario is a rather different from one in which terrorists commandeer a nuclear power facility or when a nuclear power facility is targeted with a hijacked commercial airplane or a conventional or nuclear weapon. Are these scenarios hypothetical? Unfortunately, no. In 1972, hijackers took control of a U.S. airliner and threatened to crash into the Oak Ridge nuclear weapons facility. In 1981, Iran and then Israel attacked and destroyed Iraq's Osirak nuclear power facility before it could be fueled with enriched uranium. Iraq bombed Iran's Bushehr nuclear plant six times between 1984 and 1987. The United States bombed a nuclear fuel enrichment facility and three nuclear reactors in Iraq in 1991. Also in 1991, Iraq used Scud missiles to target the Dimona nuclear power facility in Israel. In 2014, Hamas targeted the Dimona facility from Gaza. Several of these attacks were thwarted by Patriot missile defenses. Some threats to nuclear facilities have fortunately not been realized; for example, in the 1990s during the Balkan Wars, Slovenia shut down its Krško nuclear power plant, fearing a Serbian air force attack.[4] In 2007, Israel launched an attack on a Syrian reactor that was under construction and not yet fueled. Beginning in about 2009, the Iran Natanz nuclear power facility was targeted by a cyberattack with the Stuxnet virus, presumably by Israel and the United States. And very recently, Yemeni rebels claimed to have targeted the Barakah nuclear power facility that is under construction near Abu Dhabi in the United Arab Emirates.

Terrorist takeover of a nuclear facility can be prevented by counterintelligence, intervention, and adequate on-site security measures. Force-to-force exercises are performed at U.S. nuclear power facilities every 3 years. However, these measures are not foolproof. Recently, antinuclear activists entered nuclear power facilities in France and Belgium and set off fireworks to show the vulnerability of the facilities. The U.S. 9/11 Commission reported that the 9/11 terrorists initially considered targeting U.S. nuclear power facilities. The bottom line is that nuclear power facilities are no longer merely theoretical targets of terrorism or military targets. Furthermore, when we consider the possible consequences of terrorism against a nuclear power facility, radiation exposure is only part of the equation: infrastructure damage, mass evacuations, and public fear may be of a much greater magnitude than radiation-induced injuries. This is an example of potential terrorist gains from "mass distraction" and mass disruption rather than mass destruction.

The concept of nuclear power facilities as military targets has been reviewed elsewhere.[4] The International Atomic Energy Agency (IAEA) has an International Nuclear and Radiological Event Scale (INES), shown in Figure 1. The accidents at the Chernobyl and Fukushima nuclear power facilities were a 7 on this scale, whereas the event in Goiânia, Brazil (discussed below), was a 5 (www-ns.iaea.org/tech-areas/emergency/ines.asp).

RADIOLOGIC EXPOSURE DEVICES

Another scenario is one in which terrorists use a radiologic exposure device. In this scenario, terrorists steal a radioactive source — for example, material from a radiation therapy department, an inadequately secured nuclear weapons site, a nuclear power facility, or a politically unstable state — and place it in a public space. There are several reports of such thefts, including thefts of nuclear fuel rods from U.S. and U.K. nuclear power facilities. Some nations, fearing an invasion, have dispersed their nuclear weapons to many sites, which makes security more difficult. When terrorists use a radiologic exposure device, the radiation doses to the public are likely to be relatively low; few people are likely to be exposed to high doses. The most important issue is detection, which is easier if the device is stationary and more difficult if it is on a bus or train, where exposed persons enter and exit at different points.

