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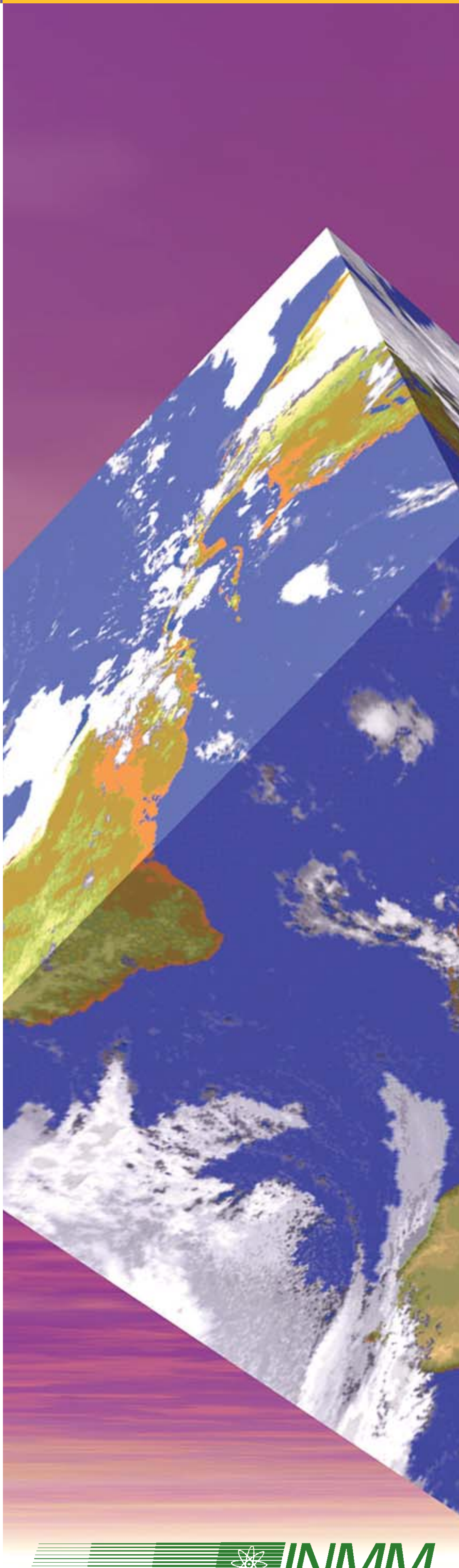

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INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

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By Nancy Jo Nicholas
INMM President

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By Dennis Mangan
Technical Editor

Introduction to Special Edition on Reducing the Threat from Radioactive Materials

Stephen V. Mladineo
Chair, Nonproliferation and Arms Control Division, INMM

At the July 2006 Annual Meeting of the Nonproliferation and Arms Control Division, Ruth Duggan volunteered to lead a new standing committee on international nuclear and radiological security. The new committee was created by consensus of the assembled division membership, and with the encouragement of the INMM President Nancy Jo Nicholas. In addition to other activities that the standing committee has begun, ruth conceived of and managed the production of this special edition of the Journal.

The Nonproliferation and Arms Control Division is one of the Institute's six Technical Divisions. It is committed to the promotion and advancement of the research, development, and application of effective technologies to control proliferation risks and reduce arms, and to public education and outreach on international arms control and nonproliferation issues. Four standing committees help organize the work of the division. The Standing Committee on International Nuclear and Radiological Security has taken the initiative to begin engaging individuals and organizations not traditionally connected to the Institute including radiological source experts and border security and customs officials. This Standing Committee has taken as its initial focus the following four topical areas:

Radiological Threat Reduction

The committee will examine the radiological material life cycle, the accountability of material throughout that lifecycle, the threats and consequences associated with use of this material as a weapon of mass destruction/disruption/exposure, the detection of illicit movement and placement of radiological material, and how the radioactive material life cycle might be altered or replaced to mitigate proliferation and consequences.

Nuclear Smuggling and Illicit Trafficking

The committee will explore the detection and illicit trafficking of nuclear material after it has left the normal system of control. It will explore technologies that assist in detection once material is known to be out of the normal system of control, the revelation and suppression of attempts to move material through likely transit points (border security, maritime security, air cargo security) of illicit nuclear and radiological materials, and analysis of trends and motivation beyond trafficking incidents.

Countering Nuclear Terrorism

The committee will explore ways in which the threat of nuclear terrorism can be reduced. There may be some overlap with the other two areas, but this area can be investigated separately as well.

Radiological Terrorism Consequence Management

The committee will examine the efforts of nuclear terrorism consequence management to determine lessons learned and opportunities for integration that could improve the response to a radiological terror event and to help mitigate its effects on public and economic health.

By sponsoring this special edition of the *Journal*, the Standing Committee on International Security of Nuclear and Radiological Materials seeks to explore each of these topical areas. Starting with an assessment of the threat and the consequences of radiological terrorism, the first two authors set the stage for the articles that follow. These include discussions of the synergies and tensions between safety and security, nuclear and radiological material transport security, and international nuclear forensics as a means to deter illicit trafficking. The remaining articles describe some of the programmatic efforts to reduce the threats of radiological terrorism.

Other Standing Committee activities include a Workshop titled Reducing the Risk from Radioactive and Nuclear Materials that took place on March 21–22, 2007, in Santa Fe, New Mexico. A summary and analysis of this workshop will appear in a future edition of the *Journal*. The focal topical areas of the Standing Committee will be discussed further at a series of featured sessions on International Security of Nuclear and Radiological Materials at the INMM Annual Meeting, July 8–12, 2007, at the JW Marriott Starr Pass Resort & Spa, Tucson, Arizona, USA.

I would like to congratulate the Standing Committee on their success in producing this special edition. Ruth Duggan and I hope you find this edition of the *Journal* enlightening and thought provoking.

Assessing the Threat of Radiological Terrorism

Charles D. Ferguson
Council on Foreign Relations, Washington, D.C., USA

Increased real and perceived threats of terrorism in recent years have provoked many security experts to predict that it is a question of when, not if, terrorists will use radioactive materials in an act of terrorism. Still, if radioactive dirty bombs are so easy to make, why haven't terrorists detonated one? To try to answer this question and to understand what improved security efforts are needed, it is first necessary to learn about the nature of the radiological terrorism threat.

A terrorist act, like a criminal act, depends on three factors: motive, means, and opportunity. As any detective knows, a criminal must be motivated to commit the crime. Motivation, however, is a necessary but not a sufficient condition. The criminal must also identify appropriate and effective means to increase the chances of success. Finally, success hinges on waiting for a propitious opportunity to acquire the means (such as a weapon or materials to make a weapon) to do the vile deed.

While an act of terrorism mirrors the major components of a crime, the motivational factor for terrorism usually is connected to objectives with larger implications than those associated with the typical crime. In a crime, the perpetrator often is just motivated by personal considerations, such as hate for the victim in an assault or murder or the desire for personal financial gain in a robbery. However, in some crimes, such as assassinations, a political objective drives the perpetrator to commit the act. An assassination not only kills the victim but is intended to influence or change an audience, such as a political party or a whole nation state. Like these types of crimes, terrorism, by definition, involves three actors: a perpetrator, a victim, and an audience.

Terrorists have to consider multiple audiences: any constituent groups they may have, adversaries, groups that can influence the adversaries, and the core members of the terrorist organization. The means chosen for a terrorist act can profoundly affect these different audiences. A simple improvised explosive device, for example, implies a low level of capability but, depending on how it is used, can help achieve the terrorists' objectives such as driving an adversary out of occupied territory. While more sophisticated means such as radiological, biological, chemical, or nuclear weapons can highlight the power of the terrorist group, such methods could alienate the group's constituencies. These constituencies could suffer retaliation as a response to use of unconventional weapons or techniques. National-separatist terrorist organizations striving to liberate territories would especially not want to expose their constituencies to retaliation that could undermine support for the liberation movement. These considerations can strongly influence the terrorists when they choose the means for a particular act of terror.

Radiological terrorism can involve many scenarios that release, attempt, or purport to release radiation to harm or try to instill terror in a group of people. For instance, terrorists may attack or threaten to attack a nuclear facility, such as a nuclear power plant or nuclear spent fuel storage site. They may want to actually release radiation or may just want to cause damage to a potent symbol of industrial might. Alternatively, terrorists may decide to acquire radioactive materials for use in a radiological weapon. Here, the analysis is solely focused on radiological weapons.

A radiological weapon can take different forms: a radiological dispersal device (RDD), a radiological incendiary device (RID), or a radiological emission device (RED). The common characteristic of these devices is that each type releases ionizing radiation. The difference among the devices is the way the ionizing radiation is released. An RDD spreads radioactive material that emits radiation over the dispersal area. A special type of RDD is called a "dirty bomb" because it employs conventional explosives to disperse the radioactive material. However, an RDD can use non-explosive dispersal methods. The effectiveness of the dispersal method, whether explosive or non-explosive, significantly depends on the chemical form of the radioactive material. An RID uses fire, ignited by an incendiary device, to spread radioactive material. In contrast to an RDD and an RID, an RED does not disperse the radioactive material but instead lets the material remain stationary while it emits ionizing radiation. An RED, for example, could be well-suited for heavily trafficked and densely populated locations.

Ionizing radiation includes alpha, beta, and gamma radiation. Alpha radiation is composed of helium nuclei (two protons and two neutrons bound together); it is not very penetrating and can usually be stopped by a piece of paper or the dead outer layer of skin on a person's body. Beta radiation is comprised of highly energetic electrons or positrons (particles with the electron's mass but with a positive charge). This radiation is more penetrating than alpha radiation and can be stopped by materials as thick and dense as a sheet of aluminum, for example. Gamma radiation, the most penetrating type, is made of highly energetic or high frequency light. Dense lead sheets or thick concrete slabs can stop most gamma radiation. In addition to these types of ionizing radiation, protons or neutrons that collide with protons can cause ionization. Ionized atoms and molecules can result in cell damage in living tissue.

Motive: What Terrorists are Interested in Using Radioactive Materials?

Fortunately, most terrorists have not expressed an interest in radiological terrorism. The psychological and political constraints are too great for most terrorist groups. But certain types of groups stand out as potential candidates for using radioactivity in an act of terrorism. In particular, some political-religious groups such as al Qaeda or apocalyptic cults such as Aum Shinrikyo tend to be attracted to unconventional means.

Aum's 1995 attack on the Tokyo subway system with sarin gas deployed with crude chemical weapon delivery devices (polyethylene bags punctured with sharpened umbrella points) was a watershed event for what many terrorism experts call the "new breed" of terrorism. While terrorists in the past tended to shy away from mass murder, the new breed was more willing to contemplate and then carry out attacks that have the potential for massive body counts and widespread destruction. Aum's leader, Shoko Asahara, for example, wanted to spark a nuclear war involving the United States and Japan to usher in the apocalypse. While Aum is not known to have conducted any radiological attacks, its track record with chemical and biological warfare agents indicates the seriousness of the unconventional terrorism threat for some terrorist groups.

In recent years, al Qaeda has sparked the greatest concern about unconventional terrorism although there are no known cases of al Qaeda terrorists actually using radioactive materials in an act of terrorism. Still, the U.S. Central Intelligence Agency has warned, "Construction of an RDD is well within [al Qaeda's] capabilities as radiological materials are relatively easy to acquire from industrial or medical sources." But to date the known cases of al Qaeda's interest in radiological terrorism indicates an unsophisticated understanding of how to effectively use radioactive materials.

Al Qaeda's efforts at radiological terrorism first made a splash on the public's consciousness with the fanfare and doom-and-gloom presentation of the U.S. government's announcement of José Padilla's apprehension. In June 2002, then-U.S. Attorney General John Ashcroft announced that Padilla, a.k.a. Abdullah Al-Mujahir, was under arrest for wanting to build a radioactive dirty bomb. Ashcroft gave the alarming impression that Padilla could have killed and injured thousands of people. Since then, the U.S. government's case against Padilla as a dreaded dirty bomber has eroded, and information about his abilities and alleged intentions have cast doubt on the government's claims. A former gang member, Padilla had converted to a radical form of Islam while serving time in prison in Florida. After release from prison, he made trips to the Middle East where he is alleged to have met al Qaeda leaders, who asked him to go on a scouting mission to the United States. Immediately upon landing at Chicago's O'Hare airport in May 2002, he was arrested and subsequently charged with an attempt to make a dirty bomb. About two years later, the press reported that government investigators believed that Padilla wanted to use uranium in a dirty bomb. But uranium is weakly radioactive and would not have powered a potent dirty bomb. More recently, the government has downplayed and then dropped allegations that he wanted to commit radiological terrorism.

In January 2003, British investigators reported that al Qaeda may have acquired radioactive materials and then constructed a dirty bomb near Herat, Afghanistan. However, an unnamed American official told the Associated Press that the report was unsubstantiated. In 2004, an al Qaeda-affiliated group in London allegedly wanted to build dirty bombs. Dhiren Barot, a.k.a. Issa al-Hindi, a leader of one of the group's cells, had researched information about radioactive materials and concluded that his cell could safely handle the types of radioactive material found in smoke detectors. He planned to acquire about one hundred smoke detectors to make a dirty bomb. But such a dirty bomb would create little or no harm because only tiny amounts of radioactivity are in a smoke detector. More than one million smoke detectors would be needed to fuel a potent dirty bomb.

While the Padilla, Afghanistan, and Barot cases illustrate either possibly hyped government allegations or amateurish capabilities, there is other evidence that al Qaeda or al Qaeda-affiliated groups are becoming more likely to use radioactive materials in an act of terrorism. For instance, Chechen rebels could become more radicalized by their association with al Qaeda-affiliated groups. During the early years of fighting, Chechen rebels, who are trying to separate Chechnya from Russia, mainly targeted their attacks on the Russian military and other symbols of Russian authority. But in the last few years, they have widened their attacks to include harming more and more civilians as shown by the takeover of a Moscow theater in October 2002 and the school siege in Beslan in September 2004, which resulted in 330 deaths, many of them children. This shift has correlated with Chechen rebels coming into closer contact with al Qaeda-affiliated Islamic extremists. Thus, the motivations for launching radiological attacks may have increased.

As early as the mid-1990s, the Chechen rebels showed they have the means for such attacks. For example, in November 1995, then-Chechen leader Shamil Basayev called a Russian television crew telling them that there was a partially buried container of radioactive cesium-137 in Moscow's Izmailovsky Park. In December 1999, Russian-supported Chechen Security Service stated that it had discovered and defused a container filled with radioactive materials and connected to an explosive mine. The container was located near a railway line. In September 1999, Chechen government officials reported that unidentified thieves had attempted to steal a container full of radioactive materials from a chemical factory in Grozny, Chechnya. In late December 2006, the U.S. National Academy of Sciences published a report that describes three radiological incidents in the Grozny area from 2000 to 2002. In one of the incidents, an insurgent reportedly testified to authorities that he had helped organize the theft of a radioactive source from an inactive chemical plant.

In 2006, additional evidence pointed to increasing sophistication in the use of radioactive materials by criminals and increasing interest in using these materials in terrorism. In September 2006, Abu Hamza al-Muhajir, the leader of al Qaeda in Iraq, called for nuclear scientists and explosive experts to assist his organization in making biological and *dirty* radioactive weapons. Later that year, the murder of former Russian spy Alexander Litvinenko captured worldwide attention. He had been poisoned in London with a small quantity (micrograms) of a radioactive substance called polonium-210. The perpetrators do not appear to have been motivated to create widespread terror, but traces of polonium were found in several locations. While this contamination was too little to possibly cause health effects in many people, the relatively high-level of expertise demonstrated in acquiring and employing this rare substance have raised concern that criminals or terrorists capabilities to use more prevalently available high-risk radioactive materials have increased.

Means: What Radioactive Materials Can Pose High Security Risks?

The world contains many types of radioactive materials that emit ionizing radiation. The materials range from medical sources and smoke detectors with very tiny amounts of radioactivity to spent nuclear fuel that is highly radioactive. The focus here is on radioactive sources that are prevalently employed in commercial, scientific, and medical activities.

The International Atomic Energy Agency (IAEA) has defined five categories of radioactive sources. This categorization is based on the harm a source can pose to human health. Such an assessment closely tracks the safety risk of a source. While safety risks tend to correlate with security risks, these risk assessments can differ depending on a consideration of factors such as portability and accessibility of a source. The IAEA categorization orders sources so that category 1 sources present the highest risk and Category 5 sources present the lowest risk.

Category 1 sources could cause permanent injury in a few minutes or death in several minutes to an hour to people near an unshielded source. These sources include radioisotope thermoelectric generators (RTGs), food irradiation sources, research and blood irradiators, and teletherapy machines (that can treat cancer). Category 2 sources could cause permanent injury in several minutes to an hour or death in a few hours to days to people near an unshielded source. Such sources include industrial gamma radiography devices (that can help check for flaws in welds) and high dose rate and medium dose rate brachytherapy sources (that are inserted in a body to treat cancer). Category 3 sources could cause permanent injury in days to weeks but are unlikely to cause death if a person is near an unshielded source. These sources include level gauges, oil well logging sources, and low dose rate brachytherapy sources. Finally, Categories 4 and 5 sources are extremely unlikely to cause permanent injury or death. Such sources include diagnostic medical sources, as well as smoke, aerosol, and chemical agent detectors.

Clearly, categories 1 and 2 are high-risk. However, there has been some disagreement among government and independent experts about how to treat Category 3 sources. While some experts have asked governments to focus more security attention to Category 3, there is at least agreement that an accumulation of sources from this category would increase security risks.

