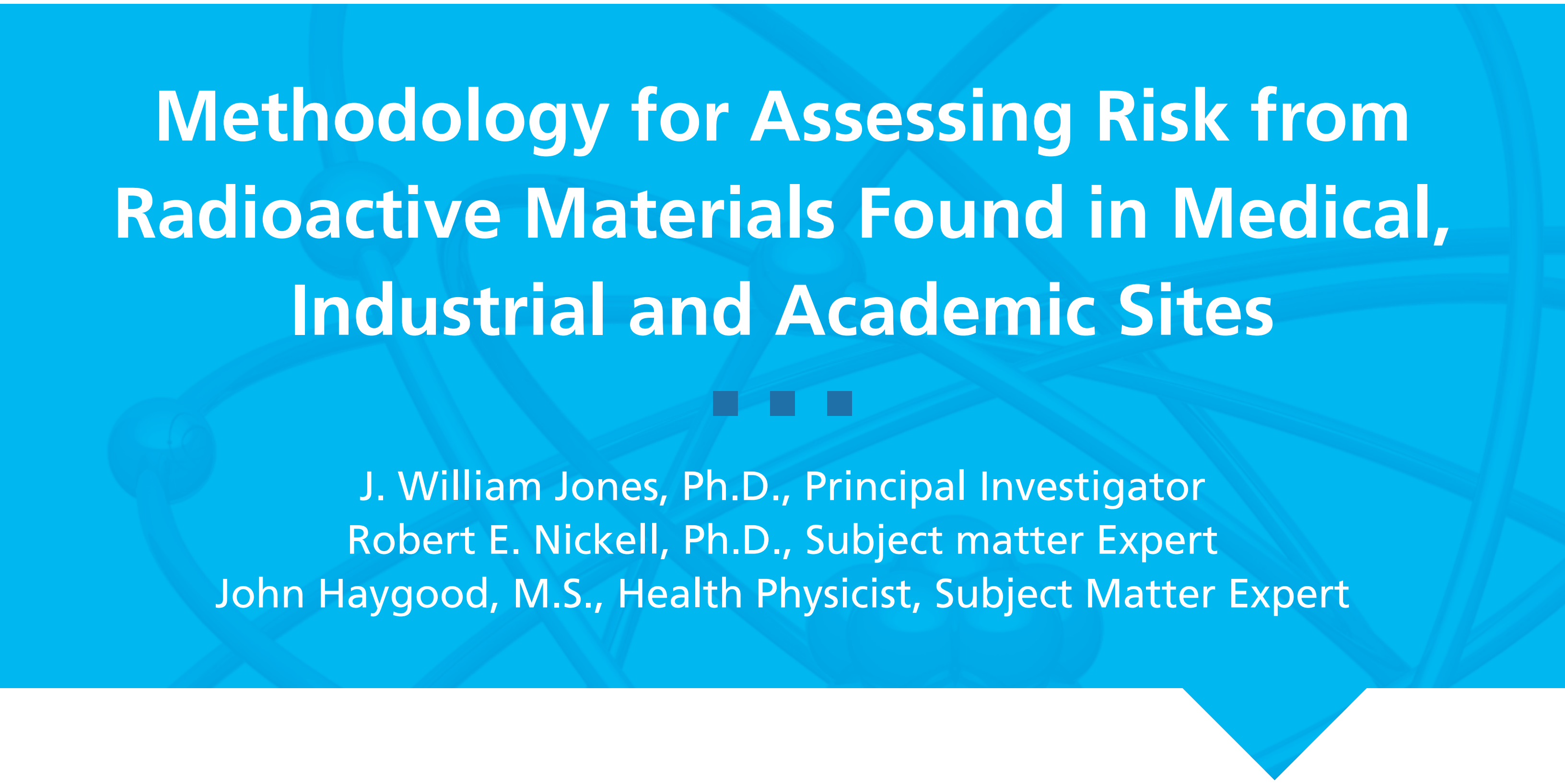

Methodology for Assessing Risk from Radioactive Materials Found in Medical, Industrial and Academic Sites

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J. William Jones, Ph.D., Principal Investigator
Robert E. Nickell, Ph.D., Subject matter Expert
John Haygood, M.S., Health Physicist, Subject Matter Expert

March 2011

ASME INNOVATIVE
TECHNOLOGIES
INSTITUTE, LLC

Final Report to the Alfred P. Sloan Foundation in Fulfillment of Grant Number 2009-10-18