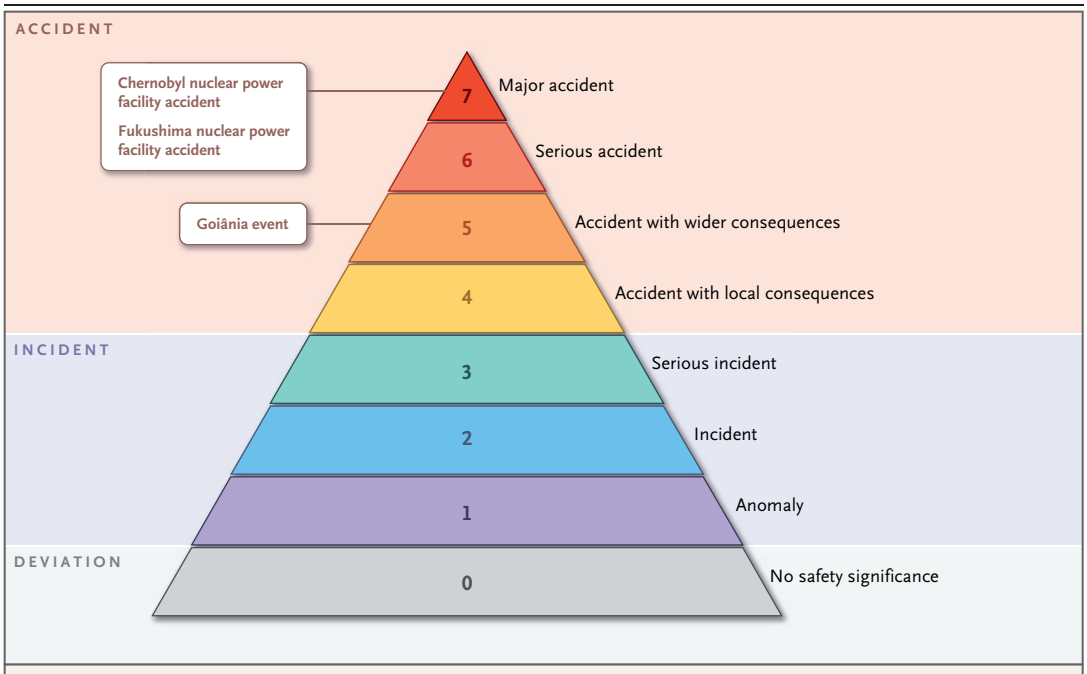

Figure 1. International Nuclear and Radiological Event Scale (INES) from the International Atomic Energy Agency.

Physicians need to be alert to the signs and symptoms of radiation exposure, and coordination by an agency such as the Centers for Disease Control and Prevention might be needed to synthesize a cogent picture. The complexity of detecting such an event was evident to us in dealing with a stolen cesium-137 radiotherapy unit in Goiânia, Brazil, in 1987, a situation in which it took more than 2 weeks from the first exposure to detection.[5] Paradoxically, delayed detection makes this strategy less useful to terrorists who rely on responses of the government and the public rather than radiation-induced casualties to achieve their political aims. Physicians should consider possible radiation exposure in persons who have a constellation of nonspecific signs and symptoms, including epilation and gastrointestinal symptoms. Low counts of blood granulocytes, lymphocytes, and platelets should increase suspicion. Guidance on how to detect radiation exposure is available from the IAEA, the World Health Organization (WHO) (www.who.int/ionizing_radiation/a_e/IAEA-WHO-Leaflet-Eng%20blue.pdf), and elsewhere.

RADIOLOGIC DISPERSION DEVICES

A third nuclear terrorist scenario involves radiologic dispersion devices. Such an attack can involve stealing radionuclides from a university laboratory or a nuclear medicine department and spreading them over a large area with a small plane, introducing radiation into a municipal water reservoir, or covering a conventional explosive device (e.g., one made with dynamite or TNT) with radioactive materials — a so-called dirty bomb. Thefts of radioactive materials are common. The IAEA has records of more than 2000 such incidents, including more than 100 in 2016. It is unlikely that intensive radiologically oriented medical interventions would be required for most victims of a radiologic dispersion device such as a dirty bomb, because percussion and projectile injuries will probably account for more injuries than radiation exposure. There may be a risk of unacceptable long-term radiation exposure at the detonation site, but this is unlikely and can be mitigated by decontamination, shielding, and, if needed, short-term or long-term evacuations. Radiologic dispersion devices are, again, more a matter of mass distraction and mass disruption than mass destruction. Terrorists' goals for deploying such devices are predominantly political and psychological. Although few people will be harmed in terms of their health, there is likely to be widespread confusion and hysteria. This may result in possibly inappropriate government actions that could