Examining the types of radioactive sources that could fuel potent RDDs, as listed in Table 1, one readily observes that a relatively small number of radioisotopes are used prevalently in these sources. These commonly employed radioisotopes can be classed in terms of whether they pose mainly an internal health hazard or both internal and external health hazards if used improperly. The internal health hazard isotopes include americium-241, californium-252, plutonium-238, and radium-226. They primarily emit alpha radiation. In contrast, the internal and external health hazard isotopes of cesium-137, cobalt-60, iridium-192, and strontium-90 mainly emit high-energy gamma radiation or high-energy beta radiation.

Underscoring the vulnerability of certain sources containing these isotopes, the IAEA's illicit trafficking database shows that the majority of trafficking incidents involved cesium-137 followed by americium-241, strontium-90, cobalt-60, and iridium-192. Moreover, these illicitly trafficked isotopes were often contained in portable or mobile radioactive sources.

Table 2 lists the main properties of the eight isotopes of top security concern. Note that all of these isotopes have relatively large specific activities (the amount of radioactivity per unit mass) and medium-length half-lives (the time required for half of a sample to undergo radioactive decay) from months to several hundred years. Thus, relatively small quantities (less than a gram in many cases) can pose a health hazard, and these isotopes emit all or a significant amount of their radioactivity within a human lifespan.

Although polonium-210 is not typically included in many of the lists of the top high-risk isotopes, the murder of Litvinenko by polonium poisoning underscores the health hazard of this isotope. Nonetheless, the U.S. Department of Energy and the Nuclear Regulatory Commission had included polonium-210 as well as the previously mentioned isotopes in their May 2003 list of the isotopes of greatest concern.

The chemical form of a radioactive substance strongly affects the ease or difficulty by which the substance can be dispersed. Cesium chloride tops the priority list of high-risk easily dispersible radioactive sources because it is a talcum powder-like substance. Just blowing on it could spread it. Almost all of this material is produced in Russia and then distributed throughout the world. In contrast, cobalt-60 is in the form of metal pins or rods and, thus, is much harder to disperse. Iridium-192 is also typically in the form of a solid metal. In general, chemicals in the form of talcum or salt-like substances can be more easily dispersed than chemicals that are solid or more tightly bound together.

Table 1: High-risk radioactive sources

Type of Source or Application	Radioisotope	Typical Radioactivity Level GBq (Ci)	Source Categorization
Sterilization and food irradiation	Cobalt-60	148 million (Up to 4 million)	1
	Cesium-137	111 million (Up to 3 million)	
Radioisotope thermoelectric generator (RTG)	Strontium-90	740,000 (20,000)	1
	Plutonium-238	10,360 (280)	
Research and blood irradiators	Cobalt-60	88,800-925,000 (2,400-25,000)	1
	Cesium-137	259,000-555,000 (7,000-15,000)	
Single-beam teletherapy	Cobalt-60	148,000 (4,000)	1
	Cesium-137	18,500 (500)	
Multi-beam teletherapy (gamma knife, e.g.)	Cobalt-60	259,000 (7,000)	1
Industrial radiography	Cobalt-60	2,220 (60)	2
	Iridium-192	3,700 (100)	
High- and medium-dose brachytherapy	Cobalt-60	370 (10)	2
	Cesium-137	111 (3)	
	Iridium-192	222 (6)	
Well logging	Cesium-137	0.74-74 (0.02-2)	3
	Americium-241/Beryllium	0.74-74 (0.02-2)	
	Californium-252 (rare use)	37 (1)	
Level and conveyor gauges	Cobalt-60	0.74-74 (0.02-2)	3
	Cesium-137	0.74-74 (0.02-2)	

Opportunity: How Could Terrorists Gain Access to Radioactive Materials?

Almost every country in the world uses radioactive sources in a variety of applications, especially for industrial, medical, and scientific purposes. The major manufacturers and distributors of commercially used radioisotopes and radioactive sources are located in nine countries: Argentina, Belgium, Canada, France, the Netherlands, Russia, South Africa, the United Kingdom, and the United States. India has also been trying to position itself as a major producer and distributor. China could also become a major producer. The companies in these countries then distribute sources to thousands of clients around the world.

Although the actual number of radioactive sources is unknown, it is estimated that millions are being used or have been used and now require safe and secure disposal. The good news is that of the millions of radioactive sources in the world only a small fraction fall into the high-risk categories. The bad news, however, is that this small fraction includes thousands of sources.

Table 2: Radioisotopes of security concern

Radioisotope	Half-Life	Specific Activity GBq/g (Ci/g)	High-Energy Alpha Emissions	High-Energy Beta Emissions	High-Energy Gamma Emissions
Americium-241 (Am-241)	433 years	125.8 (3.4)	Yes	No	Low energy
Californium-252 (Cf-252)	2.7 years	19,832 (536)	Yes	No	Low energy
Plutonium-238 (Pu-238)	88 years	636.4 (17.2)	Yes	No	Low energy
Radium-226 (Ra-226)	1,600 years	37 (1)	Yes	No	Low energy
Cesium-137 (Cs-137) [Barium-137m (Ba-137m)]	30 years [2.6 min]	3,256 [19,980 million] (88 [540 million])	N/A	Low energy [Low energy]	N/A [Yes]
Cobalt-60 (Co-60)	5.3 years	40,700 (1,100)	N/A	Low energy	Yes
Iridium-192 (Ir-192)	74 days	>16,650 (>450) std >37,000 (>1,000) high	N/A	Yes	Yes
Strontium-90 (Sr-90) [Yttrium-90 (Y-90)]	29 years [64 hours]	5,180 [20.35 million] (140 [550,000])	N/A	Yes [Yes]	N/A [Low energy]

While most of these sources are believed to be relatively secure, terrorists could try to exploit security vulnerabilities. Pathways to terrorist acquisition of sources include: bribery, blackmail, political instability, officials ideologically aligned with terrorists, illicit licensing, orphaned sources, and insider access.

Terrorists could try to bribe or blackmail custodians of radioactive sources. This path could require considerable research by the terrorists to identify corruptible custodians. Corrupt government officials could provide another way for terrorists to acquire these sources. The officials would likely be ideologically aligned with the terrorists' cause. As a variant on this route, a country undergoing a coup or other political instability could allow terrorists to exploit the chaos to acquire radioactive materials.

Poor regulatory controls could open up vulnerabilities. For instance, a terrorist group could attempt to pose as a legitimate purchaser of radioactive sources by forging a license to buy and possess the sources. Moreover, lax regulatory controls in many countries, including the United States, have allowed thousands of sources to fall outside of regulatory controls. These sources are called orphaned sources and have presented safety and security hazards. Finally, without adequate background checks of employees who have access to sources, terrorists could enlist an insider to acquire these materials.

Conclusion

Although terrorists have yet to detonate a dirty bomb or disperse radioactive material using an RDD, evidence in recent years points to increased interest in radiological terrorism. Some terrorists, thus, appear to be motivated to consider and perhaps to do this type of terrorism. The means and the opportunities for terrorist exploitation of radioactive materials are also apparent. While there are considerable uncertainties in quantifying the risk of radiological terrorism, the risk is clearly not zero, and the assessment here provides an introduction to enhanced security measurements proposed in the other articles in this issue of the journal.

Notes

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14. For more details about radioactive source security, see chapter 6 in Charles D. Ferguson and William C. Potter with Amy Sands, Leonard S. Spector, and Fred L. Wehling, *The Four Faces of Nuclear Terrorism* (New York: Routledge, 2005).

Radiological Terrorism: Societal and Human Consequences

By Igor Khripunov
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Twenty years ago, in September 1987, an abandoned radioactive source of cesium chloride (a highly-radioactive substance containing Cs^{137}) was picked up by local scavengers at the site of a closed hospital in Goiania, Brazil. The glowing blue powder from the opened source was shared among the looters, their friends and relatives, and many local residents, leading to several deaths and hundreds of cases of radiation exposure, contaminated buildings, land, water, and infrastructure. Thousands of residents had to be examined, hundreds received various doses of radiation, tons of contaminated soil and debris had to be disposed of, and the economy of a prosperous resort community of Goiania suffered significant losses. The case was ruled a combination of negligence, improper handling and disposal of radioactive substances by hospital officials, and the ignorance of the public of the dangers posed by unknown industrial materials.

No malicious intent was present in the Goiania incident,[1] yet the economic, medical, and psychological damage was substantial. Traumatic as it was, the Goiania accident provides only a partial guide to radiological terrorist attacks. Safety breaches and accidents differ considerably from acts that deliberately target the public by raising associated uncertainties to an unprecedented high and disturbing level. Such acts are seen as a perfect tool for achieving one of the major objectives of terrorism—to coerce the civilian population, or any segment thereof, beyond the immediate target or victims of the attack.[2]

Unlike accidents—and what happened in Goiania is an example—whose consequences can be more or less predicted, terrorists may strive to multiply the impact of any malicious act they cause, negating routine safety procedures. Second, as adaptive adversaries, terrorists can not only shift tactics as an attack unfolds, but also carry out concurrent or sequential operations. Third, terrorist attacks are criminal acts and, as such, the response phase is complicated by the imperatives to secure the crime scene, pursue and apprehend the criminals, and conduct an investigation—increasing the psychological stress associated with such situations. A criminal investigation, furthermore, could slow down the release of information needed to improve response procedures or communicate health-related information to the public. Law enforcement officers would be reluctant to part with forensic evidence until they had obtained a conviction.[3] When the alleged perpetrators are not identified or arrested, additional psychological trauma could result among survivors and victims' families. Hence, despite certain similarities with accidents, intentional acts bring about more uncertainty and are likely to impose more severe stresses on civilian populaces.

When compared with other types of conventional and unconventional terrorism, acts of radiological terrorism represent perhaps the most effective, readily available tool terrorist groups can use to cause panic, disrupt vital institutions, and inflict psychological damage on the public, both in the immediate vicinity of an attack and well beyond. The problem with radiation exposure—real or perceived—resulting from radiological terrorism is that radiation is colorless, odorless, and tasteless, making it impossible to detect without special instrumentation and skills. Its exclusive nature stimulates worst-case fantasies and scenarios among the general public. Radiation exposure, moreover, may not manifest itself immediately, leaving the people in affected—or potentially affected—areas in anticipating anxiety and dread. The potential impact of exposure not only on those exposed but also on their descendents can leave the victims feeling guilty and depressed. Indeed, experts believe that "from a public health perspective, the psychological effects of nuclear catastrophes may be equally, if not more prevalent than their physical health consequences."[4]

The fear of radiation exposure was imbedded in the minds of the public as a result of the Hiroshima and Nagasaki bombings, subsequent open air testing of nuclear weapons, accidents at the Three Mile Island and Chernobyl nuclear plants, and other events. The deadly and devastating power of nuclear weapons and radiation was highlighted in numerous films and books. For example, Nevil Shute's "On the Beach" (published in 1957, made into a movie with an all-star cast in 1959, then remade as a miniseries for U.S. television in 2000) described the effects of radiation as the planet slowly died in the aftermath of a nuclear exchange between the United States and the Soviet Union. This fear gradually evolved into what is now known as radiophobia — an unreasoning belief that any level of ionizing radiation is highly dangerous, if not immediately deadly.

Radiophobia is also a major reason that the social and psychological impact of radiological terrorism is so difficult to diagnose, assess, and deal with in each individual situation. Few if any reliable criteria are available to help government planners draw up standard scenarios, because each affected community will react to unknown and fearsome threats differently. The post-World War II experience clearly shows that the mysterious, unfamiliar, indiscriminate, uncontrollable, and inequitable affects of radiation give rise to disproportionate, seemingly random fears in the minds of ordinary citizens.[5]

Indeed, fear is often the hallmark of any event involving a release of radiation. It worsens the psychological injury done to the public and driven by ambiguity, fragmented information, hype, and miscommunication. There is still much confusion in the minds of people who equate devastating nuclear explosions to acts of radiological terrorism, whose consequences are much less severe. One way to manage fear and uncertainty is to work toward a common level of risk acceptance that derives not only from expert judgment but also, more importantly, from the cultural and individual values of the society at large. The public, however, tends to base its views of risk on personal experience, but the nature and consequences of a radiological event are unique. Few individuals have experienced anything that can provide meaningful clues or guidance. Experts have some advantages owing to their training, knowledge, and experience. They treat risks as synonymous with probability of harm but their criteria are often misunderstood and rejected by laypersons who are guided by different perceptions and values.

Without an acceptable approach shared by all stakeholders, including the public, the factors that shape the overall psychological impact would vary from one group of the population to another. These factors include the perceived magnitude of the consequences; proximity to the radiation release; ignorance about the nature of the hazard; how long the terror persists; the degree of physical harm that comes to oneself or fellow citizens; exposure to grotesque scenes of injury or death, especially when children are involved; the suddenness of the event; and the distrust of the institutions attempting to manage the hazards. In order to mitigate or overcome these fears, uncertainties, and gaps, the authorities must keep the public adequately informed, looking at citizens not merely as helpless attack victims or a panicked mob but as proactive, knowledgeable players with much to contribute at all stages of a radiological event. Keeping the public abreast of the latest thinking about the hazards of radiation will help the authorities make an ally of the populace during times of crisis.

This partnership with the public is the best method for leaders to build trust and promote social cohesiveness in the effort to avoid and alleviate disruptive psychological experiences. Under a closer partnership, the affected public would be able to gain the facts it needs to protect against projected and actual dangers; make well-informed decisions using all available information; take an active, participatory role in the response and recovery efforts; act as a watchdog over the public resources; and preserve or restore well-being and normalcy, including economic security, in the community.[6] Enlightened partnerships are needed nationwide to avoid, for example, social stigma for individual groups of the population associated with radioactive contamination. In the Goiania accident, 100,000 persons underwent examination and more than 8,000 were given documents certifying that they were not contaminated because hotels outside the region refused to accept guests from Goiania, buses and planes refused to transport them, and doctors refused to take new patients without the certificate.[7]

The stress arising from the direct impact and the fear of radiological terrorism can spawn serious psychological and physiological consequences. Traumatic life experiences may exceed an individual's coping ability, resulting in lasting changes in brain chemistry. Radiological terrorism is defined by *The Diagnostic and Statistical Manual of Mental Disorders—Fourth Edition* as an event that engenders fear, a feeling of helplessness, or horror in response to the perceived or actual threat of injury or death to oneself or to another. During and immediately following an act of radiological terrorism, those most affected may experience shock, confusion, fear, numbness, panic, anxiety, distancing, and "shutting down." Accordingly, the psychological responses to an act of radiological terrorism break down into three main categories: distress response, behavioral changes, and psychiatric illness.[8] The number of people who are likely to be affected could far exceed the number who are directly involved or who witness the event They are those who suffer secondary effects such as an economic downturn, relatives or friends of those affected by the event and residents of the localities with seemingly similar vulnerabilities. This is the so-called "ripple-effect" involving indirect victims and long-term effects. Reached through media and other means, they are the intended audience for terror and recognize little distinction between themselves and the direct victims, beyond the happenstance of time and place. The psychological repercussions may be protracted, albeit at significantly lower intensity, by sporadic reminders through media and other channels that another similar attack might occur.

It is impossible to quantify accurately the physical, psychological, and emotional strains on a person who experiences the effects of a radiological event, either directly or indirectly. Feelings of stress in humans stem from specific interactions between people and their environment, within the social content they perceive as straining or exceeding their adaptive capacities and threatening the basics of their well-being. Biological, genetic, personality, temperament, and socioeconomic factors, as well as prior traumatic life events, contribute to the survivors' sense of vulnerability to the radiological event. One way to prepare the public for a wide range of excessive and poorly understood new stressors that are likely to cause fear, panic, disruptions, and disorder is to develop a resilience culture. Resilience can be defined as the ability to handle disruptive challenges, characterized as emergencies that can result in crisis. Accordingly, resilience culture is an interactive product of beliefs, attitudes, approaches, behaviors, and physiology that help people fare better during adversity. Real resilience requires bringing people together by engaging them in a shared, well-understood, and rewarding process. Technical solutions and skills can contribute to resilience, but ultimately it is about values, motivation, and will. Engendering such attitudes requires cultural change, and thus efforts to build a hardy mindset among people likely to endure radiological attacks.[9]

People can build personal resilience if they start reaching out and making connections: strengthening close relationships, accepting help and support from those who care, offering help and support to others, and becoming involved in civic, faith-based, or other local groups to gain support. Developing confidence in one's ability to face life's challenges, to solve problems, and to rely on one's own instincts can all help people build resilience. A person visualizing what he or she wants, rather than worrying about what he or she fears, is more optimistic and therefore has reached a resilient way to approach life and life's challenges. In other words, the belief that people can cope and are robust must be encouraged and promoted.

It is difficult to assess the mental traumas the public may suffer as a result of radiological terrorism. The minimum that can be done in anticipation of radiological attack is to develop a common risk perception acceptable to all stakeholders including, above all, the public, lay the groundwork for a comprehensive and mutually reinforcing partnership among them all and facilitate a society-wide culture of resilience. Still, we need to determine short- and long-term impacts that would affect people's way of life, their professional skills and careers, their behavioral patterns, and, importantly, their physical health. It will be extremely helpful if we could estimate the cost of these invisible and sometimes irreversible disruptions to human beings, as distinguished from tangible destruction and contamination of physical infrastructure. Unfortunately, such estimates are hard to achieve with sufficient precision. Even so, we need to make the multidisciplinary effort to assess the societal and human cost of radiological terrorism in order to prevent as much as possible these often elusive and still insufficiently understood consequences of this mode of terrorist warfare.