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1. Executive Summary

More than 21,000 medical, industrial, and academic facilities in the United States are licensed to use radioactive materials. There are many similar sites around the world. These materials are used for various purposes, including medical and veterinary treatments, industrial applications, and academic research. There is concern that these nuclear materials may be dangerous to the public in case of a security lapse or a natural disaster. A lapse in security can result in radioactive material falling into the hands of terrorists and used for sinister purposes. If the materials should fall into the wrong hands, they could be used in a radioactive dispersal device (RDD), a so-called "dirty bomb," or be released into the environment through other means. Under extreme conditions, they can cause fatalities, serious injuries, and environmental damage, which could require costly decontamination or abandonment of valuable locations. Deployment of an RDD could cause disruption of commerce, denial of critical services and infrastructure and/or loss of access to public locations.

An RDD is not a weapon of mass destruction, such as a nuclear warhead or atomic bomb that utilizes either fission or fusion of highly refined nuclear materials. Rather, an RDD is a weapon of mass disruption or a disruptive radiation device (DRD). While a DRD is unlikely to cause large numbers of fatalities or serious injuries, it could have devastating economic consequences.

The Times Square car bomb attempt on May 1, 2010, in New York City, perpetrated by homegrown terrorist Faisal Shahzad, would have been orders of magnitude more disruptive had he included radioactive materials in the improvised explosive device (IED). Even though the explosion did not occur, the mere presence of radioactive material has the potential to create panic. The negative public perception of radioactive materials makes them particularly attractive to terrorists. By definition, it is the goal of the terrorist to induce fear in an attempt to coerce governments for political or ideological gain.[1] Fatalities or serious injuries are not necessarily the ends terrorists seek.

The public fear of radioactive materials cannot be overstated. We do not have the capability to detect the presence of radioactive materials without appropriate sensors placed in critical locations. RDDs can spread radioactive materials in a highly populated area using improvised explosives. While the risk of fatalities is primarily due to the explosion itself, and the radioactive materials can be expunged from the area by well-known decontamination methods, the fear of residual effects will greatly limit commerce and result in costly security enhancements. If such events occur, it could prove difficult to restore public confidence in government agencies tasked with preventing such events.

ASME-ITI has developed a methodology that will satisfy the regulatory handling and reporting requirements of the U.S. Nuclear Regulatory Commission (NRC) as well as provide a framework for a voluntary standard that will meet the requirements of the Department of Homeland Security (DHS) to safeguard this material. Further, it will provide a methodology for comparing risk for both natural and man-made events against risks in other economic sectors.

Some key observations resulting from this study include:

1. The risk to the general public due to natural hazards is quite low. The facilities where MIAN materials are typically stored are designated as either essential facilities or represent a substantial hazard to human life in the event of failure. As a result, such locations are required by building codes to be structurally designed to withstand all natural events that have a reasonable likelihood of occurring.

2. The use, storage, and transport of radioactive materials are well regulated by federal and state agencies. However, the radiation control regulations enforced by these agencies were developed with an emphasis on safety, rather than security. MIAN materials are typically shielded, either in shipping containers or well-secured compartments in medical devices or other commercial equipment. This shielding and security

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[1] United States Code Congressional and Administrative News, 98th Congress, Second Session, 1984, Oct. 19, volume 2; par. 3077, 98 STAT. 2707 (West Publishing Co., 1984)

containment greatly reduces the risk to the public in the event of natural hazards. Further, most buildings store radioactive materials and have sprinkler systems and elevated security that greatly reduce the risks from natural hazards and inadvertent exposure of personnel.

3. The risk resulting from terrorism is significantly higher than risk due to natural hazards and exposure of personnel in the routine use of MIAN materials.

4. The lack of a national, well-secured waste disposal site in the Unites States greatly increases the risk of terrorists obtaining materials that can be used to achieve their ideological goals. Materials are currently stored in thousands of locations, often with inadequate security, providing easy targets for terrorists to obtain sufficient quantities of material that could result in high-consequence events.

5. Obtaining radioactive materials from a site without being detected increases the probability of successful deployment. The probability of interdiction by security and intelligence personnel is greatly reduced if the materials can be obtained undetected or with delayed detection.

6. Successfully obtaining dangerous materials, if detected by the authorities and known to the public, can result in high consequences even if never deployed. The mere threat of using radioactive materials by terrorist organizations, especially when they are known to possess them, has the potential to cause economic consequences and disruption of public services.

7. Transporting radioactive materials to and from a central storage facility in a secure fashion reduces the risk to the public by limiting the proximity of these materials to populated areas.

8. The security at sites that have potentially dangerous quantities of radioactive materials is generally incapable of preventing theft by armed attack.

