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Author(s): Siegfried S. Hecker

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Siegfried S. Hecker
Los Alamos National Laboratory

Introduction

As pointed out by several speakers, the level of violence and destruction in terrorist attacks has increased significantly during the past decade. Fortunately, few have involved weapons of mass destruction, and none have achieved mass casualties. The Aum Shinrikyo release of lethal nerve agent, sarin, in the Tokyo subway on March 20, 1995 clearly broke new ground by crossing the threshold in attempting mass casualties with chemical weapons. However, of all weapons of mass destruction, nuclear weapons still represent the most frightening threat to humankind.

Nuclear weapons possess an enormous destructive force. The immediacy and scale of destruction are unmatched. In addition to destruction, terrorism also aims to create fear among the public and governments. Here also, nuclear weapons are unmatched. The public's fear of nuclear weapons or, for that matter, of all radioactivity is intense. To some extent, this fear arises from a sense of unlimited vulnerability. That is, radioactivity is seen as unbounded in three dimensions – distance, it is viewed as having unlimited reach; quantity, it is viewed as having deadly consequences in the smallest doses (the public is often told – incorrectly, of course – that one atom of plutonium will kill); and time, if it does not kill you immediately, then it will cause cancer decades hence.

Fred Iklé[1] recently stated that "The morning after…a nuclear weapon has been used, the rules of warfare throughout the world will be profoundly transformed." He added, "Democracy cannot survive if a nuclear bomb can be detonated in Paris or Manhattan." Democracy is even more vulnerable if nuclear weapons were exploded in democracies with shallower roots, such as those in Russia or India, for example. Hence, the consequences of a nuclear explosion almost anywhere on Earth would seriously impact the affairs of all nations.

Potential forms of nuclear terrorism

A nuclear weapon delivered by a missile, plane, boat, or van produces the gravest consequences of all forms of nuclear terrorism. Fortunately, the key ingredients for making a weapon, the fissile materials plutonium or highly enriched uranium, are difficult to make and the facilities to make them have quite visible signatures. A second form of nuclear terrorism that is much less devastating, but much more likely is that of radiological terrorism, that is, the dispersal of radioactive materials. These so-called radiological dispersal devices (RDDs) can be made by packaging radioactive materials with chemical explosives and detonating such devices in high-value surroundings. A third form of nuclear terrorism is sabotage of nuclear facilities.

All of these forms of nuclear terrorism are old problems – with concerns first being expressed a few years after World War II. However, the world has changed significantly since then. As already mentioned, there is a strong proclivity toward greater levels of violence. Yet, the public today has a much lower tolerance for risk. There is also considerably greater technological sophistication today and there is much more information available to the public, especially on the Internet. The greatest change, however, since the early days of nuclear weapons and nuclear power is that terrorists have easier access to nuclear and radioactive materials.

Nuclear weapons. Although nuclear weapons are complicated technological devices, it is generally agreed that a determined, well-trained sub-national group could in time build a crude nuclear device with yields on the order of a few to tens of kilotons. The atomic bombs dropped on Hiroshima and Nagasaki were less than 20 kilotons. They devastated these cities and caused several hundred thousand deaths. The most difficult part of building such bombs is acquiring on the order of the tens of kilograms of highly enriched uranium or plutonium required to build them. The difficulties that a determined adversary such as Saddam Hussain experienced in spite of the expenditure of billions of dollars is a good case in point.

However, the dissolution of the Soviet Union with the consequent loss of order and central government control, especially in the early 1990s, raised the specter of theft or diversion of nuclear weapons or weapons-usable materials from the nuclear complex of the former Soviet Union. Although the "loose nukes" concern received much play in the American media, it appears overblown. There is no evidence that Russia has lost control of any weapons in its nuclear arsenal. Unfortunately, we do not have similar confidence about the potential loss of weapons-usable nuclear materials. In fact, several high-visibility cases in the middle 1990s demonstrated that weapons-usable plutonium or highly enriched uranium were trafficked illicitly from Russia and other states of the former Soviet Union. These incidents provided a "wake-up" call for Russia. Since that time, Russia has greatly enhanced the security of its weapons-usable materials with much of the effort being financed by the U.S. Government.