Notes

1. The IAEA report characterized the case as the misuse of a radioactive medical teletherapy source not under radiation protection surveillance. 1988. *The Radiological Accident in Goiania,* International Atomic Energy Agency.
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Security and Damage Potential of Commercial Radioactive Sources

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Abstract

The planning and execution of attacks with radiological weapons is well within the capabilities of both transnational and local terrorist groups. This refers to the illegal acquisition of the radioactive material, to the design of a weapon, and to the actual execution of an attack. In this pilot study, plausible attack scenarios have been developed based on medical and industrial sources widely used in Germany. Special emphasis was put on how such sources could be obtained by a locally acting terrorist group using criminal tactics. To this end, sources handling and daily work procedures in hospitals and companies were analysed to find weak points that could be discovered and exploited by terrorist groups. This led to recommendations for modest but visible security improvements. Based on our interviews with the staff of various facilities, we also call for a change of mentality of users and manufacturers to take into account not only safety but also more thoroughly security aspects of the use of radioactive materials.

We also estimated, by means of simulations, the damage caused by a radiological attack using the sources potentially available within the country. None of the scenarios we investigated led to doses at the site of the explosion which might cause acute radiation effects. However, in some scenarios, an attack would result in the necessity of a potentially very costly clean-up of large urban areas.

Introduction

The extensive discussion of radiological weapons in the media and in the scientific community has led to the result that such devices must now be considered part of the canon of potential terrorist methods—even though no such attack has actually occurred so far. It is therefore very important that all aspects of the threat be understood. This includes the availability of materials for terrorists and the technical hurdles they may face designing a weapon. It also includes estimating the damages such an attack would cause and preparing the equipment and procedures necessary for emergency responders to cope with it.

This work is based on a pilot study carried out by the authors at the University of Bremen in 2005 and 2006. It is focussed on two aspects of the radiological weapons threat: the availability of radioactive sources for terrorists and understanding the effects of an attack with potentially available sources. Both these aspects are analyzed from the point of view of a local terrorist group based in Germany. In our scenarios, such a group would use criminal tactics (as opposed to military commando-style operations), would have sufficient technical background but potentially only limited concern for their own health. The questions we asked were:

- How could such a group acquire radioactive material?
- What amount of damage could such a group cause with a radiological weapon?

Acquiring Radioactive Materials

There are two conceivable routes to radioactive materials for terrorists. The one most talked about is the illegal acquisition in a foreign country followed by the smuggling of the source into the country where the attack is to be carried out. Such a scenario would require the logistics of a transnational group and involve many people. It may also require cooperation with an organized crime organisation. However, it is a plausible scenario and one that has drawn the attention of various national and international bodies working to improve materials security in countries of the former Soviet Union and elsewhere and to step up border security to prevent illicit trafficking of such materials.[1]

A second—and less talked about—scenario involves the stealing of radioactive sources from facilities within the country in which the attack is to be carried out. From the point of view of a European country, such scenarios are becoming more likely as terrorist cells are becoming more autonomous and in some cases may form and act completely independent of transnational terrorist organisations. Examples for these developments are the attacks in London in July 2005 and the attempted attacks by two Lebanese students on two trains in Germany in July 2006.

One obvious way to illegally acquire radioactive sources within a European country would be theft from a medical or industrial facility in which they are used. According to an estimate by the Commission of the European Communities, about seventy radioactive sources are lost every year in its member states.[2] This means the sources are no longer accounted for, i.e., they have stolen, been illegally disposed of, or are otherwise untraceable for the responsible authorities. For the United States, the corresponding estimates are 300 lost sources per year.[3] Only part of them are recovered, many times at scrap yards. Not all of the lost sources have a large radioactive inventory. But the sheer numbers illustrate that control and security of radioactive sources is not only a problem of the successor states of the Soviet Union and of developing countries. Recognizing the need for action, there have been European initiatives in the past years. In Germany, these have led to new legislation for the control of highly radioactive sources and to the set up of a nationwide central register for such sources in 2005.[4]

Regardless of these most welcome developments, questions remain about the actual state of security and protection against theft for medical and industrial sources. Our pilot study attempted to look at these questions for the case of Germany, a country with a highly developed security culture, with comprehensive legislation and functioning institutions supervising facilities and enforcing the corresponding legal provisions. Lessons learned from our study should be useful for other European countries and for the United States as well.

In order to investigate the security of radioactive sources, we analyzed facilities and working procedures at locations where such materials are used or stored. We located these places, mostly hospitals and companies, using the Internet and phone directories. Table 1 lists a number of typical sources we have encountered. We then visited the facilities and talked to the staff working with the sources. We looked for weak points in the daily routine of source handling that could be discovered and exploited by a locally acting group of motivated terrorists with sufficient educational or technical background. Since this was a pilot study, the number of hospitals and companies we visited was limited. Also, not every company we approached was willing to collaborate with us. Still, our study yielded some interesting results.

Both in hospitals and industrial facilities we found that the staff was highly responsible and well informed about the legal provisions concerning safety and security of the sources in use. These provisions were accurately implemented in the places we visited. However, it was quite obvious that in all cases the center of attention lay on the prevention of accidents and harm to people due to improper use of the sources. In other words, the staff we encountered focused invariably on the safety aspects of source handling and storage. A potential risk that the sources themselves could be subject to theft by criminals or terrorists was not clearly on their minds and was therefore only insufficiently taken into account during the daily work routine.

Consequently, there appeared to be opportunities for approaching the sources unnoticed in a number of cases. In some cases it appeared to be possible to steal sources including their shielding containers. In most but not all of the corresponding scenarios, the theft would have been noticed relatively quickly, i.e., within hours. These statements refer mostly to sources with a smaller radioactive inventory.

Table 1: Medical and industrial radioactive sources considered in the study

Isotope	Max. Activity	Application
Co-60	370 TBq	Teletherapy-units for tumor treatment
Cs-137	100 TBq	Blood and research irradiators
Ir-192	7,4 TBq	Industrial radiography
Se-75	3 TBq	Industrial radiography
Ir-192	370 GBq	Afterloading-units for brachytherapy
I-131	5,5 GBq	Capsules for therapeutic thyroid applications

In cases in which sources with a larger radioactive inventory would have to be dismantled from an immobile installation like a medical irradiator or a teletherapy unit, the source handling would have posed an obstacle very difficult to overcome. For example, the improper dismounting of a typical source from a teletherapy unit would lead within minutes to extremely high radiation doses. Not only would these doses be lethal (leading to death within days), they would also be sufficient to cause symptoms like nausea and vomiting to set in while the perpetrators are still at work and on the scene.

One additional critical point that was identified during the project and that requires further study is the security of sources during transport.

Assessing the Damage of an Attack

In the second part of our study we were interested in the damage that could be expected from attacks using locally available commercial sources, identified in the first part of the study (cf. table 1). Regarding the consequences of a radiological attack in an urban environment, there appears to be a dissent in the open literature. One often cited study by the Federation of American Scientists (FAS) predicts the necessity of an evacuation of larger urban areas after a radiological attack.[5] Others disagree with such dramatic scenarios. For instance, the German Federal Authority for Radiation Protection *(Bundesamt für Strahlenschutz, BfS)* states on its Web site, that "even in the immediate proximity of the location of the release [of radioactivity], from a radiological point of view no health hazards" are to be expected "for large parts of the population."[6] We attempted to elucidate these discrepancies by simulating attack scenarios using the software HOTSPOT 2.06, which was developed by the Lawrence Livermore National Laboratory and is in the public domain. This program is based on a simple Gaussian model.

The material specific input values about resulting particle sizes necessary for such a simulation are not generally available in the open literature. For our simulations, they were chosen using plausible assumptions based on the chemical and mechanical properties of the materials. Our assumptions concur with recently published experimental data by Harper, et al.[7] In addition, we took into account the results of explosive testing campaigns conducted in 2003 under the direction of the German *Gesellschaft für Anlagen- und Reaktorsicherheit* (GRS).[8]

Since our simulations were based on a simple transport model that does not allow for detailed analysis of wind fields in urban environments, the results must be read as rough estimates. We therefore limited ourselves to studying the following questions:

- Are there acute radiation effects to be expected for people within close proximity of an explosion?
- Can emergency responders do their work in the nearby an explosion site without exceeding the permissible limits for exposure to radiation?[9]
- What is the size of the area to be decontaminated after an attack?

Quantitative results of our simulations and details about the input values for the radioactive materials and for meteorological conditions will not be published. However, some interesting findings can be summarized as follows:

- None of the scenarios involving commercial sources potentially available in Germany yielded radiation doses that would lead to acute radiation effects in the vicinity of an explosion.
- Even under unfavorable conditions involving larger but plausible amounts of easily dispersible materials, emergency responders could still work at the scene for several hours without exceeding the permissible limits for radiation exposure.
- However, such unfavourable conditions could lead to ground contaminations that would require a clean-up of large areas. For the purposes of this study, we assumed a decontamination threshold of 10 mSv per year, which is based on recommendations of the International Commission on Radiation Protection (ICRP).[10] Using this threshold, the areas to be decontaminated could be as large as several square kilometers. It must be stressed that this is a conservative estimate for a certain class of materials, which, moreover, would be difficult to obtain. For most of the sources we have considered, the areas to be decontaminated would be smaller than one square kilometer.

Material, which is less easily dispersible, would, if exploded, break into larger particles. These particles may travel a long distance from the location of the explosion. At the places where they land, there could be an increased danger for emergency responders and the population due to the concentrated high activity and resulting external dose rates.

Note that we have not attempted to determine the size of the areas to be temporarily evacuated after an attack. Within the range of parameters chosen for this study, the HOTSPOT software provides insufficient accuracy for such predictions. Given the results presented here about areas to be decontaminated based on the relatively low threshold dose of 10 mSv, we expect the sizes of evacuation areas to be significantly lower than predicted in the FAS-study cited above.

Conclusion

The planning and execution of attacks with radiological weapons is well within the capabilities of both transnational and local terrorist groups. This refers to the illegal acquisition of the radioactive material, to the design of a weapon, and to the actual execution of an attack. There are, however, obstacles that make the preparation of a radiological attack more difficult than generally assumed, especially for local terrorist groups without specialized equipment. One such obstacle is the handling of highly radioactive sources, which, if done improperly, poses severe health risks for the perpetrators. This fact alone constitutes a certain level of theft protection, which is, however, by no means sufficient.

Our study showed that even in a country with already high standards for safety and security, hospitals and industrial facilities still need to introduce at least modest improvements in sources security. These include improved alarm systems and/or cameras for all the rooms in which sources are used and stored. Most importantly, any such facility needs to analyze its own daily work procedures and policies of who has access to which rooms, including the cleaning staff. Similar recommendations can be made for companies transporting radioactive sources. Inexpensive but visible security improvements could also function to discourage potential perpetrators, who may otherwise come to the conclusion that such sources are easy to steal, possibly underestimating the dangers posed by some of them.

One result from our study was manifest: there is an urgent need for a mentality change for users and manufacturers of radiation sources. While there is sensitivity for the safety aspects of source handling, there is hardly any for source security. In today's world, sources are not only dangerous to handle, they are also in danger of being abused for terrorist purposes. The formerly popular notion of "self-protecting" radioactive sources no longer holds.

Our simulations have shown that an explosive dispersal of some commercial sources widely in use in Germany will most likely not result in acute radiation hazards, even for people in the vicinity of the explosion site. Furthermore, emergency responders will most likely be able to do their work in the aftermath of such an attack. However, economic costs arising, for instance, from the necessary decontamination of large urban areas may be substantial.

The results presented in this paper hold, as mentioned several times, for radioactive sources widely in use and potentially available for terrorists in Germany. Larger sources, which could be acquired in foreign countries and smuggled into Germany, could potentially cause significantly more damage.

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The Tensions and Synergies Between Safety and Security of Radioactive Materials

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Abstract

Before the catastrophic terrorist events of 9/11, the fields of safety and security in the context of radioactive materials were separate and distinct disciplines. On an international scale, safety was and still is concerned with preventing the inadvertent exposure of people and the environment to harmful radiation. In a similar manner, security was primarily concerned with preventing the theft of nuclear materials that could ultimately be used for the construction of a nuclear weapon a or radiological weapon and preventing acts of sabotage that could lead to the environmental release of radioactive materials. In the post-9/11 environment, it has become apparent that the safety and security disciplines are interrelated and should establish closer collaboration and coordination, especially with regard to radioactive sources. This relationship has not only highlighted initial tensions but has also revealed synergies that could be exploited for the benefit of both disciplines.

Safety and Security

Safety and security have a similar general goal, which is the prevention of avoidable hazardous consequences. While both safety and security focus on preventing the exposure of people and the environment to harmful radiation, security is also concerned with preventing the denial of use of infrastructure capabilities due to contamination which would make continuous human contact impossible or very limited. Safety and security also have issues of common interest, such as source accountability and a need for close cooperation between the two disciplines, since the response to a radiological event is likely to be similar. However, safety and security have apparent differences, such as language (or at least the use and meaning of the language) and philosophies.

The essential difference between safety and security is the initiating event that could cause a radioactive release. For safety, the initiating event is unintentional and is intrinsic (e.g., part of a medical treatment or industrial operation) to the use of the radioactive source or due to abnormal circumstances, such as adverse weather or a design flaw. Those responsible for the activity, such as radioactive material users, can and should be expert in safety-related initiating events, including how to counter them. Safety focuses on minimizing the risk while radioactive material is in use, minimizing the likelihood of accidents, and mitigating the consequences of accidents that do occur.

Security deals with intentional, human-caused initiating events. These events are initiated with the express intent of creating harmful conditions to people or the environment. Users of radioactive materials were traditionally not expected to be experts in countering events that were intentionally initiated as they are for unintentional initiating events. Security is concerned with extrinsic initiating events of a malicious nature and is focused on prevention, detection, and response to theft, sabotage, unauthorized access, illegal transfer, or other malicious acts involving radioactive substances. The need for security arises from preventing an intentional act to disrupt or abuse a process or material for a purpose not intended by the legitimate owners of the process or material. The human (i.e., the threat) intent to disrupt or abuse can be described in terms of motivation (why?), intention (what?) and capability (how?). When motivation, intention, and especially capability are overcome, the threat is nullified.

In contrast with safety, therefore, it is possible to develop security planning criteria with the intention that security will provide a known and absolute level of protection against defined threats. Decisions can be made about which threats need to be countered, and, for a variety of reasons, which threats not to counter. These decisions can be absolute; there is no requirement to allow for the unexpected (beyond that which has already been included in the planning criteria) and no concept of continuous improvement toward an unachievable goal of perfect security.

Tensions

Traditionally, safety and security have dealt with opposite ends of the radioactive spectrum. While safety tended to be focused on machines that produce or are the source of radiation, security tended to be focused on nuclear materials. Tensions between safety and security can be attributed to differences in terminology, cultural differences, and organizational development. Although similar terms are used in each discipline, they usually have different meanings. These terms include *risk, threat, access control,* and even *security.*

Safety and security professionals do agree that the general definition of risk is the product of the probability of an event occurring and the consequence if that event were to occur. Differences arise in how each discipline quantifies risk. Safety quantifies risk on the basis of a probabilistic analysis of past events, while security quantifies risk using a malevolent threat-based approach, that considers human-caused events.

The traditional safety use of the term *security* referred to safety measures put in place to *secure* radioactive sources from inadvertent access. The implied notion was that if appropriate safety measures are in place and access is controlled, then security is also addressed. However, security professionals argue that safety measures may not comprehensively address security issues. For example, a locked door to a radioactive source storage room that has the appropriate radiation protection warning notices would be *secure* from inadvertent access. These safety measures may not provide substantial security against an intruder who intends to steal sources to intentionally expose people. Furthermore, security professionals would take into account the motivations and capabilities of the intruder (the *threat*) desiring to steal the source. The locked door may not be a substantial barrier to the intruder and warning notices would actually reveal the location of the theft target.

Cultural differences between safety and security have also created tensions. The cultural differences stem from transparency of information as opposed to confidentiality concerns and whether events (safety or security) arise from intentional or unintentional acts. In the safety environment, information is shared openly with the entire community. Safety issues and possible solutions to problems are openly communicated. Warning notices on defective parts are widespread and manufacturers take steps to ensure that their devices are recalled or properly repaired to overcome any safety issues. From the previous example, radiation protection warning notices are intended to draw attention to the presence of harmful sources of radiation. In contrast, the security environment strives to restrict access to information that would compromise security systems. Security equipment manufacturers discretely convey issues with its equipment to users, the presence or absence of security systems is not widely disseminated, and the locations of attractive targets of theft are not marked.

It has been stated previously that safety and security strive to prevent avoidable hazardous consequences. The difference, however, arises from the initiation of the event leading up to the consequences. Safety professionals strive to institute features that would prevent unsafe acts from occurring, such as unintentional acts, acts of nature, or defective designs. A common response from safety professionals would be "Why?" (Why would someone want to intentionally remove that radioactive source?). Security professionals strive to anticipate acts from people who intend to create hazardous conditions for other people or the environment. In a number of instances, security professionals designing security systems have consulted safety professionals on which security features would be appropriate. Security professionals often ask "what if" questions in an attempt to establish vulnerabilities.

Synergies

The unifying objective of safety and security is the prevention of avoidable radiological consequences. Due to the differences in terminology, culture, and organization, professionals in both disciplines have developed different approaches to issues in their respective areas, sometimes without taking into account how a feature in one discipline complements the overall effectiveness of their interests. For example, radiation protection shielding and material accountancy are features that may be common to both disciplines and could be used synergistically.