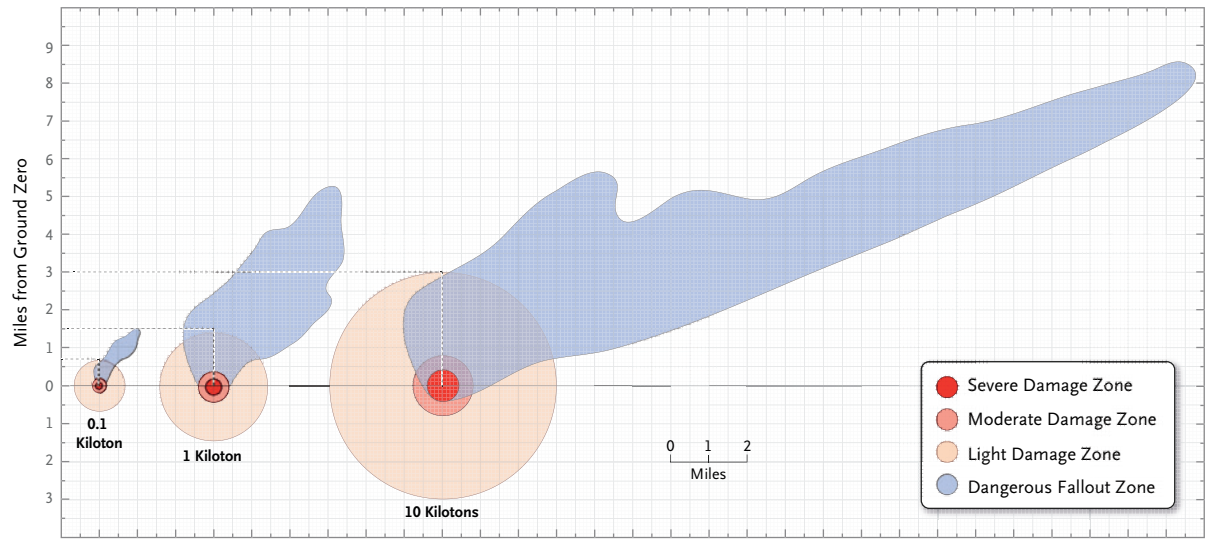

Figure 2. Severity of Damage Associated with Nuclear Devices.

Relative areas of severe damage (dark red), intermediate damage (lighter red), and light damage (pink) associated with different sizes of nuclear devices are shown. The shaded blue area represents the zone of dangerous fallout. The figure was adapted from the Federal Emergency Management Agency.[6]

complicate or even worsen the situation, such as a conventional or nuclear attack against a foreign state that is perceived as encouraging or harboring the terrorists. U.S. actions against Afghanistan immediately after the 9/11 World Trade Center attacks is an example of potential cascading events. The most effective countermeasure to radiologic dispersion devices is, again, prevention. However, education of government officials, policymakers, and the public about securing radioactive sources, early detection of radiation exposures, and, perhaps most importantly, the potential risks associated with radiation exposure is an important measure. A guide to early response to radiologic dispersion devices is available at www.crcpd.org/mpage/RDD.