9. Insider theft of dangerous quantities of radioactive materials is a weakness of the current system.

10. Large quantities of radioactive materials are transported over the highways with limited security for preventing theft, diversion, or attack by IED while en route. The most critical of these shipments are the sources for irradiation facilities. This material is shipped from Canada to over 50 sites and between irradiation facilities within the Unites States. The level of security is much lower than for an armored truck carrying cash from grocery stores to banks.

11. Economic consequences can be greatly reduced by public education. The actual risk to an individual due to an RDD is quite low relative to other normal risks that are tolerated by the public such as medical x-rays, automobile safety, etc. The fear of such an event can be reduced by educating the general public regarding the actual threat and risk before such an event occurs.

12. The news media should be educated to prevent extreme "media hype" that exacerbates public fear. The news media, with instant reporting and on-scene coverage, tend to raise public awareness and turn accidents and incidents into disasters to gain viewership. It would be prudent for MIAN facilities to have a plan for dealing with the media in the event of a security breach.

A significant effort is currently underway to increase the security of radioactive materials used in MIAN applications. The NRC has drafted new regulations, contained in Title 10 Part 37, of the Code of Federal Regulations, for securing radioactive materials. They are currently receiving comments from the user community and other affected parties, such as state regulators. Based on the comments received to date, it appears that the MIAN community is resisting the proposed new regulations. Even if the proposed changes in regulation are adopted and imposed on users, implementation of the regulations will take time and will add unnecessary overhead and cost to industry.

The National Nuclear Security Administration is also working to improve the security of high-risk radioactive sources. In testimony before the House Committee on Homeland Security, Subcommittee on Emerging Threats, Cybersecurity, and Science and Technology on September 14, 2009, Kenneth Sheely described a program to increase security for blood irradiators (Cesium-137, or Cs-137) and gamma knives (Cobalt-

60, or Co-60). One key finding of their work was that radioactive sources within self-shielded cesium irradiators could be extracted more quickly than initially thought. A delay kit (In-Device Delay or IDD) was developed to "make it orders of magnitude more difficult for an adversary to illicitly access and steal the radiological source."[2] As of the time the hearing, 840 such cesium devices were in use in the United States. At the time of the hearing, only 32 had been hardened under the program. The remaining 808 irradiators "can be hardened by FY2016." It was also stated, "each of these 840 Cs-137 irradiators has enough material that could be used in several RDDs of national significance."

Results

In the course of this project, the following items were developed:

1) Development of Risk Methodology for MIAN Materials
2) Comparison of Terrorist vs. Natural Hazard Events
3) Compilation of MIAN Materials List with Relevant Properties That Could Contribute to Malevolent Uses.
4) Development of Current Security Status Screening and Assessment Tool
5) Investigation of Materials Related Terrorist Scenarios
6) Examples of Risk Assessments for Four Postulated Events
7) Site Visits and Pilots for the Methodology
8) Peer Review of the Methodology

Conclusions

The results of the site visits and the peer review comments indicate the need for enhancing current security practices and educating the licensees with respect to possible breaches in security. The risk posed by malevolent events has not been transmitted adequately to the licensees. While the licensees are diligent in protecting MIAN materials, they are not fully aware of the extensive consequences that can result from the loss of material. Most have not considered that armed terrorists willing to sacrifice themselves would present a threat that cannot be met with existing security measures. The need to report missing materials must be reinforced. If a terrorist plot is to be interdicted, law enforcement must be informed in time to apprehend the perpetrator before deployment.

During the pilot studies the interviewees indicated that they would utilize an enhanced security tool if it were available at little or no cost and not overly burdensome. There is a need to continue to develop a voluntary assessment tool that could be used to determine the current security status, compare the level of security to established benchmarks based on the materials and quantity of material on site, and suggest ways to further enhance security without incurring prohibitive costs. The interviewees suggested several ways to increase public awareness of the actual danger of a terrorist event as well as ways to reduce the psychological consequences. These suggestions should be implemented through an awareness and education program working with existing professional societies and industry organizations.

Recommendations

- Continue to develop the security enhancement tool. Include additional security measures suggested by the interviewees and provide guidance for enhancing security. Provide metrics to compare assessed site security to a range of scores that would be acceptable for sites storing materials of this type and quantity.
- Obtain feedback from licensees and regulators and other knowledgeable individuals regarding scoring and what acceptable levels are for different amounts and types of materials, including development of a table for comparison of program levels of security.
- Add suggestions for improving security and possibly create a handbook for security.