In security systems, detection, delay, and response integrate to form effective systems. In safety, systems are designed to address time, distance, and shielding. The interplay between these demonstrates some of the possible synergies. For example, from a safety perspective, shielding reduces the risk of exposure; from a security perspective, shielding also provides a measure of delay that increases the difficulty of theft or sabotage. Similarly, the hazards of handling radioactive materials provides an intrinsic delay to the threat, which must resort to using special handling tools and additional shielding in order to remove a source from its original shielding.

Radioactive materials can be used in many different ways. They can be used for medical purposes, in irradiators for mining and agricultural applications, or as radioisotopic thermal-electric generators used to power remote coastal beacons. In many of these applications, the radioactive material is treated as standard industrial equipment and has not been subject to the accountability controls and protection necessary to protect these materials. Accountability of these materials is a necessary foundation for developing both security and safety plans.

Additionally, once material is accounted for and no longer needed, disposition becomes an issue. Both safety and security can be enhanced through source and hardware designs that provide additional safety and security should they become abandoned.

The regulatory control of radioactive materials is another feature that can be exploited for the benefit of safety and security. Effective safety and security systems have a shared requirement for the following control measures: regulatory infrastructure; national registry of sources; material categorization; illicit trafficking detection and response; emergency response plans; and disposition system of unwanted sources. These are all areas that can be exploited for the benefit of safety and security.

International Setting

The International Atomic Energy Agency (IAEA) has been at the forefront for setting international standards for both safety and security of radioactive materials. The IAEA is mandated under its statute to promote safety standards in connection with activities in the field of atomic energy. This mandate is broadly accomplished through the promotion of obligatory conventions, nonbinding guidance, and expert services. The Convention on Nuclear Safety is an example of binding safety standards. The Code of Conduct on the Safety and Security of Radioactive Sources and RS-G-1.9, "Categorization of Radioactive Sources," were developed primarily from a safety perspective to minimize inadvertent exposure to radioactive sealed sources.

The IAEA's responsibilities in the security discipline are not specifically identified in its statute. However, it has adopted an international role through the promotion of the Convention on the Physical Protection of Nuclear Material and other guidance. Information Circular 225 (INFCIRC 225) provides guidance on the physical protection of nuclear materials and facilities while "Guidance on the Security of Radioactive Sources" (TECDOC 1355) provides interim guidance.

Within the IAEA, as well as within many other national systems, safety and security are and continue to be historically separate disciplines within the context of nuclear materials. However, 9/11 has shown a need for greater interaction between safety and security of other radioactive materials. Safety professionals are beginning to consider that human caused intentional events could create just as significant of a harmful release of radiation as an accident. Security professionals are considering how their measures could have an impact on the beneficial use and safe application of radioactive sources.

Conclusion

Practices for safety and security practices have developed independently to meet different objectives in dealing with radiological events. Both strive to prevent radioactivity exposure to people and the environment. While terrorist events such as 9/11 highlighted tensions between the two, coordination on the common control measures can help the effectiveness of safety and security systems. Coordination at the policy level will also make both safety and security planning more efficient and effective.

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Nuclear and Radiological Material Transport Security

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Abstract

Transport of radioactive material is a highly regulated undertaking and the transport safety regulations have been in effect for decades. However, transport security requirements for many types of radioactive material are just now being developed and applied. This paper examines the development of the requirements and describes several problem areas identified by shippers and carriers in implementing them.

Introduction

Transport of radioactive material is an activity that was largely "born regulated." In the early stages of nuclear technology development it was recognized that these materials presented unique hazards during transport, so safety requirements were developed to ensure protection of people and property. Several countries developed their own approaches and in the late 1950s efforts were undertaken that led to the publication of the first international regulations on radioactive material transport safety, the International Atomic Energy Agency's (IAEA) "Regulations for the Safe Transport of Radioactive Material"[1] (hereafter, Transport Regulations).

The transport safety regulations also have a long history of implementation that has resulted in their rather uniform application throughout the world. Most developed countries and the international transport modal organizations use the IAEA Transport Regulations as the basis for their requirements. Shippers and carriers have designed their transport operations to comply with these requirements and compliance is generally found to be very good.

Except for some fissile materials, the security of radioactive materials while in transit was not a major concern before September 11, 2001. Normal commercial practices were considered adequate to prevent loss of the material and there was little concern that anyone would want to acquire the material for malicious purposes. That belief has been disproven with the revelation that adversaries not only have examined the possibility of using radioactive materials for malicious acts but have also demonstrated a willingness to use all means at their disposal to carry out such acts.[2]

Transport Security

Security requirements for radioactive material during transport, however, are just now being developed and implemented. While the security of nuclear (fissile) material[3] has been addressed since 1979, and guidance material[4] has been available to support implementation, the same situation does not exist for nonfissile radioactive material. Heightened awareness of the need to secure such materials during transport has led to a series of developments aimed at defining and supporting the uniform implementation of transport security requirements.

Dangerous Goods Transport Security

Following the events of September 11, 2001, the UN Committee of Experts[5] introduced measures to enhance security for the transport of all dangerous goods in the 12th Revised Edition of the Model Regulations. These security measures were developed with input from many affected parties and reflect what the committee believes is a balanced approach to security. The measures are included primarily in Chapter 1.4, which contains basic security requirements applicable to the transport of all dangerous goods and additional requirements for "high consequence dangerous goods." An indicative list of high consequence dangerous goods is provided in the chapter.

Radioactive Material as Class 7 Dangerous Goods

As part of the process to develop the dangerous goods security requirements, the Committee of Experts consulted with IAEA regarding the definition of high consequence radioactive material. With very little time for consultation with member states, IAEA provided the committee with its recommendation, based on other provisions within the Transport Regulations.

Beginning with the early versions of the Transport Regulations, there has been a threshold for denoting what constitutes a "large quantity" of radioactive material. In the current Transport Regulations this is 3,000 A_1 for special form material and 3,000 A_2 for non-special-form material. So IAEA advised the committee that this was a suitable threshold for identifying high consequence radioactive material, with the observation that the dangerous goods security requirements should not apply to nuclear (fissile) material that is already subject to physical protection requirements during transport. These recommendations provided the basis for the Class 7 (radioactive material) requirements in the Model Regulations.

IAEA Transport Security Draft Guidance

While the security measures and definition of high consequence radioactive material added to the Model Regulations were recognized as a very positive step, IAEA initiated a review of these provisions to ensure they were technically sound and consistent with other approaches used in nuclear and radioactive material security. A series of consultants meetings and technical meetings were held between October 2003 and January 2006 to review the transport security provisions and develop guidance to assist member states in implementing appropriate measures. The recommendations and guidance developed by this series of meetings includes:

- Some radioactive materials, such as excepted packages, low specific activity materials, and surface contaminated objects that can be shipped unpackaged, do not warrant security measures above prudent management practices.
- Two categories of security measures, basic and enhanced, are sufficient for specifying appropriate measures and are consistent with the approach used for other dangerous goods.
- The threshold for high consequence radioactive material should be revised to take into account analyses done on the consequences of intentional dispersal and developments in the safety and security of radioactive sources. The threshold should be applied on a "per package" basis to facilitate compliance by carriers.
- While the security requirements in the Model Regulations are an adequate set of baseline measures, there are additional measures that member states might wish to consider when the national design basis threat indicates it might be appropriate, in situations of increased threat, or for particularly attractive material.

These recommendations result in three groups of transport security measures as illustrated in Figure 1.

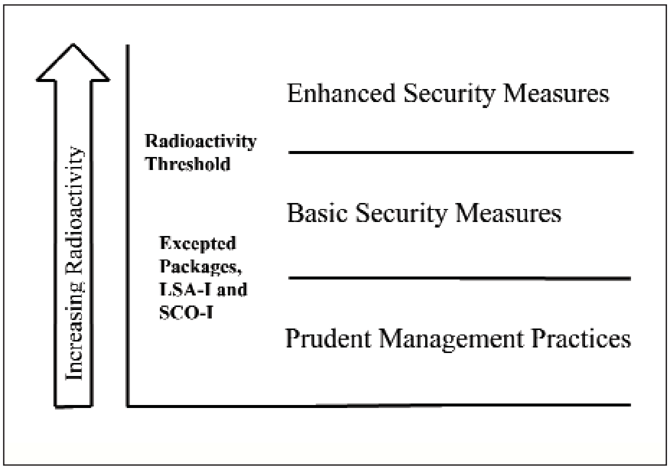
The guidance is generally consistent with the approach in the Model Regulations since it was recognized that establishing a set of unique provisions for radioactive material would be costly and perhaps impractical to implement. Dangerous goods carriers have implemented security measures consistent with the Model Regulations, and they would be reluctant to incur the additional cost and complexity of a unique set of radioactive material transport security measures because in most cases this is a very small part of their business.

Exceptions from Security Requirements

Malicious use of radioactive material could involve exposure to radiation (a radiation exposure device) or dispersal of the radioactive material (a radiological dispersal device). Small quantities of radioactive material and low activity concentration materials would not be very effective in such applications as the consequences of their use would be low. Therefore, the draft guidance recommends that no transport security measures above prudent management practices should be required for the following:

- excepted packages,
- low specific activity material in category LSA-I that can be shipped unpackaged, and
- surface contaminated objects in category SCO-I that can be shipped unpackaged.

Figure 1: Incremental transport security measures.



Two Categories of Security Measures

Radioactive materials as they are currently transported present a wide spectrum of attractiveness for malicious use. Materials and packages with potentially significant but limited consequences such as Type A packages, LSA-II, LSA-III, and SCO-II have some attractiveness. By contrast, packages containing high activities such as large sealed sources or bulk quantities of radionuclides (especially in dispersible form) could be very attractive for malicious use. Even with this broad spectrum of attractiveness, it was concluded that two security categories could be used to specify appropriate measures, particularly in light of the desirability to be consistent with the Model Regulations.

Two security categories were recommended, a "basic level" and an "enhanced level." The specific security measures recommended for each level were drawn from the Model Regulations and, where necessary, tailored for application to radioactive material shipments.

At the basic level the security measures include security awareness training and periodic retraining, maintenance of training records, using known or identified carriers, and using properly secured in-transit storage areas.

Enhanced security measures include a requirement that consignors, carriers, and others (including infrastructure managers) adopt, implement, and comply with a security plan that addresses the following

- allocation of responsibilities and authority to fulfill these responsibilities;
- material transport records;
- reviews of operations and assessments of vulnerabilities;
- clear statement of measures to be used to reduce security risks;

- procedures for reporting and dealing with security threats, breaches, and incidents;
- testing, periodic review, and update of security plans; and
- security of information including limiting distribution of information.

Threshold for High Consequence Radioactive Material

Extensive discussions were held on how the threshold for high consequence radioactive material should be defined. From a strict security standpoint there are advantages to using a "per conveyance" basis as this best identifies conveyances that are carrying a total quantity of material that should be protected. From an operational standpoint, a "per package" basis is much more feasible to implement because this would not require carriers to keep a tally of the total radioactivity being transported. It was concluded that the per package basis was acceptable, and a radioactivity threshold was then defined to identify those packages that should be subject to the enhanced security measures.

Analysis of potential consequences such as denying the use of an area due to dispersed radioactive material was performed. As a benchmark, the radioactivity required for causing the resettlement of a 1 km^2 land area was calculated for a set of representative radionuclides. A simple planar distribution model was used to determine the radioactivity required to cause a 1,000 mSv lifetime dose (the criteria recommended by the International Commission on Radiological Protection for resettlement). Using the long-term dose conversion factors for deposited radionuclides from IAEA TECDOC-955,[6] the radioactivity required to cause resettlement was calculated for a list of representative radionuclides.

The IAEA Code of Conduct on the Safety and Security of Radioactive Sources[7] (the Code) is being implemented by many countries. Eighty-eight countries have notified IAEA of their intent to implement the Code.[8] Among other requirements, the Code and its Supplementary Guidance on the Import and Export of Radioactive Sources[9] require certain measures such as notification and consent before the import or export of Category I and II radioactive sources. The desire to ensure consistency between the transport security measures and the Code was strongly held by many countries participating in the development of the transport security guidance. Consequently it was decided to align the radioactivity threshold for the twenty-five radionuclides contained in the Code with the Category II radioactive source threshold. This threshold corresponds to ten times the quantity of material that defines a "dangerous radioactive source".[10]

For radionuclides not included in the Code, it was recommended that a multiple of the A_2 values used in the Transport Regulations be used. Based on the dispersion analysis, a threshold of 3,000 A_2 was determined to be a reasonable threshold value. As a result, the recommended threshold is 3,000 A_2 in a single package except for the radionuclides listed in the Code (shown in the following table).

Table 1:

Radionuclide	Transport Security Threshold (TBq)	Radionuclide	Transport Security Threshold (TBq)
Am-241	0,6	Pd-103	900
Au-198	2	Pm-147	400
Cd-109	200	Po-210	0,6
Cf-252	0,2	Pu-238	0,6
Cm-244	0,5	Pu-239	0,6
Co-57	7	Ra-226	0,4
Co-60	0.3	Ru-106	3
Cs-137	1	Se-75	2
Fe-55	8000	Sr-90	10
Ge-68	7	Tl-204	200
Gd-153	10	Tm-170	300
Ir-192	0.8	Yb-169	3
Ni-63	600		

Additional Security Measures

While the basic and enhanced security measures are generally consistent with the Model Regulations, there may be instances when a country believes that the security situation calls for additional measures. Additional measures may be warranted in elevated threat conditions, when the design basis threat of the country indicates this is appropriate, or when the attractiveness of the material is high. The guidance document provides a list of possible additional security measures that countries might wish to consider imposing when appropriate, including:

- additional training
- licensing of carriers and formal approval of their security plans
- automated and real-time tracking of shipments
- formal security clearances for personnel
- use of guards
- use of conveyances specifically designed or modified for security purposes

While country-specific measures might create more difficulty in making international shipments, they are clearly warranted under high or elevated threat conditions.

Nuclear Material Transport Security

Since the transport of nuclear (fissile) material is already subject to security requirements as specified in the *Convention for the*

Physical Protection of Nuclear Material and the supporting guidance in IAEA INFCIRC/225, there is some overlap between the two sets of recommendations. A comparison of INFCIRC/225 and the draft transport guidance shows that for

- Category I nuclear material—the security measures of INFCIRC/225, while roughly comparable to the enhanced security measures are more stringent (e.g., requiring escorts);
- Category II nuclear material—the security measures of INFCIRC/225 are roughly comparable to the enhanced security measures; and
- Category III nuclear material—the security measures of INFCIRC/225 are roughly comparable to the basic security measures.

Consequently, if Category III nuclear material with an activity per package exceeding the radioactivity threshold is being transported, it must meet additional security measures because of its radiological potential for malicious use.

Status of the IAEA Guidance on Transport Security

In November 2006, the draft guidance was circulated to IAEA member states for comments, which have been requested by April 16, 2007. After receipt of the comments and making any needed revisions, the guidance will be published in the IAEA Nuclear Security Series of documents.

Transport Security Compliance Experience

Since the IAEA guidance document has not yet been published, there is no direct experience in complying with those requirements. However, since the security requirements contained in the Model Regulations are reflected in the international modal organization requirements (IMO and ICAO in particular), there is experience in complying with those. Existing modal requirements for high consequence dangerous goods apply to only a few radioactive material shipments due to the relatively high radioactivity threshold. However, there is some experience with shipments related to applications such as teletherapy and irradiators that do meet the existing definition of high consequence radioactive material.

Several shippers and a carrier were contacted to obtain their input and experiences in complying with the security requirements. Shippers of large radioactive sources reported that while additional costs and complications are incurred in meeting the modal security requirements, major compliance problems have largely been avoided. This is credited to carriers being prepared to handle high consequence dangerous goods in general, so security measures for radioactive shipments are not unique.

The U.S. Nuclear Regulatory Commission has issued more stringent controls for the security of Category I and II radioactive sources, including specific transport security measures.[11] Shippers surveyed reported that there have been some difficulties that they attributed to special requirements that some highway carriers have decided are not worth undertaking. These carriers apparently have concluded that the small number of radioactive shipments is not worth the cost involved in establishing programs to address requirements such as trustworthiness of personnel. A major carrier reported that difficulties were being encountered in detailed interpretation and application of the requirements, particularly where they were more stringent that the general dangerous goods security requirements.

Several points were consistently mentioned by the shippers and carrier as being critical to implementing increased security measures internationally without undue cost and disruption. These included: (1) adoption of uniform radioactive material transport security requirements by countries and the international modal organizations; (2) consistency with other dangerous goods transport security requirements; and, (3) uniform interpretation and application of the requirements.

If countries wish to implement the transport security requirements for radioactive material as seamlessly as possible, the use of the IAEA guidance as a basis for the requirements is a key step. Building on this uniform basis, if steps can be taken to ensure uniform interpretation and application of the requirements, impacts on transport operations can be minimized while encouraging a high level of international and inter-modal compliance.

Conclusion

The IAEA draft security guidance for transport of radioactive material is patterned after the Model Regulations, but there are some variations and additional measures that countries may wish to impose. During the current comment period regulatory authorities, shippers, and carriers are encouraged to review the draft guidance and consider the potential impacts of compliance. Following member state review and comment, IAEA will be in a better position to identify any needed revisions to improve the guidance before its publication.

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The Importance of International Technical Nuclear Forensics to Deter Illicit Trafficking

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Illicit trafficking of nuclear materials is a transboundary problem that requires a cooperative approach involving international nuclear forensics to ensure all states understand the threat as well as the means to best deter the movement of nuclear contraband. To achieve the objectives, all cases involving illicit trafficking of nuclear and radiological materials must be vigorously pursued and prosecuted when appropriate.