IMPROVISED NUCLEAR DEVICE

Things can get considerably worse. The U.S. Department of Homeland Security and the Federal Emergency Management Agency (FEMA) developed 15 Disaster Planning Scenarios to deal with potential terrorist attacks and natural disasters. Scenario 1 is entitled "Nuclear Detonation — 10 Kiloton Improvised Nuclear Device." In this scenario, planners consider a situation in which terrorists from a "Universal Adversary" assemble a 10-kiloton nuclear device stolen from a nuclear facility in the former Soviet Union, smuggle the components into the United States, assemble it in a van, and detonate it in the center of Washington, D.C.[6] What would happen? First, the percussive force, projectiles, and superfires would cause complete destruction or severe damage to buildings within 1 km of the epicenter and extending out to approximately 6 km. (A nuclear weapon is most effective when detonated approximately 1 km above the hypocenter rather than at ground level.) Communications would be disrupted by electromagnetic forces from the detonation. Many people within the immediate vicinity would be killed immediately, as would emergency and medical personnel, including many physicians and health care providers. Persons at greater distances, including first responders, would be exposed to high doses of neutron and gamma radiation from the initial blast and from radioactive fallout, which typically occurs after a ground detonation (Fig. 2). Figure 3 compares the relative effects of a nuclear weapon, an improvised nuclear device, a radiologic dispersion device, and a radiologic exposure device. In the scenario of an attack with an

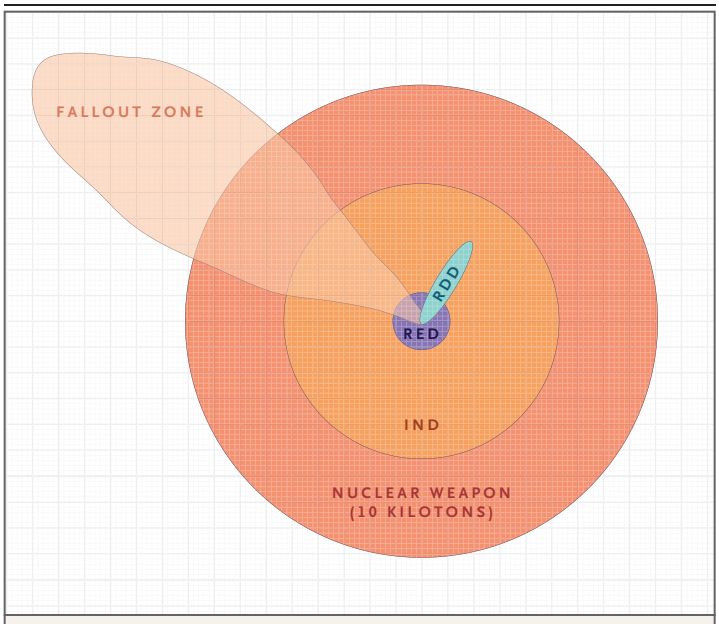

Figure 3. Sizes of Regions Affected by Different Types of Nuclear Device.
The relative sizes of regions affected by a radiologic exposure device (RED), a radiologic dispersion device (RDD), an improvised nuclear device (IND), and a sophisticated nuclear weapon are shown. The fallout zone shown is for the IND.

improvised nuclear device, there would be approximately 100,000 immediate deaths and another 100,000 casualties requiring medical intervention. Guidelines for triaging these huge numbers of casualties have been published.[7] Approximately half a million people would need to shelter in place for hours or days, after which they would leave the area in a planned and, hopefully, orderly evacuation. Although there are, of course, huge political, economic, social, psychological, and societal consequences associated with this scenario, our focus here is on medical preparedness and especially on dealing with radiation-induced bone marrow failure.

If you think the notion of commandeering a nuclear weapon is far-fetched, consider this: during the recent attempted military coup in Turkey, dozens of U.S. nuclear weapons were at risk for takeover at the Incirlik Air Base, which is close to the border with Syria, where a civil war has been raging for 7 years. And although some argue that these weapons would be inoperable because of electronic safeguards (permissive action links), we and others are not convinced.