Although, the quickest way to deliver a nuclear weapon is by missiles, that remains an unlikely probability for a decade or more. Crude nuclear devices would be most easily transported to the desired site by boat, plane, or van. Although nuclear devices have a distinct radioactive signature that can be detected by sophisticated sensors, this signature is attenuated significantly by distance and by shielding. Moreover, the number of entry points into the United States or other states that have a significant U.S. presence is overwhelming. Hence, today we must assume that if a group possesses a nuclear device, there is a very high probability that such a device could be delivered to a place where it could cause unacceptable damage. Hence, our government must remain ever vigilant to prevent nuclear weapons or weapons-usable materials from falling into the wrong hands.

Radiological terrorism. The human consequences of radiological devices detonated in high-value places are orders of magnitude less than those of a nuclear detonation. The immediate effects are principally those of the chemical explosive used to detonate the RDD. Dispersing the radioactive materials limits their immediate lethality. Furthermore, the lethality depends strongly on the nature of the radioactive material. Plutonium and highly enriched uranium, which are most feared by the public, are unlikely to result in a large number, if any, immediate deaths because they do not emit highly penetrating radiation. Even the long-term cancer potential of their dispersal may not be terribly great.

However, radioactive materials with intensely penetrating radiation may cause significant casualties. Such materials result from the burning of uranium in nuclear reactors (that is, their spent fuel or nuclear waste from reprocessing of spent fuel) or from medical or industrial radiation sources used to generate intense radiation. Fortunately, the more lethal a terrorists choice of radioactivel material, the less likely it is for a terrorist to be able to fashion it into an RDD without first killing the terrorist. Moreover, the easier it would be to detect such a device unless it is heavily shielded.

Hence, it is generally agreed that the greatest consequences of an RDD are public fear and the potentially enormous cleanup costs along with the consequent economic losses. Unfortunately, there is essentially no barrier to terrorists acquiring a wide range of radioactive materials. By far the most vulnerable, are medical and industrial radiation sources. There are currently more than 135,000 licensees of medical and industrial radiation sources in the United States with more than 1.8 million sources in use[2]. Even in the United States, which has rather stringent regulations for the use and disposition of radioisotopes, approximately 200 sources are reported lost, stolen, or abandoned annually. Around the world, more than 110 States have no minimum infrastructure to properly control radiation sources.[3] In Russia, there were 500 reported incidents involving unlawful movements of materials with elevated levels of ionizing radiation in the year 2000 alone. The International Atomic Energy Agency has reported that since 1993 there have been 175 cases of trafficking in nuclear material and 201 cases of trafficking in other radiation sources. Fortunately, only 18 of these cases have actually involved small amounts of highly enriched uranium or plutonium. It is somewhat reassuring that historically there have been surprisingly few incidents of the theft or smuggling of radioactive materials for malevolent purposes. However, the increased proclivity of toward greater violence in terrorist acts gives one much reason for concern.

Nuclear sabotage. Blowing up a nuclear facility constitutes another form of potential nuclear terrorism. The well-over 1000 nuclear facilities around the world constitute a target-rich environment. Although nuclear power reactors are typically well guarded and some are designed to withstand a significant external insult, the radioactive source terms at such facilities have the potential of causing massive casualties. Such power reactors, like other critical facilities such as dams and chemical plants, pose potentially serious hazards for nearby populations. The potential damages resulting from terrorist attacks on nuclear power plants depend on inherent design features and on local protective measure, which, in turn, vary widely from country to country. The IAEA reports that there are 438 nuclear power reactors in operation worldwide (with 103 of these in the United States). Following the Oklahoma City bombing, the U.S. Nuclear Regulatory Commission has overseen a significant safety enhancement of U.S. nuclear power reactors against the truck bomb threat.

The situation for storage sites housing spent fuel or high-level waste resulting from reprocessing is similar to that for nuclear reactors. The radiation source terms are potentially enormous. In addition, there are 651 research reactors (only 284 are currently in operation) and 250 fuel cycle plants around the world, including uranium mills and plants that convert, enrich, and store nuclear materials. These nuclear facilities represent a much smaller source term, but are also typically much less secure.

Although sabotage of some power reactors may cause Chernobyl-like damages, most sabotage attempts would most likely result in the dispersal of some radioactive materials without mass casualties, but with enormous public fear and economic losses. In addition to these consequences, any successful act of nuclear terrorism would also most likely set back any expansion of nuclear power or other peaceful uses of the atom for decades.

How to deal with the threat of nuclear terrorism?

Much has been written over the years about the nature of the threat. During the past four years, the U.S. Defense Science Board has twice focused on the nuclear terrorism threat during its summer studies. The principal recommendation from these studies is to develop a comprehensive architecture to counter all aspects of nuclear terrorism. Such an architecture should include:

- Information and intelligence.
- Security
- Detection
- Disablement
- Mitigation
- Attribution.