The importance of outreach and formal government-to-government relationships with partner nations affected by nuclear trafficking cannot be underestimated. States that are situated on smuggling routes may be well motivated to counter nuclear crimes to bolster their own border and transportation security as well as strengthen their economic and political viability. National law enforcement and atomic energy authorities in these states are aggressively pursuing a comprehensive strategy to counter nuclear smuggling through increasing reliance on technical nuclear forensics. As part of these activities, it is essential that these organizations be given orientation to the best practices in this emerging discipline including the categorization of interdicted nuclear material, collection of traditional and nuclear forensic evidence, data analysis using optimized analytical protocols, and how to best fuse forensics information with reliable case input to best develop a law enforcement or national security response. The purpose of formalized U.S. government relationships are to establish an institutional framework for collaboration in international forensics, improve standards of forensics practice, conduct joint exercises, and pursue case-work that advances international security objectives.

Just as outreach and formalized relationships are important to cultivate international nuclear forensics, linking nuclear forensics to ongoing national assistance in border and transportation security, including port of entry monitoring, nuclear safeguards, and emerging civilian nuclear power initiatives including the Global Nuclear Energy Partnership are crucial components of a successful nuclear detection and security architecture. Once illicit shipments of nuclear material are discovered at a border, the immediate next question will be the nature and the source of the material, as well as the identity of the individuals involved in the transfer as well as their motivations.

The Nuclear Smuggling International Technical Working Group (ITWG) is a forum for the first responder, law enforcement, policy, and diplomatic community to partner with nuclear forensics experts worldwide to identify requirements and develop technical solutions in common. The ITWG was charted in 1996 and since that time approximately thirty member states and organizations have participated in eleven annual international meetings. The ITWG also works closely with the International Atomic Energy Agency (IAEA) to provide countries with support for forensic analyses. Priorities include the development of common protocols for the collection of nuclear forensic evidence and laboratory investigations, organization of forensic round-robin analytical exercises, and technical forensic assistance to requesting nations. To promote the science of nuclear forensics within the ITWG the Nuclear Forensics Laboratory Group was organized in 2004. A Model Action Plan for nuclear forensics was developed by the ITWG and published as an IAEA Nuclear Security Series document in 2006 to guide member states in their own forensics investigations.

Through outreach, formalized partnerships, common approaches and security architectures, and international working groups, nuclear forensics provides an important contribution to promoting nuclear security and accountability.

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The Global Threat Reduction Initiative (GTRI): Working Toward Permanent Threat Reduction

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The greatest threat to our national security is the possibility of terrorists acquiring the materials needed to construct and then use a nuclear or radiological weapon of mass destruction.

As recently as September 2006, an al-Qaeda leader in Iraq, Abu Hamza al Muhajer, called for nuclear scientists and explosive experts to join the *"holy war against the West…We are in dire need of you…the field of jihad can satisfy your scientific ambitions, and the large American bases are good places to test your unconventional weapons, whether biological or dirty, as they call them."*

The detonation of a crude nuclear weapon or radiological dirty bomb would result in significant loss of life, economic hardship, and psychological effects that would forever change the world.

The bipartisan 9/11 Commission report shows that al-Qaeda has tried to acquire or make weapons of mass destruction for at least ten years. The 9/11 Commission believes there is no doubt that the United States would be a prime target.

In his 2006 *National Security Strategy of the United States of America,* President George W. Bush identified preventing the transfer of fissile material to rogue states or terrorists as a top priority to protect the American public. In July 2006, Bush and Russian President Vladimir Putin announced a *Global Initiative to Combat Nuclear Terrorism,* aimed at strengthening international cooperation to secure nuclear and radiological materials and to prevent the use of these materials in terrorist acts.

In previous decades, nuclear nonproliferation focused on preventing non-nuclear-weapons states from acquiring nuclear weapons. International safeguards and export controls under the Treaty on the Nonproliferation of Nuclear Weapons (NPT) were the main tools used to prevent the spread of nuclear weapons.

In recent years, the threat of a large-scale sophisticated terrorist attack has dramatically increased. The U.S. Department of State's Country Reports on Global Terrorism 2005 notes that in addition to al Qaeda's organized terrorist operations, other loose networks of terrorist groups have emerged and are conducting an increasing number of attacks on civilian targets. This demonstrates that al Qaeda and other terrorist groups have and will continue to attempt attacks with the purpose of inflicting heavy loss of life, frightening and disrupting civilian populations, and damaging global infrastructure.

In the post-9/11 world, nonproliferation and threat reduction efforts are expanding and accelerating to prevent nuclear and radiological materials from falling into the hands of terrorist groups. Nuclear and radiological materials are located at thousands of civilian sites in more than ninety-five countries worldwide. Of particular concern are the thousands of civilian sites where nuclear and radiological materials are used for legitimate and beneficial commercial, medical, and research purposes. Unfortunately, materials at many civilian sites are poorly guarded or are no longer needed, making them attractive targets for theft or sabotage, with their quantities sufficient for crude nuclear weapons and radiological dirty bombs.

In response to this threat environment, the U.S. Department of Energy's (DOE) National Nuclear Security Administration (NNSA) established the Global Threat Reduction Initiative (GTRI). GTRI was officially announced at International Atomic Energy Agency (IAEA) headquarters in Vienna, Austria, on May 26, 2004, at a joint event between the United States, the Russian Federation, and the IAEA. GTRI consolidated several fragmented and separately managed threat reduction programs within the DOE into a single program to focus and accelerate NNSA's threat reduction efforts.

GTRI complements traditional nonproliferation programs, such as international safeguards and export controls, by providing permanent threat reduction through the removal and elimination of unnecessary nuclear and radiological materials at civilian sites worldwide.

What Does GTRI Do?

GTRI's directly links to the DOE's strategic goal to "prevent the acquisition of nuclear and radiological materials for use in weapons of mass destruction and in other acts of terrorism." GTRI's unique mission is to reduce and protect vulnerable nuclear and radiological materials located at civilian sites worldwide.

GTRI works towards permanent threat reduction through three technical pillars—Convert, Remove, and Protect. The three pillars provide a comprehensive approach to achieving the mission and denying terrorists access to high-risk and vulnerable nuclear and radiological materials.

GTRI activities result in permanent threat reduction by 1) converting research reactors by minimizing, and to the extent possible, eliminating the use of HEU in civilian applications, 2) removing the material so there is one less source of bomb material, and 3) upgrading physical security at vulnerable sites until a permanent threat reduction solution can be implemented.

GTRI Converts Research Reactors from the Use of Highly Enriched Uranium Fuel to Low Enriched Uranium Fuel

Scope of Work: By 2018, convert to LEU 129 of 207 HEU reactors. Two hundred-seven research reactors in the world use highly enriched uranium fuel. Seventy-eight research reactors are used for defense purposes or are a unique design and therefore not convertable. GTRI is working with the owners of these research reactors to identify scope and timelines to convert these reactors to the use of LEU fuel. (see Figure 1)

GTRI Removes Nuclear and Radiological Materials by Repatriating Russian-Origin Highly Enriched Uranium

Scope of Work: By 2013, remove or dispose of 2,150 kg of nuclear material (HEU and plutonium) from civilian sites, enough for eighty-six crude nuclear weapons. (see Figure 2)

GTRI Removes Nuclear and Radiological Materials by Repatriating U.S.-Origin Highly Enriched Uranium

Scope of Work: By 2013, remove or dispose of about 1,260 kg of nuclear material (HEU and plutonium) from civilian sites (enough for fifty crude nuclear weapons). There are additional nuclear materials located at civilian sites that are not targeted for removal because they have an acceptable disposition path or the materials are in secure locations. GTRI will continue to remove U.S.-origin LEU from foreign research reactors until 2019 as an incentive for converting research reactors from HEU to LEU fuels. (See Figure 3.)

GTRI Removes Nuclear and Radiological Materials by Removing Other High-Risk, Vulnerable Highly Enriched Uranium and Plutonium

Scope of Work: By 2013, remove or dispose of more than 970 kilograms of HEU and plutonium from civilian sites, enough for forty-two crude nuclear weapons. There are additional nuclear materials located at civilian sites that are not targeted for removal because they have an acceptable disposition path or the materials are in secure locations. (See Figure 4.)

GTRI Removes Nuclear and Radiological Materials by removing Excess, Sealed Radiological Sources in the United States

Scope of Work: By 2020, remove 31,700 excess U.S. radiological sources totaling ~450,000 curies (enough for 2,255 radiological dirty bombs). (Each year about 2,000 radioactive sources containing approximately 30,000 total curies are registered unused or excess in the United States. (See Figure 5.)

GTRI Protects Nuclear and Radiological Materials by Protecting At-Risk WMD-Usable Nuclear and Radiological Materials from Theft and Sabotage

Scope of Work: By 2010, complete safe and secure long-term storage of 3,000 kilograms of plutonium and 10,000 kilograms of HEU, enough material to fabricate 775 crude nuclear weapons, from the BN-350 reactor in Kazakhstan. The objective of the DN-350 program is to provide long-term (up to fifty years) safe and secure storage.

By 2010, complete physical protection upgrades at twenty-two research reactor facilities outside of the former Soviet Union. This activity will ensure that all vulnerable nuclear materials are protected from theft or diversion until permanent disposition of the material can be implemented.

By 2028, protect 3,300 high priority radiological sites totaling about 50,000,000 curies, enough for 50,000 radiological dirty bombs. The IAEA estimates that there are millions of radiological sources located at tens of thousands of civilian sites worldwide. These radioactive sources are used for medical, industrial, and other commercial purposes and range from a fraction of a curie up to 10,000,000 curies each. The GTRI program has focused on protecting about 3,300 vulnerable sites located in other-than-high-income economy countries that store sources of 1,000 curies or greater and that are near U.S. strategic interests overseas. (See Figure 6.)

GTRI plays a critical role in achieving national and global security objectives. With the continuing support of the Administration and the Congress, our growing budgets will allow us to continue to expand and accelerate efforts toward permanent threat reduction. Each kilogram or curie of these dangerous materials that are removed reduces the risk that a terrorist bomb will go off.

GTRI in the News

December 2006: More than 265 kilograms of fresh HEU removed from **Germany** and returned to Russia

December 2006: Fifty-five curies of cesium-137 removed from **Massachusetts**

October 2006: Research reactor at **University of Florida** converted from HEU to LEU

September 2006: Research reactor at **Texas A&M University** converted from HEU to LEU

August 2006: About forty kilograms of fresh HEU removed from **Poland** and returned to Russia

July 2006: Over three kilograms of fresh HEU removed from **Libya** and returned to Russia

July 2006: Nearly four kilograms of fresh HEU returned from **Argentina** to the United States

June 2006: Almost sixty kilograms of spent HEU removed from **Netherlands** and **Germany** and returned to the United States

January 2006: **Libyan research reactor** converted from HEU to LEU

October 2005: **Netherlands research reactor converted** from HEU to LEU

October 2005: **Czech Technical Institute** research reactor, first Russian-origin reactor—converted from HEU to LEU fuel

September 2005: Fresh HEU removed from the **Czech Republic** and returned to Russia

Updates are available on the Web at www.nnsa.doe.gov/docs/newsreleases.

Figure 1.

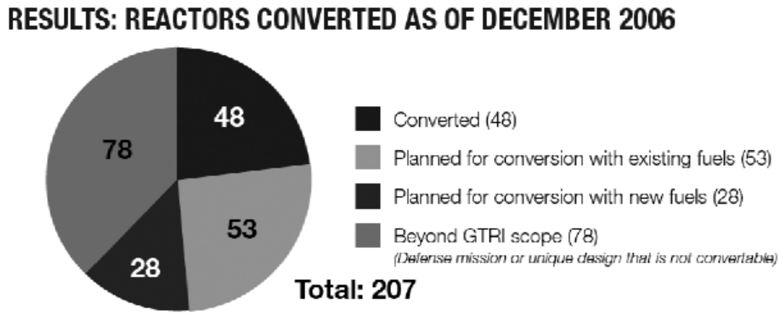
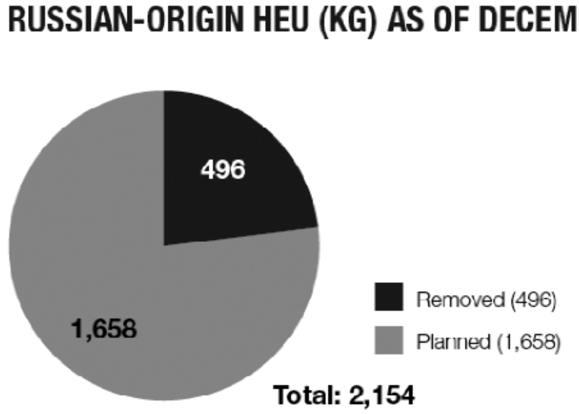
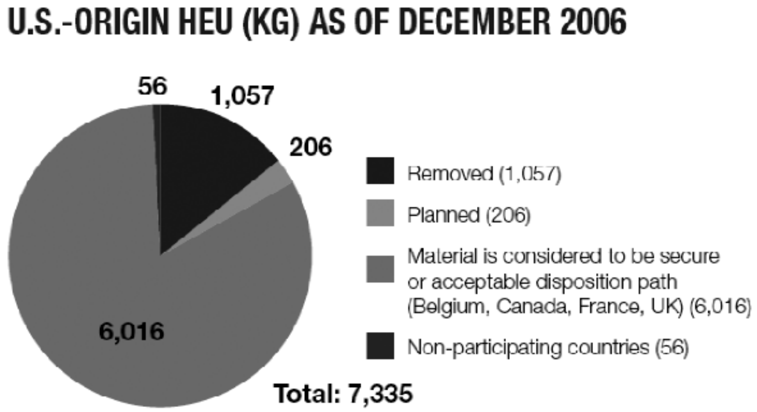


Figure 2.



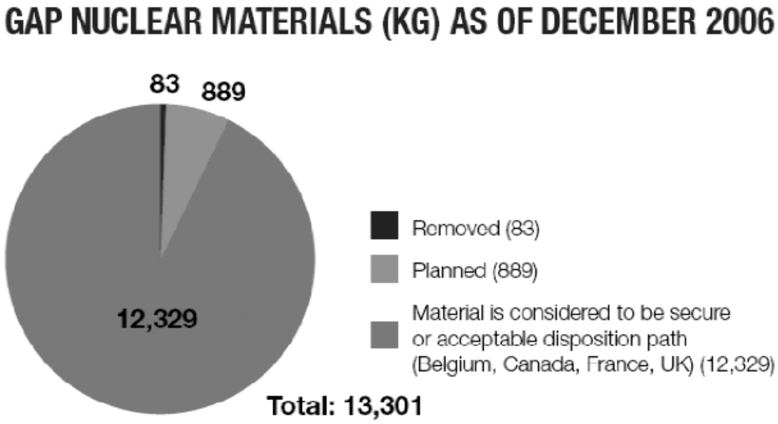
Russian-origin fresh fuel removal from Latvia

Figure 3.



Unloading U.S.-origin spent HEU removed from Germany

Figure 4.



Gap fresh HEU removal

Figure 5.

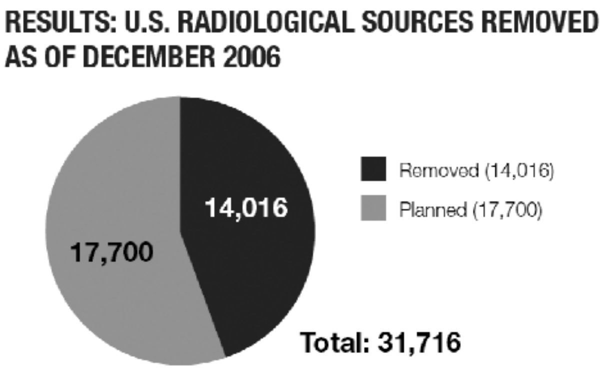
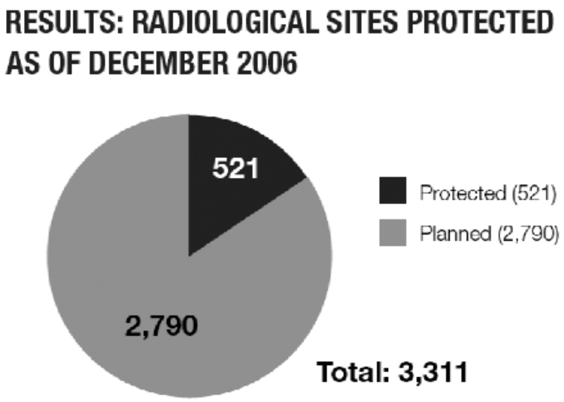


Figure 6.



Reducing Terrorist Threat Through the Management of Radioactive Sources in Latin America and the Caribbean

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Introduction

There is a growing worldwide concern about potential terrorist acts involving radioactive sources, mainly when used in conventional explosives laced with radioactive materials (radiological dispersal devices), primarily because of the disturbing psychological impact and the major costs of decontamination that such events would trigger. A large number of radiation sources are used around the Americas' region in radiation therapy; with many more found in other medical, industrial, and food irradiation devices. The security of radioactive materials used in these applications has traditionally been relatively low. In many Latin American and Caribbean countries, the regulatory oversight of radiation sources and national policies on radioactive waste management are insufficient or absent. Radiation safety standards in these countries are so poor that even large radioactive sources are outside of any regulatory control and could easily be stolen, especially if those involved have no regard for their own health. There were two serious accidents, both caused by thefts of radiotherapy sources from abandoned cancer clinics and subsequent dispersal of radioactive material: in Ciudad Juarez, Mexico, in 1984, and in Goiânia, Brazil, in 1987. Minor incidents have also been reported by the Pan American Health Organization, Regional Office of the World Health Organization for the Americas (PAHO/WHO). PAHO/WHO and the International Atomic Energy Agency (IAEA) have been aware of the issues and taken action.