NUCLEAR WAR

The ultimate nuclear terrorism scenario is a nuclear war, which could be one weapon launched by a rogue state, an accidental or intentional strike with one or a few nuclear weapons by an adversary (real or perceived) or even an ally, or a full-scale nuclear war. The United States and Russia together have approximately 8500 stockpiled nuclear weapons, 3000 of which are operationally deployed. An attack or counterattack with even a fraction of these weapons is not properly defined as terrorism, and we do not discuss this scenario further. It is estimated that there are 1100 nuclear weapons in seven other countries, including the United Kingdom, France, India, Pakistan, Israel, and North Korea. The average destructive force of modern nuclear weapons is equal to approximately 1 megaton of TNT, but some weapons, such as the Soviet RDS-220 hydrogen bomb, is equivalent to 50 megatons of TNT or approximately 5000 times more powerful than "Little Boy," the bomb that was dropped on Hiroshima. Planning an effective medical response to an attack with weapons like these is futile. Areas of fireball, percussive, and thermal damage for different targets of one or more nuclear weapons of sizes ranging from 100 tons to 100 megatons for an airburst at 3 km can be modeled at http://nuclearsecrecy.com/nukemap/.

BIOLOGIC EFFECTS OF IONIZING RADIATION EXPOSURE

Exposure to high doses of ionizing radiation in one or more of the terrorist scenarios we describe has adverse biologic effects. Tissues such as the skin, lung, gastrointestinal tract, and bone marrow are the most severely immediately affected targets within a survival dose range. Persons exposed to less than 2 Gy of uniform whole-body ionizing radiation, equivalent to approximately 200,000 chest radiographs, generally do not require immediate medical intervention and will probably recover without medical intervention. At the other extreme, persons exposed to more than 12 to 15 Gy will probably die despite medical intervention. Consequently, the focus of medical preparedness for nuclear terrorism is on persons exposed to 2 to 10 Gy, in whom the most immediate problems are bone marrow failure and gastrointestinal damage. However, in

many of the radiation-exposure scenarios we describe, victims will have concurrent injuries from percussive forces, projectiles, thermal burns, and chemicals. Interventions that might save some patients from death from bone marrow failure will be only partially effective because of these competing causes of death. In addition, trauma, especially burns, often increases mortality due to any level of radiation exposure in experimental models. This was seen among victims of the Chernobyl accident.[8] There are also long-term consequences of radiation exposure, including diverse cancers (e.g., thyroid cancers and other thyroid disorders, leukemias, and solid cancers), infertility, and an increased risk of cardiovascular disease, all of which were seen among the A-bomb survivors.

RADIATION DOSE

Effective therapy for persons exposed to ionizing radiation requires an accurate dose estimate. Exposed persons will almost certainly not have radiation-monitoring devices. However, because many survivors have smartphones, it is possible to perform electron paramagnetic resonance spectroscopy on the display glass of smartphones and to perform optically stimulated luminescence analysis of smartphone resistors in order to estimate the dose of radiation.[9] Other physical measurements include electron spin resonance measurements of dental enamel and some clothes (such as clothing made of cotton but not synthetic fibers) and neutron capture of urine samples. These physical measurements are technically demanding and not readily available, especially not quickly or on a large scale. Biologic dosimetry can be performed on blood or bone marrow samples, including analyses of dicentric chromosomes, micronuclei, premature chromosome condensation, gamma H2AX foci, and chromosome painting — but only if health care facilities are intact and trained technical personnel are available. Computer-based dose reconstruction with the use of source–dispersion models requires time and is rarely victim-specific. Even when a combination of these approaches is used, point estimates of dose are often inaccurate and have wide confidence intervals or credibility limits.[10,11] These data may be sufficiently accurate for triage but not for some therapy decisions, such the decision about whether to perform transplantation. After the Chernobyl accident, we used a combination of clinical variables, including the kinetics of decline of blood lymphocytes and granulocytes. This approach, of course, is possible only if there are surviving medical personnel nearby to obtain serial blood samples, surviving machines to analyze the blood samples, and surviving experts to analyze the data. One or more of these conditions may not be met in the context of a major nuclear event. There is also confounding in the interpretation of these data when other injuries are present, as is likely to be the case. One simple way to triage large numbers of potentially exposed persons is to exclude those who have not had nausea and emesis within 4 hours. Not everyone with these symptoms has a radiation dose of more 2 Gy, but patients without such symptoms can be reasonably excluded.[12]