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[2] Kenneth Sheely, Associate Assistant Deputy Administrator, National Nuclear Security Administration, Testimony before the House Committee on Homeland Security, Subcommittee on Emerging Threats, Cybersecurity, and Science and Technology, U.S. Senate, September 14, 2009, (http://nnsa.energy.gov/mediaroom/congressionaltestimony/09.14.09, accessed January 2011).

- Encourage adoption of the methodology on a voluntary basis.
- Work with states and organizations such as the Conference of Radiation Control Program Directors, DHS and the Agreement States to adopt the process.

- Find ways to inform the public about the risk and the actual dangers regarding deployment of MIAN materials. Use existing organizations such as the Health Physics Society and the American Association of Physics Medicine and working committees to develop spokespersons and web sites. Inform media about the existence of these sources of information. Develop an information resource that can reduce the psychological impact in the event of a nuclear terrorism event.

While increased security measures that are currently being implemented will reduce the risk of a terrorist attack, implementation will not be fully completed for several years. Further, these measures do not consider many of the terrorist scenarios that are described in this report nor do they extend to all materials that pose a danger to the public. Appendix D provides several example scenarios that utilize MIAN materials in events other than an RDD. The need for a voluntary security assessment program that will aid those who possess MIAN materials to determine if they are in compliance with existing regulations and how they can improve existing security programs is clear.

2. Background

2.1 The MIAN Project

The events of September 11, 2001, heightened the nation's concern that radioactive material could be used in a malevolent act. Such an attack has been of particular concern because of the widespread use of radioactive materials in the United States and abroad by industry, hospitals, and academic institutions. Loss or theft of such materials could lead to their diversion for malicious use.

In 2009, the Federal Bureau of Investigation (FBI) and Interpol expressed their concern about the potential use of radioactive material as a terrorist tool, due to inadequate security, to ASME and the Alfred P. Sloan Foundation. Consequently, ASME Innovative Technologies Institute, LLC (ASME-ITI) applied for and received a grant from the Sloan Foundation to develop a risk-based methodology to help identify and prioritize significant risk to the public from radioactive materials used in the medical, industrial, and academic communities. These materials are handled and regulated separately from those of nuclear power generation and nuclear weapons.

Prior to 9/11, security of radioactive materials was barely functional. For example, a user of a large industrial source might only be required to have a padlock on the storage container and a written procedure that stated materials could only be handled by authorized personnel. Radiation protection was the major concern of radiation regulatory organizations. After 9/11, the security requirements were greatly increased and solidified.

In 2005, the U.S. Nuclear Regulatory Commission (NRC) issued an order requiring the development and implementation of increased controls (IC) by licensees by both NRC and Agreement State (AS) licensees possessing certain types and quantities of radioactive material. The requirements included more stringent procedures for allowing access to radioactive materials, such as documented background checks of authorized users and implementation of security systems capable of initiating a timely armed response from a local law enforcement agency. In 2008, fingerprinting and an FBI background check were added to the requirements. With the development of stringent radiation protection and security requirements over the years, the question remains: are our current procedures adequate to protect public safety from natural and man-made disasters?

A risk-based methodology has been developed that provides a way of evaluating the safety and security or MIAN materials. This methodology is based on Risk Analysis and Management for Critical Asset Protection (RAMCAP) Plus®, which has been used extensively for risk assessment of natural hazards and terrorism for numerous economic sectors. Risk to MIAN materials can be categorized into three primary classifications:

1) Accidental or inadvertent exposure;
2) Exposure due to natural hazards; and
3) Purposeful use of MIAN materials as a weapon of terrorism.[3]

The vast majority of MIAN materials are not useable as dirty bombs or other manners of high consequence. Only in very large quanti¬ties are they especially dangerous in intentional or accidental release. They are generally well protected, but when there are so many opportunities for something to go wrong, there is always risk. It is the purpose of this project to identify the risks and to develop steps to address them. The primary goal of NRC requirements and regulations in the past was to ensure the safety of the users of these materials. While safety is important, increased security of MIAN materials has now become essential.

With the recent rise in terrorist activity, especially the willingness of individuals to commit suicide to achieve their objectives, it is prudent to reconsider current procedures. A major goal of this project is to identify gaps in security and ways to make the system more secure. Further, it was necessary to consider all reasonable scenarios for obtaining materials that could be used by terrorists and to estimate the probability of successfully obtaining the materials given the security at the site. Finally, an attempt was made to predict how these materials could be deployed to achieve the maximum possible consequences. This overall assessment methodology was cast in the RAMCAP Plus® framework consistent

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[3] The findings of this report demonstrate that terrorism presents the highest level of risk.

with existing risk methodologies used by the Department of Homeland Security (DHS).