Use of Radioactive Sources in Latin America and the Caribbean

With the exception of Argentina, Brazil, and Mexico, which have nuclear power reactors, and of Colombia, Chile, Jamaica, and Venezuela, which have research reactors—albeit in decommissioned status—most radiation sources in Latin America and the Caribbean are those used in medical and industrial applications. The medical applications of radioactive sources include the use of sealed sources in radiotherapy treatments and unsealed sources for use in nuclear medicine for both treatment and diagnosis. The industrial applications are predominately in the area of non-destructive testing and, to a smaller extent, in measurement devices such as soil moisture gauges. In nuclear medicine, the most common radionuclides are technetium-99m, iodine-131, and iodine-125, up to tens of GBq per month. In radiotherapy, cobalt-60 sources for teletherapy are on the order on several hundreds of TBq. Brachytherapy sources involve high-dose rate brachytherapy afterloading machines that use 370 GBq of iridium-192 every three to four months, and low-dose rate or manual brachytherapy utilizing cesium-137 sources of the order of thousands of MBq per treatment. Some countries also have strontium-90 for ophthalmologic applications. Radium-226 is still used in some countries.

The number, type, and quantity of radioactive sources used in industry are not well known. The most common radionuclides used for industrial applications are cesium-137, iridium-192, and americium-241. In the Netherlands Antilles, one of the best surveyed countries in the Caribbean, activities range from 30 kBq to 7 TBq.[1]

The security of radioactive materials used in all these applications has traditionally been relatively low. Not only there are problems regarding their disposal after they are no longer useful; there are problems securing the sources even when they are in use. For example, there are few security precautions on radiotherapy equipment in medical facilities and a large source could be removed quite easily, especially if those involved have no regard for their own health.

Regulatory Control of Practices Involving Radiation Sources in Latin American and Caribbean Countries

The main problem facing the countries of the region is the lack of proper or limited infrastructure regarding the regulation of import/export, use, and disposal of radiation sources. In many Latin American and Caribbean countries, private companies wanting to use radioactive sources for industrial applications such as logging and welding are not obliged to request authorization from the government for either the import/export of these sources, or for their use within the country. In the medical field, the biggest problem is the disposal of teletherapy and brachytherapy sources used in cancer management. Radium-226 sources, which are very dangerous, can either be conditioned and stored[2] or removed and brought to the United States.[3]

In 1994, only nineteen countries in the Americas had legislation/regulations in radiation safety. That year, aware of the increasing use of ionizing radiation in the Americas regions and its potential deleterious effects on health, the XXIV Pan American Sanitary Conference endorsed the International Basic Safety

Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources (BSS),[4] jointly sponsored by the Food and Agriculture Organization of the United Nations (FAO), the IAEA, the International Labor Organization (ILO), the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (NEA/OECD), PAHO, and WHO. Full and proper application of the BSS requires that governments establish a regulatory authority to regulate the introduction and conduct of any practice involving sources of radiation. The regulatory authority must also be independent of authorized persons by registration or license, and of the designers and manufacturers of the radiation sources used in practices.[5]

In some countries regulatory responsibility for different practices or different aspects of radiation safety may be divided between different authorities, see Table 1. It is important to note, however, the effort made by some of these countries to align policies, coordinate efforts, and avoid duplications. The best example is Mexico, which in 1996,[6] signed a formal agreement between the Ministry of Health and the Ministry of Energy and Mines (and with the "Comisión Nacional de Seguridad y Salvaguardias" and the "Instituto Nacional de Investigaciones Nucleares" under the latter), which clearly delineates each agency's responsibility and sphere of action.

PAHO/WHO and the IAEA have been actively involved in assisting Member States to either establish the necessary infrastructure for the development of legislation/regulations ?when they did not have one.[7] Regulations based on standards based on BSS have been enacted by Argentina, Bolivia, Brazil, Chile, Mexico, and Peru, and are being considered in practically all of the other Latin American countries.

To expedite the process, in 1994 the IAEA established The Radiation Protection Model Project (INT/9/143), the largest and the most complex technical cooperation project ever undertaken by the IAEA. It was originally designed for five years, and its performance was peer-reviewed by technical experts. In 2000, it was discovered that "the level of achievement in areas of legislation and establishing a radiation control infrastructure was gratifying, but the level of inadequacy in issuing regulations and especially establishing some type of authorization and inspection program was a disappointment. The time needed to implement the goals, especially the legal process with radiation legislation and regulations, was initially underestimated."[8] At present, the Model Project is assisting ninety-two developing member states of the IAEA.[9] In its ten years of operation, it has trained more than 4,800 national staff, fielded more than 1,700 expert missions, and provided a great deal of equipment and materials to the participating countries. If training organized by the countries themselves is added, as their part of the project, the number of trained staff increases to about 23,000.

To ensure uniformity in the implementation and to facilitate measuring the progress achieved by each country, the five milestones, listed in Table 2, were introduced covering all the topics of the work plans.

Table 1. Radiation protection legislation, region of the Americas

Country	Regulatory Authority
Argentina	H & E
Barbados	H
Bolivia	E
Canada	H & E
Chile	H & E
Coloumia	H & E
Costa Rica	H
Cuba	H & E
Dominican Republic	E
Ecuador	E
El Salvador	H
Guatamala	E
Mexico	H & E
Nicaragua	E
Panama	H
Paraguay	H & E
Peru	E
United States	H & E
Uruguay	E
Venezuela	H & E

H: Ministry of Health
E: Atomic or Nuclear Energy Commission

Table 2. The radiation protection model project (INT/9/143) (Rabat)

Milestones are:
1. The establishment of a regulatory
2. The establishment of occupational exposure
3. The establishment of medical exposure
4. The establishment of public exposure
5. The establishment of emergency preparedness and response capabilities

Ten Latin American and Caribbean countries, i.e., Bolivia, Colombia, Costa Rica, Dominican Republic, El Salvador, Guatemala, Jamaica, Nicaragua, Panama, and Paraguay, joined the Model Project before 1999: In 1999, Haiti joined and in 2000, Ecuador and Uruguay did too, followed by Venezuela in 2002. The results were presented at the IAEA's International Conference on National Infrastructures for Radiation Safety, held in Rabat, Morocco, in 2004.[10] Conference recommendations have since resulted in development of a twenty-eight-point action plan[11] directed at strengthening regulatory infrastructure development, education and training, emergency preparedness, and radiation protection improvements in ninety-two Model Project recipient states. The action plan aims to accelerate activities to improve regulatory control of radioactive sources by 2007. There are eighteen countries in the America's region that are member states of PAHO/WHO but not of the IAEA—all of them without adequate radiation safety infrastructure.

Radioactive Waste Management in Latin American and Caribbean Countries

Disposal methods for radioactive materials in the Americas vary depending on the country and the activities involved. Low-level activity sources such as those used in diagnostic nuclear medicine and industrial applications are placed in a storage area to decay for several half-lives and are then handled as regular waste. Radiotherapy sources are supposed to be returned to their suppliers after their useful life, but in many cases the original manufacturers no longer exist, and in other instances, the sources are replaced with non-radioactive sources, such as is the case of cobalt-60 teletherapy units being replaced with linear accelerators worldwide. PAHO/WHO has been advising ministries of health to include a provision regarding disposal of the old radioactive source when inviting bids for new radiotherapy equipment, regardless of whether the new machine is another cobalt unit or a linear accelerator.[12,13] In all cases, and assuming that a manufacturer is willing to accept the source, the costs involved are very high.

As a consequence, many Latin American and Caribbean countries just bury the unwanted (discarded) sources (as it is described in Note 3).

In the early 1990s, industrial as well as medical sources were found in a hole in the garden of a Nicaraguan facility, near an incompletely built radioactive storage area. The hospital was abandoned after an earthquake and three cobalt-60 teletherapy sources, one still in its original treatment unit, were kept in the abandoned hospital, risking a fate similar to that of Ciudad Juarez and Goiânia. Eventually the IAEA decommissioned and conditioned the sources, but they are still in the same old facility.

In Honduras a discarded Co-60 teletherapy unit had allegedly been buried for several years in a garbage dump. Despite a weeklong survey with the assistance of the government of Mexico, using a five-inch NaI(Tl) detector and a multichannel analyzer, the source—presumably still in its head-could not be located. It was recommended that the government periodically monitor the garbage dump and test the water in the area for potential radioactive contamination.

Concerned about potential radiological emergencies caused by medical radioactive sources no longer in use, PAHO's Radiological Health Unit developed a program in the Americas to locate these sources and facilitate their permanent storage and/or disposal. In countries without an infrastructure in radiation protection, the latter task is difficult. A decision was made to dispose of these sources in industrialized countries, such as the United States, that can provide repository sites with appropriate safety and security measures. In 1991, PAHO's Procurement Unit opened an international tender for the conditioning and removal of radioactive material and NSSI/Sources and Services, a U.S. company based in Houston, Texas, won the bid.

In Trinidad and Tobago, the encapsulation of some cesium-137 tubes had broken when they were removed from the disposable rubber Manchester applicators where they had been kept for years. When the tubes were placed in a newly acquired leaded safe, they contaminated it, as well as other brachytherapy sources. NSSI, aided by the local physicists, removed all the contaminated sources and evaluated the site for potential additional contamination. None was found.

In the Dominican Republic, a radiation oncologist had cut a Ra-226 needle to fit it in the tandem of a gynecological applicator. When he saw the spilled radium salts, he tried to wipe them with a cloth which he then washed in a sink. In the process, he contaminated the entire minor surgery suite. The radium sources were placed in a safe, from where NSSI personnel removed them, using a disposable glove box. The precautions taken by the recovery team are illustrated in Figure 1. After decontaminating the area, low activity items, which would have cost too much to transport, remained in an underground hole, where they had been placed prior to PAHO's intervention.

In Haiti, radium sources had been buried for safety purposes in a hole in the ground of the hospital garden in a room without a door to prevent access. In the process of removing these sources, other containers with sources unbeknown to the hospital staff appeared in another hole and were removed as well.

In 1995 NSSI/Sources and Services was again contracted to remove from Guyana radium sources jammed in an old storage vault consisting of a rotating drum with pie-shaped drawers inside an outer cylindrical shield. The mechanism was successfully dislodged and the sources transported to the United States for final disposal under PAHO ownership.

The examples described above illustrate a disposal method that will work well when a few relatively small sources are involved, but not in the case of large amounts of radioactive waste.

Therefore, it is necessary to have access to a repository for the waste.

International Efforts to Address the Issues

A range of international efforts are being taken. Within PAHO, the Radiological Health Program collaborates closely with the Emergency Preparedness and Disaster Relief Program advising their ministries of health on prevention, preparedness, and response regarding nuclear/radiological emergencies. PAHO, as a regional office of WHO, participates also in WHO's radiation emergency network: Radiation Emergency Medical Preparedness

Figure 1. View of the sealed disposable glove box to prevent environmental contamination when the safe was opened and its radioactive sources removed and placed in two leaded containers shown at the right of the photograph. Not shown is an environmental radiation detector placed on top of the glove box, with an audible signal that monitors the radioactivity level in the room and alerts potential radon escape from the sealed glove box.

and Assistance (REMPAN), composed of WHO Collaborating Centers located in specialized radiological institutions worldwide.[14]

PAHO is also member of two interagency committees: the Interagency Committee on Radiation Safety (IACRS) and the Interagency Committee on Radiological/Nuclear Accidents (IACRNA). The IACRS, formed by the European Commission (EC), FAO, the IAEA, ILO, NEA/OECD, PAHO, UNSCEAR, and WHO, has the goal of harmonizing radiation safety standards worldwide. Its most important activity was the development of the BSS. Another set of Safety Requirements, titled "Preparedness and Response for a Nuclear or Radiological Emergency" were co-sponsored by FAO, the IAEA, ILO, NEA/OCED, the United Nations Office for the Co-ordination of Humanitarian Affairs (OCHA), PAHO, and WHO.[15] The Convention on Early Notification of a Nuclear Accident (the 'Early Notification Convention') and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (the 'Assistance Convention')[16] are the prime legal instruments that establish an international framework to facilitate the exchange of information and the prompt provision of assistance in the event of a nuclear accident or radiological emergency. In 2002 PAHO became part of the "Joint Radiation Emergency Management Plan"[17] which describes the inter-agency framework for preparedness for and response to an actual, potential or perceived radiation emergency.

The application of the Joint Plan is limited to the participating international organizations, namely the EC, the European Police Office, FAO, the IAEA, the International Civil Aviation Organization, the International Criminal Police Organization, NEA/OECD, PAHO, the United Nations Environment Program, OCHA, the United Nations Office for Outer Space Affairs, WHO, and the World Meteorological Organization. The IAEA is the main coordinating body for maintenance of the Joint Plan.

The reader should notice though that none of these international efforts will be successful unless accompanied by strong national policies and governments' commitment against radiological terrorism.

Conclusion

The countries of Latin America and the Caribbean have to strengthen their capacity to prevent and respond to nuclear/radiological incidents/accidents whether unintentional or deliberate. To achieve this, they need to develop and/or upgrade national radiation safety legislation/regulations and to develop national and sub-regional policies concerning nuclear/radiological emergencies and nuclear/radioactive waste management. In addition, it is essential that governments enforce security measures to tighten the surveillance around potential terrorists' sites. Countries with insufficient infrastructure should have radioactive sources, which are no longer in use and pose a potential serious risk, moved to another country where they can be safely and securely stored. In this effort, it is important that the countries of the region make clear to the international community, through organizations like PAHO and the IAEA, that vulnerability exists and welcome the technical cooperation of other countries. The United States, which has launched its "Global Radiological Threat Reduction Initiative", should be especially conscious of the radioactive source problems of the Latin America and Caribbean countries and should consider the value to its own security interests of providing help in cooperation with other international efforts.

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The Office of Global Threat Reduction: Reducing the Global Threat from Radiological Dispersal Devices

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Abstract

The Office of Global Threat Reduction (GTRI) of the U.S. National Nuclear Security Administration (NNSA) is actively working both domestically and abroad to reduce the threat presented by the malevolent use of radiological sources in a radiological dispersal devices (RDDs). The GTRI program has undertaken substantial efforts to identify types and quantities of materials of concern, what are the likely consequences of an RDD event, where these materials are used, how well these materials are protected, and what must be done to help ensure that they are not stolen. These materials are distributed throughout the world. We estimate that there are about 4,000 facilities sources globally possessing radiological sources of sufficient size to present a significant risk to U.S. or foreign strategic interests. In response to this threat, NNSA started an initiative in 2002 to help prevent the theft and illicit use of these materials for terrorist purposes. A multifaceted program is now underway to secure these materials. GTRI has now provided security upgrades at more than 520 vulnerable radiological sites around the world containing more than 7,000,000 curies—enough for approximately 7,000 dirty bombs. The program has also established multilateral and bilateral efforts to broaden the program's reach. This paper summarizes the threat presented by these materials, the approach the program has adopted to help secure these sources, and the progress to date.

Introduction

Radioactive materials such as Co^{60}, Cs^{137}, Sr^{90}, and Am^{241}, which are used worldwide for many legitimate purposes, could be exploited by terrorists to produce a radiological dispersion device (RDD), or dirty bomb. In response to the events of 9/11, terrorists openly stating their intent to acquire these materials, and global concerns about this specific threat, the Nuclear Security Administration (NNSA) established the Radiological Dispersion Threat Reduction Program in 2002 to identify, recover, and secure vulnerable, high-risk radiological sources. The program initially focused on securing sources in the countries of the former Soviet Union. In 2003, NNSA expanded the scope of the program to secure sealed sources worldwide, ultimately establishing the Office of Global Threat Reduction (GTRI). The program's primary objectives are to (1) implement rapid physical security upgrades at vulnerable sites containing radioactive sources; (2) locate, recover, and consolidate lost or abandoned high-risk radioactive sources; and (3) support the development of the infrastructure necessary to sustain security enhancements and establish regulatory controls, including the development of regional partnerships to leverage international resources. This paper summarizes the threat presented by these materials, the approach the program has adopted to help secure these sources, and the progress to date.