The consequences of inaccuracies in dose estimates vary. For some interventions, such as oral antibiotic or antiviral drugs, an inaccurate estimate may be inconsequential. This is less true for parenteral drugs, such as intravenous antibiotics, red-cell and platelet transfusions, and hematopoietic growth factors (e.g., filgrastim and sargramostim [granulocyte and granulocyte–macrophage colony-stimulating factors]), which use more health care resources and personnel and have greater associated risks of adverse events. There is far less tolerance for an inaccurate dose estimate in the context of contemplated hematopoietic-cell transplantation.

Another issue is dose uniformity. Even if the estimated midline dose is accurate, there is no guarantee of uniform exposure. If a person's arm or leg is shielded by an automobile or concrete, some of the bone marrow may be unexposed or less exposed, and hematopoietic-cell transplantation may not be required. Unfortunately, it is unlikely that physicians will be able to make correct informed decisions regarding the benefits and risks of diverse medical interventions, especially ones with substantial potential adverse effects, in many of the terrorist scenarios we describe (as discussed below).

MEDICAL PREPAREDNESS

How do we best prepare for nuclear terrorism? Our focus is on major events, such as an attack with an improvised nuclear device or a limited nuclear strike, accidental or intentional. Although

stockpiling drugs such as antibiotics, antivirals, and hematopoietic growth factors seems wise, deciding who needs these interventions and determining who is alive to estimate the radiation doses or to give parenteral drugs will be complicated if many or most health care and technical personnel are casualties and if a substantial part of the infrastructure, including hospitals, clinics, transportation facilities, and communications, is destroyed.[13,14] (The Nagasaki A-bomb hypocenter, for example, was directly over the Nagasaki University School of Medicine.) Details of the U.S. Strategic National Stockpile (SNS) are reviewed elsewhere.[15] Storing hematopoietic cells — for example, in a bank of umbilical cord blood cells — seems sensible, but not if the cells are exposed to the same high-dose ionizing radiation as the victims who might benefit from receiving them. It can be argued that cells could be transported from unexposed sites; this may be difficult in some instances and almost certainly would be impossible in the context of a multisite nuclear attack. Two other sources of hematopoietic cells for transplantation are HLA-haplotype–mismatched relatives and HLA-matched unrelated volunteers. However, there is a high likelihood that in a large-scale event, relatives of a radiation victim will also be exposed or injured. Identifying potential unrelated donors elsewhere in the United States or overseas is time consuming and requires intact telecommunications and computer networks, resources that are unlikely to be available soon after a major nuclear event.

There are nation-specific and international plans and organizations for responding to radiation and nuclear incidents, including transporting patients with severe radiation exposure across state, provincial, or even international borders. The IAEA hosts an Incident and Emergency Centre (IEC) that coordinates international responses to nuclear or radiologic incidents and emergencies (www.iaea.org/topics/emergency-preparedness-and-response-epr) and publishes preparedness guidelines (www-pub.iaea.org/MTCD/publications/PDF/Pub1055_web.pdf). There are also guidelines from the National Council on Radiation Protection and Measurements (NCRP) and the Health Physics Society.[16,17] Another example is the U.S. Radiation Injury Treatment Network (https://ritn.net), which provides diverse services, including educational materials for health care providers, advice regarding triage, access to centers with expertise in treating persons with bone marrow failure, and training exercises. These efforts are admirable. However, our experience after much smaller nuclear events, such as the Chernobyl and Fukushima nuclear power facility accidents and the accidents and incidents in Tokaimura, Japan, and Goiânia, Brazil, suggests that much of this planning is unrealistic and unlikely to be effective, especially in the instances of a large nuclear or radiologic terrorist event, and it is obviously useless in the context of the detonation of a nuclear weapon or even a limited nuclear war.