It is not difficult to imagine the psychological impact of weaponizing radioactive material. To a domestic or foreign enemy committed to achieving ideological objectives through coercion, exploiting fear of radioactive weapons is an obvious tactic. If the taking of life was the main purpose of terrorism, then use of radioactive materials would not serve the terrorists' purpose well. For example, setting off an explosive device that also contained radioactive material might result in some immediate deaths attributable to radiation exposure, but not necessarily any more than those caused by the explosion itself. Thus, the desire to obtain these materials from state and non-state actors remains.

The introduction of radioactive material to the inventory of terror serves a dual purpose. It enhances fear and requires more resources expended for societal and commercial recovery. Additionally, the societal/psychological impact of a radioactive dispersal device (RDD) would be much larger than an attack via an improvised explosive device (IED). It is also likely that media outlets will be filled with sensationalized stories leading to more panic.

Resources will also be stressed. Regulatory difficulties and high expenses for clean up and disposal of radioactive waste, even when concentrations are extremely low, are to be expected. Government will be considerably distracted by having to deal with the "fall-out" from extensive publicity and financial burdens imposed by recovery efforts. Cascading effects could extend to other less publicly visible situations that could lead to increased social and economic costs.

Given these considerations, even quantities of radioactive material that are less than "risk-significant" could be used to further a terrorist's cause. "Risk-significant" is used by regulatory authorities to indicate amounts of radioactive material deemed to be sufficient to deliver a lethal dose in a very short period of time.[4] Risk-significant quantities of radioactive material can be found at the following types of facilities:

- Commercial and research reactors;
- Fuel fabricating facilities;
- Fuel reprocessing facilities;
- Large hospitals;
- Cancer treatment facilities;
- Large irradiators;
- Industrial radiography facilities;
- Some well logging facilities; and
- Low-level and high-level radioactive waste disposal facilities.

Federal and state regulators are now occupied with developing and implementing security procedures for the risk-significant radioactive materials and industries that produce and use them. The RAMCAP Plus® methodology provides a voluntary avenue for users of radioactive material that does not qualify as a risk-significant quantity to assess the potential costs should their materials be obtained by terrorists. This allows them to establish priorities for investing resources in additional security. The number of licensed users of radioactive material who do not fall into the category of users of risk-significant quantities of radioactive material far exceeds the number of those who do.

2.2 History and Development of the Regulation of Nuclear/Radioactive Materials

Early work with radiation began in 1895 when Wilhelm Roentgen used an electron beam directed toward a cathode to create "mysterious rays" that penetrated his wife's hand and placed an image of her skeleton on a photographic plate. Antoine Becquerel, a French physicist, became interested in Roentgen's work and began studying fluorescence and phosphorescence. He found that while fluorescence, phosphorescence, and x-rays had many similarities, they also had significant differences. In 1896, Becquerel stored some crystals containing uranium and some photographic plates together. He found that the plates had been exposed from "invisible emanations" from the crystals. No external energy source was required to initiate the emanations, as was necessary for fluorescence, phosphorescence, and x-rays. However, Becquerel did not pursue investigations into this "discovery of radiation."

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[4] U.S. NRC, "Risk-significant," (http://www.nrc.gov/reading-rm/basic-ref/glossary/risk-significant.html, accessed January 2011).

During his work, Becquerel had noted that the emanations from uranium caused conductivity in air. Marie and Pierre Curie, working in the Becquerel lab, began researching emanations from various elements to determine their ability to cause conductivity. In 1898, when testing pitchblende, an ore of uranium, they found that it provided 300 times the current of that caused by pure uranium. The Curies concluded that an unknown substance was present in the pitchblende and named it Polonium (Po), after Poland, Marie's native country. They coined the phrase "radio-active" to describe the property of emanations from the unknown material.

During the years that followed, x-rays were slowly adapted to medical and industrial uses, while radioactive materials remained in the "research arena." The end of World War II and the start of the Cold War nuclear arms race ushered in the atomic age. Atomic energy, however, could be used for non-weapon purposes.

The federal government recognized that there were both benefits and pitfalls in the use of radioactive materials, and so the Congress passed the Atomic Energy Act of 1946. The Act established the Atomic Energy Commission (AEC) and placed all control and ownership of radioactive material into the hands of the federal government. Private use or ownership of radioactive material was not permitted.