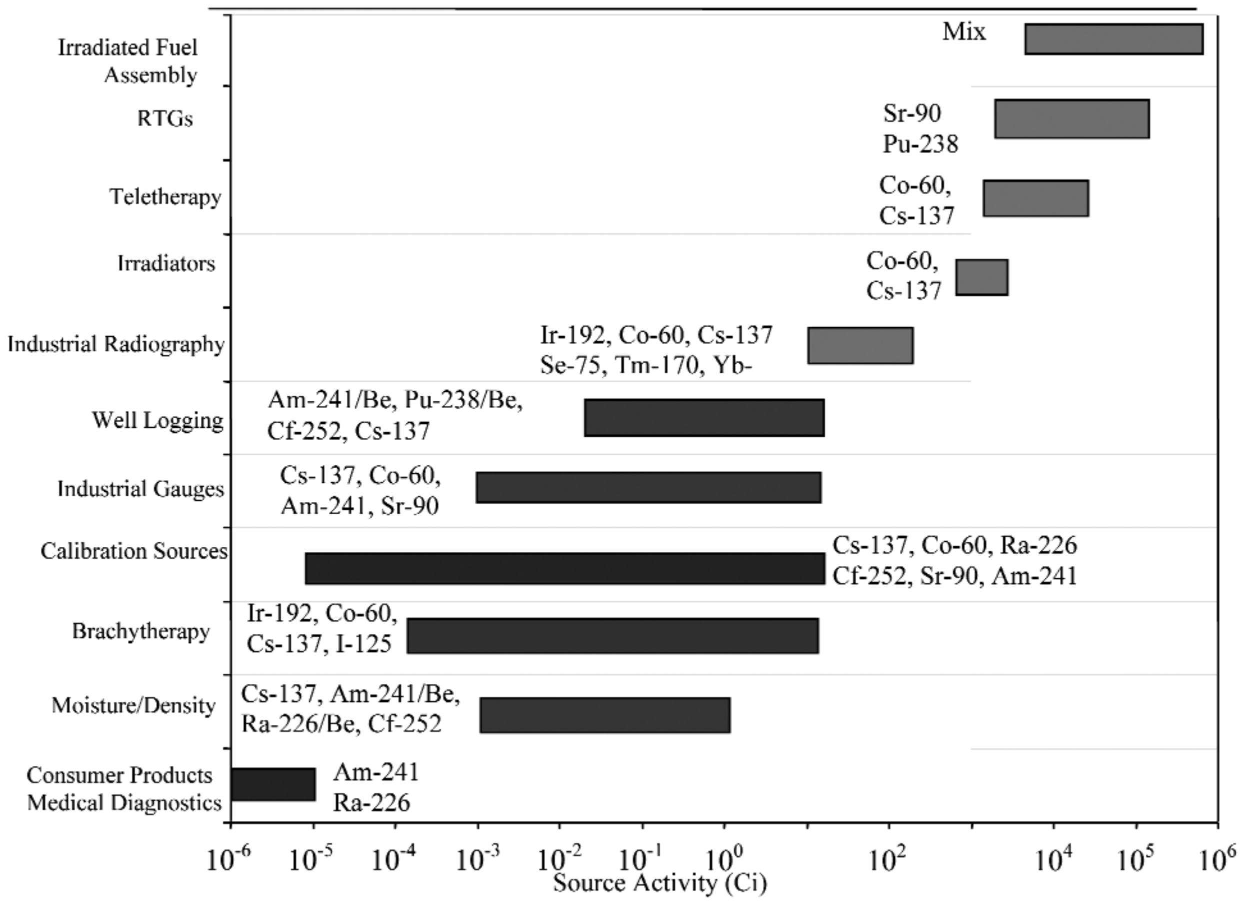
What is an RDD?

RDDs are unconventional weapons that terrorists might use to disperse radioactive materials. An RDD can be constructed with materials having different radiological emissions (e.g., alpha vs. beta vs. gamma), physical (e.g., a radioactive gas), chemical (e.g., water soluble), and biological properties. In an explosive RDD (conventional explosives laced with radioactive materials or sabotage of radioactive materials), a plume produced by an RDD passes over an area, and radioactive material may settle onto the ground and other surfaces. People remaining in the area will be exposed through ingestion of radioactive materials, external radiation from material deposited on the ground, and through inhalation of resuspended material. The total dose from deposited material may be more significant than that due to direct exposure to the plume, because the exposure time can be much longer than the time for plume passage. Although it is normally expected to be of only minor importance, the inhalation pathway would contribute additional doses to internal organs. The health risks from other pathways, such as beta dose to the skin and direct ingestion of dirt, are also expected to be minor in comparison to the risks due to external gamma radiation. Skin and inhalation doses would, however, be important exposure pathways for source terms with significant fractions of pure beta emitters, and inhalation dose would be important for source terms with significant fractions of alpha emitters. Not all RDD's need be explosively driven. Other non-explosive mechanisms exist for the distribution of these materials over large areas.

What are RDD Source Materials of Concern?

RDD source materials are used for legitimate commercial purposes including irradiation of foods and plastics, industrial radiography, gauging and instrumentation, instrument calibra-

Figure 1. Source activity-application matrix



tion, and medical uses. These sources are located in almost every country around the world at thousands of locations. Commonly used sources available in sufficient quantities to be an RDD device capable of causing harm of national significance include:

Beta/Gamma Sources and Civilian Applications: Typical beta/gamma sources used in commercial applications include Co^{60}, Cs^{137}, Ir^{192}, Ra^{226},Se^{75}, Sr^{90}, Tm^{170}, and Yb^{169}. These may be present in irradiated fuel assemblies, heat sources like radioisotope thermoelectric generators (RTGs), panoramic irradiators, medical teletherapy units, and industrial radiography equipment. These materials may also be found at interim storage facilities such as airport, rail and shipyard warehouses and in waste disposal facilities.

Alpha Sources and Civilian Applications: Typical alpha sources used in commercial applications include Am^{241}, Cf^{252}, Cm^{244}, Pu^{239}, Pu^{238}, and Th^{232}. These isotopes may be used in well logging, industrial gauges, brachytherapy, moisture/density, calibration sources, and consumer products usually in quantities ranging to a maximum of <100 Ci. Like beta/gamma sources, these materials may also be found at interim storage facilities such as airport, rail, and shipyard warehouses and in waste disposal facilities.

Although a small amount of radioactive material used in an RDD would cause panic and terror, GTRI has a risked-based approach for focusing on those radioactive materials that would cause a large RDD. The GTRI program defines a large RDD to be a source of sufficient size to contaminate an area of 0.78 square miles (500 acres) and produce a predicted dose > 2 rem/yr in the first year for persons residing in the impacted area. At a dose level of 2 rem/yr, U.S. Environmental Protection Agency/Department of Homeland Security (EPA/DHS) guidelines calls for the relocation of people living in that area. The estimated beta/gamma and alpha source quantities needed to produce these dose levels are:

- 1,000 Curie (Ci) beta/gamma emitter
- 20 Ci alpha emitter

Figure 1 shows source activity levels for different devices commonly used around the world.

What are the Consequences of an RDD Attack?

A terrorist act using an explosive RDD would result in many explosion related deaths; possibly a few immediate radiation induced-deaths and more longer-term cancer induced deaths; and, substantial near and long-term economic losses due to decontamination and public fear. However, the economic consequences of such an explosion could be severe, perhaps in the billions of dollars.

Some accidents involving sealed sources can provide a measure of understanding of what the possible impacts of a dirty bomb could be. In 1987, an accident involving a medical teletherapy machine containing Ce^{137} (~1,400 curies), which is generally in the form of a powder similar to talc and highly dispersible, killed four people in Brazil, injured many more and caused about $36 million in damages to the local economy. This accident had such an enormous psychological impact on the local population that the atomic symbol was added to the region's flag as a lasting reminder of the accident's consequences. While no dirty bombs have been detonated, in the mid-1990s, Chechen seperatists placed a canister containing cesium-137 in a Moscow park. Although the device was not detonated and no radiological material was dispersed, the incident demonstrated that terrorists have the capability and willingness to used radiological sources as weapons of terror. Similarly, there are other examples in Russia where radiological sources have been used for criminal purposes resulting in both the loss of life and in significant contamination.

Table 1 compares the relative costs, casualties, and damage that could result from a terrorist attack using a radiological dirty bomb against the Oklahoma City bombing. These costs, casualties, and damages are best estimates using publicly available information. The data for RDD event represents a scenario involving a large-radioactivity-laced Oklahoma City-size conventional bomb.

Table 1. Consequences of a conventional explosive and RDD event

Event / Consequences	Conventional Explosion	RDD
	Oklahoma City April 19, 1995[A]	New York City[B]
Explosive Power (Tons of TNT)	2.4	2.4
Deaths from the Explosion	168	Hundreds
Deaths Due to Cancer	0	6
People Subject to Relocation	Hundreds	Tens of Thousands
Area of Complete Destruction (Square Miles)	0.2[C]	0.2
Area requiring decontamination (Square Miles)	0	1.7
Recovery Time	Weeks	Years

Notes:

A. *Source suggests 4,800 pounds of ammonium nitrate, an agricultural fertilizer, and nitromethane, a highly volatile motor-racing fuel — a mixture also known as Kinepak (ammonium nitrate/fuel oil). See City of Oklahoma City, "Alfred P. Murrah Federal Building Bombing, April 19, 1995: Final Report," http://www.mipt.org/murrahfinalrpt.asp.*

B. *Derived principally from Sandia National Laboratories scenario involving large radioactive source July 2006.*

C. *Structural damage was several blocks around the site but windows and doors were damaged even further out. Total number of buildings damaged was 381. http://www.johnmartin.com/research/pdfs/rdplate17.pdf.*

Table 2. Worldwide estimate of facilities with radiological sources of concern (Number of facilities within country)

Material Attract.	Other Than High Income				High Income				Total
	External Threat Level				External Threat Level				
	Very High	High	Normal	Subtota l	Very High	High	Normal	Subtotal	
10,000 Ci Beta/Gamma or > 200 Ci Alpha	82	1,170	310	1,562	96	29	39	164	1,726
1,000 – 10,000 Ci Beta/Gamma or 20 – 200 Ci Alpha	347	318	1,398	2,063	364	62	69	495	2,558
Totals	429	1,488	1,708	3,625	460	91	108	659	4,284

Where are These Sources Now Located?

Table 2 presents an analysis developed by GTRI of numbers of facilities possessing radioactive materials around the world. Table 2 has been subdivided into various groupings that are used by GTRI for program management purposes. The major categories include:

- **Material Attractiveness Level**—Material attractiveness is based on material type, quantity, form, weight, Ci level, and its ability to produce severe consequences if used in an RDD.
- **External Threat Environment**—Refers to an analysis of the external threat present in different countries around the world prepared and released by the U.S. intelligence community.
- **Country Income**—For operational and analytical purposes, the World Bank's main criterion for classifying economies is gross national income (GNI) per capita. The groups are: Low Income, $875 or Less/Lower Middle Income, $876-$3,465; Upper Middle Income, $3,466-$10,725; and High Income, $10,726 or more. For analytical and programmatic purposes, GTRI divided these groupings into High Income and Other Than High Income (i.e., includes, Low Income, Lower Middle Income, and Upper Middle Income).[4] Countries that are High Income, for the most part, are not now a point of focus for GTRI support programs.

Analyses of these data suggest that:

- There are >4,000 sites worldwide with RAD facilities that have significant quantities of materials; >3,600 are in OTHI. Further, ~2,000 are in locations with either Very High or High External Threat Levels.
- 1,066 sites are in High Threat, OTHI countries are Russian RTGs of which 115 have already been secured and sixteen are Russian RADONS of which eight have already been secured.
- Per the GTRI Programmatic Guidelines for Site Prioritization and Protection Implementation document, the ~700 sites in High Income Countries are not likely to be provided security upgrades by the GTRI program, rather there will be coordination on standard protection practices.

How is GTRI Protecting These Sources?

The program's primary approaches to helping protect vulnerable high-activity radiation sources abroad are to (1) implement rapid physical security upgrades at vulnerable sites containing radioactive sources; (2) locate, recover and consolidate lost or abandoned high-risk radioactive sources into fewer locations in fewer countries ; and (3) support the development of the infrastructure necessary to sustain security enhancements and establish regulatory controls, including the development of regional partnerships to leverage international resources.

The upgrades provided by GTRI are consistent with those listed in IAEA INFCIRC/225/Rev. 4 and IAEA TECDOC 1355. The physical protection of materials at sites is attained via a combination of administrative and technical measures. The main goal of the physical protection system is to deter the adversary. Sample upgrades provided at sites with at-risk sources are shown in Table 3.

Table 3. Representative upgrades provided by GTRI to sites with at-risk high activity radiation sourcesv

Protection Function	Protection Actions
Preliminary	Provide basic security protection training
Detect	Provide site intrusion detection system
Delay	Secure safes and containers for material storage
Response	Remote monitoring to off-site response force
Material Control & Accounting	Tamper indicating devices
Sustainability	Three-year warranty on new systems and hardware
Counter-Sabotage Protection	Walk-through metal and/or explosive detectors at site entrances

Accompleshments to Date

During the past four years, GTRI's radiological protection efforts have made substantial progress in its international and domestic efforts to prevent terrorists from acquiring and using radiological sources in an RDD. GTRI's specific accomplishments to reduce the threat from radiological materials

- Provided security upgrades at 521 radiological sites around the world containing more than 7 million curies, enough for approximately 7,000 dirty bombs.
- Cooperated with the Government of the Russian federation to remove more than 5,500 curies of radioactive Co^{60} and Cs^{137}, enough material for at least five "dirty bombs," from Chechnya and safely returned to Russia for protection.
- Recovered more than 200 radiological dispersal devices worth of material has been from twenty-three different sites in cooperation with the Russian Federation.
- Recovered 14,000 excess sealed sources containing ~171,000 curies from 590 industry, academia, health care facilities, and government laboratories located in the United States.
- In cooperation with DHS and the Nuclear Regulatory Commission, provided security consultation and training services to law enforcement, health, education, industry, and professional organizations in the United States
- Funded the recovery of 115 Russian RTGs ; each has activity levels ranging from 25,000 to 250,000 curies of Sr^{90}—similar to the amount of Sr90 released from the Chernobyl accident in 1986.

- Created innovative partnership between the United States, Russia, Norway, Denmark, Canada, and Germany to save U.S. taxpayers funds while accelerating threat reduction through the removal of RTG.
- Accelerated its efforts with the Russian Federation to secure and consolidate RTGs as part of Bratislava commitments.
- Provided security consultation and training services to law enforcement, health, education, industry, and professional organizations.
- Implemented Tripartite Initiative with Russia and the IAEA to improve the security of high-risk radioactive sources in the former Soviet Union.
- Launched the Global Search and Secure project to provide radiation measurement instruments and training to partner countries to locate and secure high-risk abandoned radioactive sources. More than 1,600 sources have been located and secure to date and cooperation has been expanded to twenty countries. The U.S. State Department Nonproliferation and Disarmament Fund contributed $1.24M for equipment deployments for the effort.
- Installed security upgrades at eighteen sites at radiological sites in Greece in advance of the 2004 Olympic Games. In addition to the security upgrades, IRTR donated 110 handheld radiological detection devices to the Greek Atomic Energy Commission (GAEC) and to Greek law enforcement officials.
- Collaborated with Department of Defense (DoD) officials on Operation Maximus, which removed 1,000 highly radioactive sources from the former Iraq nuclear research facility.
- Completed or undertook security upgrades at fifty-three identified radiological repository sites in twenty-two countries.
- Partnered with Interpol, to execute the Cooperative Radiological Instrument Transfer (CRITr) project. Since its initiation in 2004, over 300 individual radiation detection instruments have been transferred and more than 500 police officers have been trained in basic radiation detection and safety. CRITr training and equipment were contributing factors involved in the resolution of a suspected illicit trafficking incident in southwest Kyrgyzstan in January 2005, the arrest of suspects selling 173 grams of 17 percent enriched uranium in Istanbul, Turkey in August 2005, and the arrest of suspects and confiscation of radioactive material on two separate occasions in Dar Es Salaam, Tanzania in March 2006.

Despite this substantial progress, much remains to be done.

Notes:

1. Federal Register. *Preparedness Directorate; Protective Action Guides for Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents.* January 3, 2006. Vol 1. No.1.
2. F. Steinhäusler, Countering Radiological Terrorism: Consequences of the Radiation Exposure Incident in Goiania (Brazil), presented at the NATO Advanced Research Workshop on “Radiological Terrorism: Public Response and the Search for Resilience. The Bratislava Report.” Center for International Trade and Security, the University of Georgia, Athens, Georgia.
3. M. Savkin et al., 2005. Final Technical Report: Criminal Application of Radionuclide Sources: Survey of Incidents and Lessons of Hygienic, Dosimetric and Clinical Investigation, prepared for Brookhaven National Laboratory, Upton, NY under contract to GTRI, NNSA.
4. *World Development Indicators* (WDI) publication is the World Bank’s premier annual compilation of data about development. The 2006 WDI includes more than 900 indicators in more than eighty tables organized in six sections: World View, People, Environment, Economy, States and Markets, and Global Links, London, UK.

Development of the Special Form Capsule for Sealed Sources

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Introduction

The Off-Site Source Recovery Project (OSRP) at the Los Alamos National Laboratory (LANL) recovers and manages excess and unwanted radioactive sealed sources and other radioactive materials that present a risk to public health, safety, and national security; and for which no disposal options currently exist. Sealed sources that present a potential loss of control by U.S. Nuclear Regulatory Commission (NRC) or agreement state licensee are a U.S. Department of Energy (DOE) responsibility under the Low-Level Radioactive Waste Policy Amendments Act (Public Law 99-240). Due to their age, lack of available manufacturer data and unknown origin, or the potential for leakage, some of the radioactive sealed sources targeted for recovery by the OSRP do not meet U.S. Department of Transportation (DOT) Type A requirements. Therefore, there has been a need to address these sources. Sealed sources that are special form can be shipped using DOT Type A, 7A packages, which provide increased flexibility in shipping.

Development of Special Form Capsule

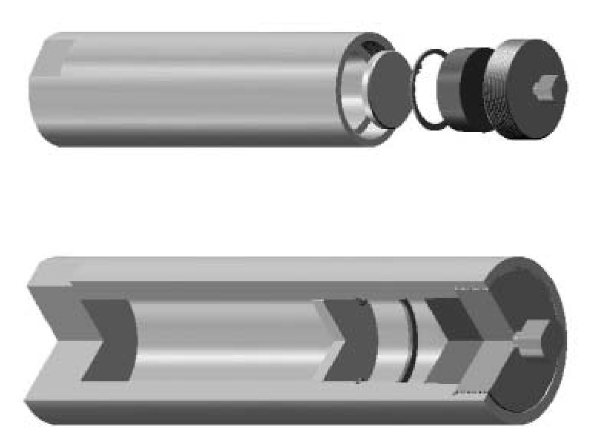
According to the *Implementing Guide for Occupational Radiation Protection* (GN5400.9/M1) *Sealed Radioactive Source Accountability and Control,* a sealed source is radioactive material that is contained in a sealed capsule, sealed between layers of non-radioactive material, or firmly fixed to a non-radioactive surface by electroplating or other means. The confining barrier prevents dispersion of the radioactive material under normal and most accidental conditions related to the use of the source.