There has been little progress made in educating government officials, policymakers, and the public about the real consequences of exposure to ionizing radiation. This oversight comes at our own peril. This knowledge gap has been and will continue to be exploited by rogue states and terrorists to further their political agendas.

POLITICS AND PUBLIC POLICY

Several recent trends and events beyond those already mentioned are disturbing. One is that the U.S. government considers Russia to be in violation of the 1987 Intermediate-Range Nuclear Forces Treaty, and Congress has approved measures to expand and increase the capability of nuclear weapons in the U.S. arsenal. The Trump administration recently gave the Air Force permission to develop a stealth nuclear cruise missile and approved funds to begin replacing the aging Minuteman missiles in silos across the United States. The United States recently decided to develop smaller nuclear weapons that could be used in tactical settings; the smaller size of the weapons increases the likelihood that they would be used and increases the number of weapons that could be stolen by terrorists and transported into the United States. Our treaties, such as the Strategic Arms Limitation Treaty (SALT), to limit, reduce, and eventually eliminate nuclear weapons are in disarray. We are not alone. Russia is taking parallel steps to increase its nuclear attack capabilities.

Contrary to what one might have hoped for 25 years after the end of the Cold War, the Bulletin of the Atomic Scientists Doomsday Clock has been set 3 minutes closer to midnight than in 2014, reflecting global nuclear weapons mod-

ernization, outsized nuclear-weapons arsenals, and collapsing nuclear-weapons treaties, which pose extraordinary and undeniable threats to the continued existence of humankind. These scenarios, whether they result from an accident or from an intentional detonation of a nuclear weapon or a terrorist action, require diverse strategies that include policy decisions, public education, medical preparedness, and, as a last resort, medical interventions for an effective response. However, as in all of medicine, prevention is better than cure.

POLICY IMPLICATIONS

Educating government officials, policymakers, and the public about the risk of nuclear terrorism is essential. Understanding what we can achieve — and especially what we cannot realistically achieve — with medical preparedness is also essential. Preventing nuclear terrorism is key but is unlikely to be universally successful. Several of the scenarios we describe can be dealt with by careful planning. At the other extreme are scenarios involving hundreds, thousands, or even millions of casualties, for which medical preparedness is likely to be ineffective and possibly dangerous in fostering the impression that we can respond successfully to these events. We believe the best approach is a carefully conceived, long-term plan within the public education system to provide lessons on radiation biology. Because this subject is usually not well taught in medical schools, health care providers, including physicians, also should be required to take an informational course, much as several states require for responses to child abuse, therapy options for breast and prostate cancer, and management of Alzheimer's disease. Unfortunately, many medical schools lack appropriate educators to accomplish this task.[18] Also needed after such an event are a well-informed command and control structure and credible, independent medical experts working in concert to provide instructions and information to the public when government credibility is compromised, as was the case after the Chernobyl and Fukushima accidents. We and others have published nontechnical books, directed toward people with a high school–level education, that may help.[19]

CONCLUSIONS

There is increasing public concern over nuclear terrorism, an accident or attack against a nuclear power facility, intentional or unintentional use of a nuclear weapon, or the use of radiologic dispersion or exposure devices, such as a dirty bomb. Dealing effectively with these events requires diverse strategies, including policy decisions, public education, prevention, and, as a last resort, medical preparedness. Prevention is the most effective strategy. Planning for these events is important, but we should realize the limitations and not be misled into thinking that preparedness trumps prevention.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

From the Haematology Research Centre, Division of Experimental Medicine, Department of Medicine, Imperial College London, London (R.P.G.); and the Department of Medicine, Division of Hematology and Oncology, University of Nebraska Medical Center, Omaha (J.O.A.). Address reprint requests to Dr. Gale at the Haematology Research Centre, Division of Experimental Medicine, Department of Medicine, Imperial College London, London SW7 2AZ, United Kingdom, or at robertpetergale@alumni.ucla.edu.