Until the 1930's, little consideration was given to radiation protection. In 1934, a committee of representatives from professional societies and X-ray equipment manufacturers recommended a dose limit of 0.1 roentgens per day of whole body exposure. This dose was considered to be a "tolerance dose" that would unlikely cause injury. However, continuing research showed that even small doses could cause changes in reproductive cells and so the tolerance dose began to be less accepted. In 1946, the National Council on Radiation Protection & Measurements (NCRP) was formed and it introduced the concept of the "maximum permissible dose."

In 1948, the NCRP recommended a maximum permissible dose of 0.3 roentgens per six-day work week. The limit was based on exposure of the "most critical tissue in blood-forming organs, gonads, and lens of the eye."[5]

Congress, in an effort to expand peaceful atomic energy uses, passed the Atomic Energy Act of 1954. This Act ended the total federal control of radioactive material and required the AEC to encourage research and development of peaceful uses of radioactive material as well as promulgate regulations that would protect the "public health and safety." This allowed private industry, medical and educational facilities to apply for licenses authorizing the possession and use of radioactive material, whether they were for nuclear power production or the more mundane uses of relatively small quantities of radioactive materials.

Little progress was made in the development of nuclear power plants until Congress passed the Price Anderson Act in 1957. The Act backed insurance companies and allowed them to insure up to $60 million per power plant. Section 274 of the Atomic Energy Act, added in 1959, authorized the AEC to enter into an agreement with the governor of any state to allow the state to regulate "byproduct materials, source materials, and special nuclear materials"[6] in quantities not sufficient to form a "critical mass." The agreement also removed the authority of the AEC in those states, except that the AEC retained authority for certain uses, facilities, and operations. Nuclear power plants, export/import, and some disposal processes remained under AEC jurisdiction as did federal facilities. This action did not address radioactive materials that occurred naturally or were produced by accelerators. The states had authority over the latter.

In the late 1950's, public concern and even opposition of nuclear matters began to develop due to the emerging public awareness of the hazards associated with nuclear power and other uses. While the AEC emphasized stimulation of atomic development, it also was concerned with safety issues and developed regulations that "reflected careful consideration of the best scientific information and judgment available at the time."[7] The AEC believed that "compliance with its regulations would make the chances of a serious accident very small."[8]

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[5] U.S. NRC, "Short History," (website, accessed December 2010).

[6] U.S. NRC, "§ 8.4 Interpretation by the General Counsel: AEC jurisdiction over nuclear facilities and materials under the Atomic Energy Act," (website, accessed December 2010).

[7] Ibid. NRC Short History.

[8] Ibid.

The AEC had begun developing relationships with the states in the early 1950's. In 1955, the AEC formed an advisory committee of state officials to advise them on federal/state relations. In 1962, under Section 274, an agreement was signed between the Commonwealth of Kentucky and the AEC. The agreement allowed Kentucky to regulate the use of most radioactive materials within its borders while the AEC continued regulation of federal uses and certain other types of licenses. Therefore, Kentucky became the first Agreement State. As more and more states signed agreements, the number of AS licenses grew and exceeded the number of AEC licenses in 1971. Adoption of applicable federal radiation control regulations was one of the requirements for a state to sign an agreement with the AEC. Today there are 37 Agreement States with other state applications pending.[9]

Electric utilities became concerned with the environmental problems caused by the use of coal-fired electric plants and the production of electricity by nuclear plants began to look more and more appealing. In the late 1960's, a "reactor boom" was evident as more and more applications were received for larger nuclear plants. While the AEC's nuclear power workload increased tremendously, staff increases could not keep up. Thus, the AEC's attention was directed more towards nuclear plants than towards other uses of radioactive materials. The licensing process became very lengthy.

Many detractors of the AEC were concerned that it could not both develop and regulate nuclear technology successfully. With the energy crisis created in 1973 and 1974 caused by the Arab oil embargo, Congress was asked by the President to create an agency that could concentrate more on licensing of nuclear power plants. In response, Congress passed the Energy Reorganization Act (ERA) of 1974. The ERA divided the AEC into the Energy Research and Development Administration (ERDA), which would later become the Department of Energy (DOE), and the NRC.

During the 1960's and 1970's, many states began developing emergency response plans in the event that natural or manmade disasters might occur. Consequently, the AEC/NRC required the power plant operators to integrate state emergency plans into their procedures. Even though the states did not regulate the nuclear plants, the state radiation control programs became increasingly involved in the overall operations of the plants.