By definition, special form is Class 7 radioactive material that satisfies the following conditions; it is either a single solid piece or is contained in a sealed capsule that can be opened only by destroying the capsule; the piece or capsule has at least one dimension not less than 5 millimeters (0.2 inch); and it satisfies the test requirements of 49 CFR 173.469.

During many of the recoveries, OSRP came across several sealed sources that were no long special form. It was recognized that some method to qualify suspect or leaking sources as special form was needed. OSRP found a capsule, the SFC-7, which had been developed and patented by Radiation Service Organization, Inc. (RSO) in 1989. RSO had developed the SFC-7 to facilitate shipments of Radium 226 sources as special form in Type A packages for disposal. The size limitation of the SFC-7 restricted its usefulness and it was agreed upon with RSO that LANL would take on the task of expanding the design into a series of capsules that would serve a large size range of sources.

OSRP developed a sealed source overpack called the Special Form Capsule (SFC) to provide a method to ensure DOT special form containment of radioactive sealed sources during transport. A key feature of the SFC was that it could be easily assembled in the field and allowed sealed sources that did not have current special form certification or documentation for domestic transport to be made special form by field encapsulation in a SFC. Its development also expanded the capabilities to efficiently transport and store sealed sources. See Figure 1.

Figure 1. Special form capsule design

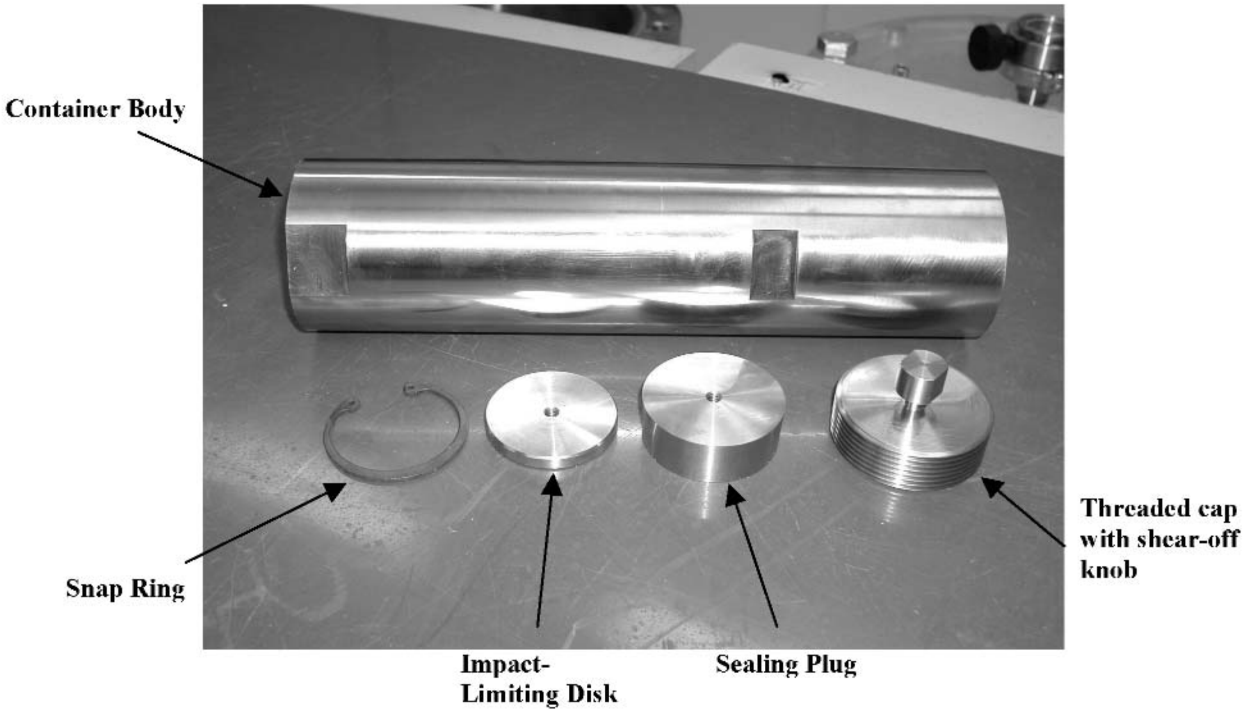


During the development phase of the SFC, a series of in-house tests were conducted to verify the adequacy of the design. Once the design was validated, capsules were fabricated, assembled, and sent to Pacific Testing Laboratories (PTL) in Valencia, California, for independent testing.

The capsules were tested to the requirements of "special form radioactive material," as defined in 49 CFR 173.469(b)-(1)-(4). All tests, except the heat and leakage tests, were carried out at ambient temperature and were done using a capsule fabricated according to drawing specifications. A different capsule was used for each of the tests. In order to evaluate the performance of the capsules, the test criteria specified that the leak-tightness be determined following each test.

Following the tests, PTL issued a certificate of conformance indicating that the SFC has been tested and certified to meet all

Figure 2. General components of the special form capsule are a body, snap ring, impact limiting disk, and sealing plug



requirements specified by the DOT in Title 49 Part 173 of the Code of Federal Regulations, Section 469 (49CRF173.469) ANSI N43.6 Annex E for special form material.

The SFC consists of five components: the container body, a sealing plug, an impact limiting disk, a snap ring and the threaded cap. The SFC has exterior dimensions of 3" OD x 11" long. The container body is fabricated from SS 304 bar stock. The SFC incorporates a tapered plug, made of the same material. A cap, utilizing 2 1/2 -10 ACME 2G threads, is used to apply pressure on the tapered plug forming a seal against the inner wall. The impact limiting disk and snap ring are used to ensure the integrity of the seal. The cap incorporates a knob that shears off during assembly as part of the sealing process to a final containment that cannot be opened without machining, which would result in the destruction of the capsule. The capsule components are shown in Figure 2.

When the shear-off knob is torque off the capsule, the sealing plug is firmly seated into the capsule. The sealing surfaces provide a metal-to-metal seal. Once seated, the plug requires about 250 pounds of external force to extract. It would require 67 psi of pressure within the SFC to generate the same force. The threaded cap remains in place and serves to protect and retain the sealing plug within the capsule. After the shear-off knob is removed, the assembly cannot be opened and reused without destroying the capsule. See Figure 3.

Figure 3. When the source is placed inside the capsule, the knob is sheared-off.

The walls of the housing are 0.5" thick. The SFC has an internal height of 8.5" and can hold a payload of ~2 inches OD X 8.25" long. See Table 1. The design is detailed in LANL drawing 90Y-219998, Revision G. Fabrication is conducted in compliance with the quality assurance specifications in 10 CFR 71 subpart H.

Table 1. Special Form Capsule Dimensions

SFC	Internal Height	Overall Length	ID	OD	Weight (grams)
Model II	8.5"	11.75"	2.062"	3.0"	6290

Conclusion

The materials intended for encapsulation by the LANL SFC are limited to metal-clad sealed sources or leaking sealed sources containing dry solids. In general, use of the SFC by LANL is for radioactive sources containing the following alpha-emitting isotopes: Pu^{238}, Pu^{239}, Am^{241}, Np^{237}, Cm^{244}, and Ra^{226} with a total weight of 2,400 grams.

Safe and cost-effective recovery of sealed sources requires efficient packaging and transport. Radioactive sealed sources in special form can be transported in DOT Type A containers in quantities up to the A1 limit reported in 49 CFR 173.435. For isotopes such as Pu^{238}, Pu^{239}, and Am^{241}, the special form A_1 limit is 10,000 times greater than the normal form A_2 limit.

The design characteristics of the capsule and successful testing allow us to state that the capsules meet the requirements of ANSI N43.6 Annex E, ISO 2919, and ISO 1979-02-15.

In 2006, LANL teamed up with QSA Global Inc. to obtain a DOT special form certificate for the Special Form Capsules. As of, February 8, 2006, the capsules have DOT approval, an International Atomic Energy Agency Certificate of Competent Authority, and can now be used internationally.

More information on the SFC is available at http://osrp.lanl.gov.

References

1. Implementing Guide for Occupational Radiation Protection (GN5400.9/M1) Sealed Radioactive Source Accountability and Control
2. Code of Federal Regulations, Title 49, Part 173, Section 173.469
3. Code of Federal Regulations, Title 10, Part 71, Subpart H
4. Health Physics Society, Sealed Radioactive Sources–Classification, American National Standard ANSI/HPS N43.6 Annex E
5. International Standard, ISO 2919:1999(E) *Radiation Protection–Sealed Radioactive Source–General Requirements and Classification,* Second edition 1999-02-15
6. Technical Report 4826, *Sealed Radioactive Sources – Leak Test Methods,* Published ISO 1979-02-15, Ref. No. ISO/TR 4826-1979(E)

Almost 600 Pounds of Highly Enriched Uranium Returned to Russia

With assistance from the U.S. Department of Energy's National Nuclear Security Administration (NNSA), more than 590 pounds of highly enriched uranium was returned from a former East German civilian nuclear facility to Russia.

The shipment of 268 kilograms (more than 590 pounds) of highly enriched uranium (HEU) is the largest shipment of Soviet-origin HEU ever conducted under a key NNSA nonproliferation program, the Global Threat Reduction Initiative (GTRI), since the inception of GTRI. The five-day operation took place at the Rossendorf nuclear facility near Dresden, Germany.

The effort was completed in cooperation with Germany, the Russian Federation, and the International Atomic Energy Agency (IAEA). The HEU fresh (unirradiated) fuel was loaded into eighteen Russian TK-S16 specialized transportation containers at Rossendorf with NNSA technical experts and IAEA safeguards inspectors monitoring the fuel loading process. The canisters were transported under heavy guard and then airlifted from Dresden Airport to a secure facility in Russia.

The shipment was part of the prioritized, accelerated schedule in support of the Bush-Putin Bratislava Joint Statement on Nuclear Security

The HEU fresh fuel will be permanently downblended from HEU to LEU in Russia to ensure that it cannot be used to make nuclear weapons. NNSA provided technical support and Germany provided the funding for this operation.

U.S., Panama Sign Pact to Combat Nuclear Smuggling

The United States and Panama in February signed a Declaration of Principles to help prevent the smuggling of nuclear and other radioactive material. The U.S. Department of Energy's National Nuclear Security Administration (NNSA) and the U.S. Department of Homeland Security's (DHS) Customs and Border Protection (CBP) cosigned the declaration. The document covers implementation of NNSA's Megaports Initiative and CBP's Container Security Initiative, as both programs continue working together to stop nuclear material from being smuggled to U.S. ports.

NNSA's Megaports Initiative works with foreign governments to install specialized radiation detection equipment and enhance capabilities to deter, detect, and interdict illicit shipments of nuclear and other radioactive materials at international ports. The initiative is currently operational in six countries, and at various stages of implementation and negotiations with approximately thirty other countries around the world.

Under the Container Security Initiative (CSI), officers from both CBP and DHS' Immigration and Customs Enforcement are stationed at key seaports abroad to work with host governments to identify high-risk shipments bound for the United States and to examine these shipments prior to loading. CSI operates at fifty ports in North America, Europe, Asia, the Middle East, and North, South, and Central America. About 83 percent of all cargo containers destined for U.S. shores originate in or are transshipped through CSI ports.

NTI Commits $50 Million to Create IAEA Nuclear Fuel Bank

The Nuclear Threat Initiative (NTI) will contribute $50 million to the International Atomic Energy Agency (IAEA) to help create a low-enriched uranium stockpile to support nations that make the sovereign choice not to build indigenous nuclear fuel cycle capabilities, NTI Co-Chair Sam Nunn announced in Vienna, Austria, in September 2006.

In his speech, Nunn said, "A country's decision to rely on imported fuel, rather than to develop an indigenous enrichment capacity, may pivot on one point: whether or not there is a mechanism that guarantees an assured international supply of nuclear fuel on a non-discriminatory, non-political basis to states that are meeting their nonproliferation obligations. We believe that such a mechanism can be achieved, and that we must take urgent, practical steps to do so."

NTI´s contribution is contingent on two conditions, provided they are both met within the next two years:

- that the IAEA takes the necessary actions to approve establishment of this reserve
- that one or more member states contribute an additional $100 million in funding or an equivalent value of low enriched uranium to jump-start the reserve

Every other element of the arrangement—its structure, its location, the conditions for access—would be up to the IAEA and its member states to decide. Warren Buffett, one of NTI´s key advisors, is financially backing and enabling this NTI commitment.

The proposal comes at a time when more nations are seeking nuclear energy to meet their development needs and are weighing available options to determine what will be the most secure and most economical way to ensure a reliable supply of nuclear fuel. As more nations seek nuclear energy, concerns have been raised about the nuclear fuel cycle. The report of the UN High Level Panel on Threats said that "the proliferation risks from the enrichment of uranium and from the reprocessing of spent fuel are great and increasing."

NNSA to Upgrade Last Russian Nuclear Warhead Site Under Bratislava Agreement

The U.S. Department of Energy's National Nuclear Security Administration (NNSA) will begin upgrading the ninth and final Russian nuclear warhead site that it was assigned under the 2005 joint statement between Presidents George W. Bush and Vladimir Putin in Bratislava. Under the 2005 statement, the United States and Russia agreed to cooperate on nuclear security issues, and subsequently, NNSA was designated as the lead organization to upgrade nine Russian nuclear warhead facilities that needed improved security.

NNSA, through Sandia National Laboratories, completed the security upgrade design work and finalized contract negotiations under its Material Protection, Control, and Accounting Program in order to complete the work by December 2008.

The security upgrades that will be installed at the site, which is under the control of the 12th Main Directorate, are designed to protect against the risk of theft or attack by terrorists, and include installing physical protection systems, such as intrusion detection sensors, access controls and hardened defensive positions.

NNSA has previously provided security upgrades at sixty-one military-affiliated sites in the Russian Federation, and has contracts in place to install security systems at twenty-three additional sites by December 2008.

Radioactive Material Removed from Massachusetts

In December 2006, the U.S. Department of Energy's National Nuclear Security Administration (NNSA) announced that it has secured radioactive material from a small business in eastern Massachusetts. The material, which could potentially be used in a "dirty bomb," was recovered and sent to secure storage.

This mission recovered 55 curies of cesium-137 and less than one curie of radium-226 from a small business in Plymouth, Massachusetts. The recovery was funded by NNSA's Global Threat Reduction Initiative (GTRI) and organized in close cooperation with the U.S. Nuclear Regulatory Commission (NRC) and the Massachusetts Department of Public Health's (MDPH) Radiation Control Program.

The MDPH program has been closely monitoring this small business, and when there were indications that the business could no longer safely manage the material, the MDPH contacted the NRC and NNSA. The material was removed before there was any risk or threat to the public.

GTRI's domestic source recovery program is implemented by the Los Alamos National Laboratory and works around the United States to remove and securely manage radioactive materials that could be at risk for theft and diversion for use in a radiological dispersal device. The program recovers and managed excess, unwanted, or abandoned radioactive sealed sources and other radioactive material. Sources containing radioactive plutonium, americium, cesium, cobalt, and strontium have been recovered from medical, agricultural, research and industrial facilities throughout the nation. To date, the program has recovered more than 13,000 sources—enough radioactive material to make more than 1,400 potent dirty bombs—from more than 500 facilities.

Author Submission Guidelines

The *Journal of Nuclear Materials Management* is the official journal of the Institute of Nuclear Materials Management. It is a peer-reviewed, multidisciplinary journal that publishes articles on new developments, innovations, and trends in safeguards and management of nuclear materials. Specific areas of interest include physical protection, material control and accounting, waste management, transportation, nuclear nonproliferation/international safeguards, and arms control and verification. *JNMM* also publishes book reviews, letters to the editor, and editorials.

Submission of Manuscripts: *JNMM* reviews papers for publication with the understanding that the work was not previously published and is not being reviewed for publication elsewhere. Papers may be of any length.

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Format: All papers must include:

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- Name and address of the organization where the work was performed
- Abstract
- Camera-ready tables, figures, and photographs in TIFF format only
- Numbered references in the following format:
  1. Jones, F. T. and L. K. Chang. 1980. Article Title. *Journal* 47(No. 2): 112–118.
  2. Jones, F. T. 1976. *Title of Book*, New York: McMillan Publishing.
- Author(s) biography

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Calendar

April 23–26, 2007
Occupational and Environmental Radiation Protection: Principles and Practices of Radiation Safety Conference
Harvard School of Public Health
Boston, Massachusetts, USA
Organizer:
Harvard School of Public Health Center for Continuing Professional Education
Contact: Shelley Akers
E-mail: contedu@hsph.harvard.edu
Web Site:
http://www.hsph.harvard.edu/ccpe/programs/OERP.shtml

June 3–8, 2007
13th International Conference on Emerging Nuclear Energy Systems (ICENES 2007)
Istanbul, Turkey
Web site: http://www.icenes2007.org/

June 24–28, 2007
ANS Annual Meeting
It's All About the People: The Future of Nuclear
Boston, Massachusetts, USA
Sponsor:
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July 8–12, 2007
48th INMM Annual Meeting
JW Marriott Starr Pass Resort & Spa
Tuscon, Arizona, USA
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October 21–26, 2007
PATRAM 07
Marriott Doral
Miami, Florida, USA
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Web site: www.patram.org

November 11–15, 2007
ANS/ENS International Winter Meeting and Nuclear Technology Expo
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