1. Committee for the Compilation of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki. Hiroshima and Nagasaki: the physical, medical, and social effects of the atomic bombings. New York: Basic Books, 1981.
2. Douple EB, Mabuchi K, Cullings HM, et al. Long-term radiation-related health effects in a unique human population: lessons learned from the atomic bomb survivors of Hiroshima and Nagasaki. Disaster Med Public Health Prep 2011;5:Suppl 1:S122-S133.
3. Christodouleas JP, Forrest RD, Ainsley CG, Tochner Z, Hahn SM, Glatstein E. Short-term and long-term health risks of nuclear-power-plant accidents. N Engl J Med 2011;364:2334-41.
4. Ramberg B. North Korea's other nuclear threat: why we have more to fear than just bombs. Foreign Affairs. August 28, 2017.
5. Butturini A, De Souza PC, Gale RP, et al. Use of recombinant granulocyte-macrophage colony stimulating factor in the Brazil radiation accident. Lancet 1988;2:471-5.
6. FEMA.gov. Planning guidance for a response to a nuclear detonation (https://www.fema.gov/media-library/assets/documents/24879).
7. Lerner EB, Schwartz RB, Coule PL, et al. Mass casualty triage: an evaluation of the data and development of a proposed national guideline. Disaster Med Public Health Prep 2008;2:Suppl 1: S25-S34.
8. DiCarlo AL, Hatchett RJ, Kaminski JM, et al. Medical countermeasures for radiation combined injury: radiation with burn, blast, trauma and/or sepsis: report of an NIAID Workshop, March 26-27, 2007. Radiat Res 2008;169:712-21.
9. Sholom S, McKeever SW. Integrated circuits from mobile phones as possible emergency OSL/Tl dosimeters. Radiat Prot Dosimetry 2016;170:398-401.
10. Wojcik A, Oestreicher U, Barrios L, et al. The RENEB operational basis: complement of established biodosimetric assays. Int J Radiat Biol 2017;93:15-9.

11. Ainsbury EA, Samaga D, Della Monaca S, et al. Uncertainty on radiation doses estimated by biological and retrospective physical methods. Radiat Prof Dosimetry 2017 September 18 (Epub ahead of print).
12. Demidenko E, Williams BB, Swartz HM. Radiation dose prediction using data on time to emesis in the case of nuclear terrorism. Radiat Res 2009;171:310-9.
13. Waselenko JK, MacVittie TJ, Blakely WF, et al. Medical management of the acute radiation syndrome: recommendations of the Strategic National Stockpile Radiation Working Group. Ann Intern Med 2004;140:1037-51.
14. Smith TJ, Bohlke K, Lyman GH, et al. Recommendations for the use of WBC growth factors: American Society of Clinical Oncology clinical practice guideline update. J Clin Oncol 2015; 33:3199-212.
15. Singh VK, Romaine PL, Seed TM. Medical countermeasures for radiation exposure and related injuries: characterization of medicines, FDA-approval status and inclusion into the strategic national stockpile. Health Phys 2015;108:607-30.
16. Key elements of preparing emergency responders for nuclear and radiological terrorism. Commentary no. 19. Bethesda, MD: National Council on Radiation Protection and Measurements, 2005.
17. Radiation and risk: expert perspectives. McLean, VA: Health Physics Society, 2017 (https://hps.org/documents/radiation_and_risk.pdf).
18. Dynlacht JR, Zeman EM, Held KD, Deye J, Vikram B, Joiner MC. Education and training needs in the radiation sciences: problems and potential solutions. Radiat Res 2015;184:449-55.
19. Gale RP, Lax E. Radiation: what it is, what you need to know. New York: Alfred A. Knopf, 2013.

DOI: 10.1056/NEJMsr1714289