Today, the NRC and the AS work together to both regulate the uses of radioactive materials and to develop appropriate radiation safety and control regulations. There are a number of additional organizations that participate in the process. The FBI, the Environmental Protection Agency (EPA), Health and Human Services Department (HHS), Department of Transportation (DOT), Department of Defense (DOD), DOE, and DHS are principal federal agencies involved in radiation matters, along with the various states with radiation control programs.[10]

After 9/11, the security requirements were greatly increased and solidified. For example, in July 2002 the DOE/NRC Interagency Working Group on Radiological Dispersal Devices was formed in order to evaluate methods for improving the control of nuclear materials in the United States that could be used for such potential weapons. This led to the publication in May 2003 of the Working Group's first product, "Radiological Dispersal Devices: An Initial Study to Identify Materials of Greatest Concern and Approaches to Their Tracking, Tagging, and Disposition." This study identified the "radioactive materials of greatest concern" and recommended a National Source Tracking System (NSTS), which was later codified into law. Shortly thereafter, in July 2003, the International Atomic Energy Agency (IAEA) issued IAEA-TECDOC-1344, "Categorization of Radioactive Sources," which formalized the Category 1 and Category 2 list of isotopes and quantities that were later adopted in the United States.

The next major step in the United States was the enactment of the Energy Policy Act of 2005. This legislation led to four important developments:

(1) the formal requirement for a mandatory radiation source tracking system (NSTS);
(2) the issuance of IC on some licensees possessing certain quantities of Category 1 and Category 2 materials;
(3) a requirement for an annual report to the

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[9] U.S. NRC, "Agreement State Program," (website, accessed December 2010).
[10] ASME Innovative Technologies Institute, LLC, RAMCAP: The Framework, Version 2.0, (Washington, D.C., ASME-ITI, 2006).

Congress on the status of increased security, including efforts with the AS; and

(4) a requirement for a study by the National Research Council to identify the legitimate uses of high-risk radiation sources and the feasibility of replacing them with lower-risk sources.

Later in 2005, the NRC issued an order requiring the development and implementation of IC by licensees (both NRC and AS licensees) possessing certain types and quantities of radioactive material. The requirements included more stringent procedures for allowing access to radioactive materials (such as documented background checks of authorized users) and implementation of security systems capable of initiating a timely armed response from a local law enforcement agency.

In 2008 the National Research Council completed its study, "Radiation Source Use and Replacement," which reviewed the current status of the 55,000 or so high-activity sources licensed for use in the United States, concentrating on the four natural or manufactured radionuclides – americium-241, cesium-137, cobalt-60, and iridium-192 – that comprise 99% of those sources. While public policy has not followed the recommendations from that study (the primary recommendation appears to be aggressive replacement of cesium chloride sources), the 2008 National Research Council report contains a wealth of relevant background information.

In 2009, attempts were made to extend the formal NSTS tracking system to Category 3 sources, or to at least some Category 3 sources. However, with a 2-2 deadlock within the NRC, that attempt was blocked. Prior to that in 2008, fingerprinting and an FBI background check were added to the requirements for licensees subject to IC. In recent months, the NRC has become much more active in implementing additional security and control requirements, with a rulemaking in June 2010 to impose physical protection requirements for Category 1 and Category 2 quantities of radioactive material through Title 10 Part 37, of the Code of Federal Regulations (10 CFR 37). This proposed rulemaking was subject to public comment until November 12, 2010. Licensees remain subject to the NRC IC orders.

The NRC staff has already produced guidance for licensees on how to meet these proposed new requirements. In particular, Subpart B of the rulemaking addresses background checks, fingerprinting, access authorization, and related requirements. Subpart C is concerned with physical protection during use, and has a requirement for a security program that generally follows the guidance provided in IAEA Nuclear Security Series No. 11, "Security of Radioactive Sources, Appendices I (Description of Security Measures) and Appendix II (Examples of Content for a Security Plan). Subpart D addresses physical protection in transit. This is comprehensive rulemaking that appears to attempt to eliminate some of the existing gaps in the protection of the public health and safety. It is worth noting that, while the proposed 10 CFR 37 rulemaking covers "security program review," no particular requirement for individual licensee risk assessment is included, even though IAEA Nuclear Security Series No. 11 contains an Appendix III (Description of a Vulnerability Assessment).

With the development of stringent radiation protection and security requirements over the years, the question remains: are our current standards adequate to protect the public health and safety from both natural and man-made disasters?

3. RAMCAP Plus® Methodology[11]

The RAMCAP® methodology and its updated version, RAMCAP Plus®, is an all-hazard risk and resilience management process for critical infrastructure. Its purpose is to identify and prioritize investments in preparedness of the nation's critical infrastructure, including protection, i.e., avoiding adverse events and their consequences and resilience, i.e., continuing to function during or rapidly returning to full function after such events.