Some aspects of nuclear terrorism, such as the dispersal of radiation sources, have low consequences but virtually no barriers. Others, such as a nuclear detonation have unacceptable consequences but significant barriers. Hence, information and intelligence about potential terrorist activities is paramount to provide as much early warning as possible. Keeping radioactive materials secure – that is, protected, controlled, and accounted for – is very important, especially for weapons-usable plutonium and highly enriched uranium. Security of radiation sources is most problematical. A major worldwide effort is necessary to have every country with such sources develop a proper regulatory framework and system of control. The threat of nuclear sabotage calls for extending tight security requirements to all nuclear facilities.

Unlike biological and chemical agents, nuclear materials and radioisotopes have a distinct radioactive signature that can be detected at a distance. Unfortunately, this signature is attenuated by distance and by shielding, which makes it more difficult to detect some of these materials in a sea of cosmic background radiation. For example, plutonium's $7x10^7$ gammas/second/kilogram are attenuated by a factor of one million by one kilometer in air and a factor of one thousand by one inch of lead shielding. Detecting radiation at a distance continues to be one of the most important technological challenges in nuclear terrorism.

Disabling a nuclear device is extremely difficult but possible if one can gain access and render the device safe. The U.S. nuclear weapons laboratories have over the years developed several potential approaches. Any knowledge of the type of device or its country of origin would prove very helpful in attempting to render the device safe. If a device is actually detonated, then treating the casualties promptly and effectively becomes crucial. Likewise, rapid and effective clean-up of contaminated areas will help to limit the economic damages. Again, the United States has significant training experience with the Department of Energy's Accident Response Group (ARG) and its Nuclear Emergency Search Teams (NEST). Likewise, there is a substantial body of expertise for decontamination and clean-up based on experience with decommissioning nuclear facilities and cleaning up nuclear dispersal accidents. Lastly, a comprehensive architecture must include attribution. Forensics must be developed to determine the identity of the perpetrators, both for the purpose of retaliation and to guard against a potential repeat attack.

One additional critical dimension of an integrated architecture to respond to terrorism is education of the public along with the role of mass media. This is especially important for nuclear terrorism because of the public's lack of understanding of radiation and the great fear that accompanies this lack of understanding. For example, the likelihood of radiological terrorism in the near future is quite high – the necessary materials are readily available. However, it is important for the public to understand that the threat to human life is very limited from most such devices. The economic consequences from contamination, disruption, and clean-up, however, can be severe. Radiological sabotage represents a considerably greater threat to human life in the vicinity of nuclear facilities. However, there are immediate actions, including well-established medical treatments, that can reduce the threat to human life. Even a nuclear explosion with its enormous destructive power has a limited range of lethality. Mass media can play an important role in helping to educate the public on the real nature of the various nuclear threats.

I believe that any integrated architecture would also benefit substantially from U.S. – Russian cooperation on a wide front of activities designed to deal with nuclear terrorism. The first cooperative agreement between the United States and Russia to combat terrorism in general dates back to September 1993 with a memorandum of understanding between the U.S. Department of Defense and the Russian Federation Ministry of Defense. Although not much activity has occurred under this agreement, recent statements made by President Bush and Russian Minister Ivanov underscore the importance of this problem.

Specifically, I believe that cooperation between the Russian Academy of Sciences and the U.S. National Academies would be very beneficial. I believe that since this problem has so many dimensions, it should be viewed from as many different points of view as possible, including those of scientists and engineers. There are many areas in which specialists can help with the science and technology dimensions of nuclear terrorism. The U.S. National Academies have a long record of involvement in the counter terrorism arena. Working jointly with the Russian Academy of Sciences would prove very beneficial to both countries. Also, often the informal dialog resulting from the discussion of specialists under the umbrella of the Academies can help to catalyze necessary government actions.

[1] Fred C. Iklé, "The Second Coming of the Nuclear Age," *Foreign Affairs,* **Vol. 75**, Jan./Feb. 1996, p. 119.
[2] Joel O. Lubenau, "A Century's Challenges: Historical Overview of Radiation Sources in the USA," *IAEA Bulletin,* **Vol. 41,** No. 3, 1999, p. 2.
[3] Abel J. González, "Strengthening the Safety of Radiation Sources & The Security of Radioactive Materials: Timely Action," *IAEA Bulletin,* **Vol. 41,** No. 3, 1999, p. 2.