It includes hazards due to terrorism, naturally occurring events, supply chain dependencies, product contamination, and proximity hazards. It is a general approach, expressly designed to be used by the staff and management of infrastructure facilities with limited training or access to outside expertise. It is especially effective when tailored into a sector-specific version, eight of which have been completed.[12] American National Standards based on RAMCAP Plus® have been issued for water/wastewater systems as well as higher education institutions.

RAMCAP Plus® is an objective, quantitative, and standardized approach which permits direct comparisons of risk, resilience, and the benefits of security and resilience investments. This is essential for rational resource allocation at scales ranging from assets to sectors, across sectors to regions or national economies, and across time. Looking to the future, an overarching RAMCAP Plus® standard is now being drafted as an American National Standard.

3.1 Origin and Development

Following the attacks of September 11, 2001, ASME (formerly known as the American Society of Mechanical Engineers) convened more than one hundred industry leaders, at the request of the White House, to define and prioritize the requirements for protecting our nation's critical infrastructures. Their primary recommendation was to create a risk analysis and management process to support decisions allocating resources to initiatives that reduce risk. This process would necessitate quantitative objectivity; common terminology; common metrics; and consistent processes for analysis and reporting – often tailored to the technologies, practices and cultures of the respective industries. This commonality would permit direct comparisons within and across industry sectors, scales of analysis from asset to region to nation, and time for measuring trends, measuring effectiveness and maintaining accountability. Such direct comparisons were seen as essential to supporting rational decision-making in allocating limited private and public resources to reducing risk and enhancing resilience of critical infrastructures.

In response to this recommendation, ASME assembled a team of distinguished risk assessment experts from industry and academia to develop a suitable methodology. The team defined a seven-step methodology that enables asset owners to perform assessments of their risks and risk-reduction options relative to specific attacks. A series of reviews with infrastructure executives and engineers added the design criterion: to be accepted, used and useful to personnel at facilities of concern, the methodology must be *appropriate for self-assessment by on-site staff in a relatively short period of time.* The original version was simplified and streamlined to meet this criterion.

The simplified version of RAMCAP[13] served as the basis for consistent sector-specific guidance documents for the following:
(1) nuclear power generation;
(2) spent nuclear waste transportation and storage;
(3) chemical manufacturing;
(4) petroleum refining;
(5) liquefied natural gas offloading terminals;
(6) dams and navigational locks; and
(7) water and wastewater systems.

Experience in field testing these tailored processes, the devastation of recent natural disasters, and growing appreciation of the range of threats to critical infrastructures caused the simplified process to evolve into the present RAMCAP Plus®.

3.2 Risk and Resilience Defined

Consistent with the widely held definition that risk is the expected value of the consequences of an adverse event, i.e., the combination of the event's

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[11] This section is excerpted from "Risk Analysis and Management for Critical Asset Protection (RAMCAP Plus)", Jerry P. Brashear and J. W. Jones, Wiley Handbook of the Science and Technology of Homeland Security, in press (February 2010), John Wiley & Sons, New York. Voeller, John (ed.),

[12] Sector-specific guidance based on RAMCAP have been completed for nuclear power plants, spent nuclear fuel facilities, chemical plants, petroleum refineries, liquefied natural gas storage facilities, subway systems, railroad systems, and highway systems

[13] ASME Innovative Technologies Institute, LLC, RAMCAP: The Framework, Version 2.0, ASME-ITI, Washington, D. C., 2006

likelihood and consequences, the *National Infrastructure Protection Plan*[14] and RAMCAP Plus®[15] [3] split the likelihood term into event likelihood and the conditional vulnerability, given the event:

Risk = (Threat) x (Vulnerability) x (Consequence) or R = T * V * C (Eq. 3.1)

Where

Risk = The potential for loss or harm due to the likelihood of an unwanted event and its adverse consequences. When the probability and consequences are expressed as numerical point estimates, the expected risk is computed as the product of those values.

Threat (T) = The likelihood that an adverse event will occur within a specified period, usually one year. The event could be any with the potential to cause the loss of or damage to an asset or population.

Vulnerability (V) = The probability that, given an adverse event, the estimated consequences will ensue.

Consequence (C) = The outcomes of an event occurrence, including immediate, short and long-term, direct and indirect losses and effects. Loss may include human fatalities and injuries, economic damages and environmental impacts, which can generally be estimated in quantitative terms, and less tangible, non-quantifiable effects, including political ramifications, decreased morale, reductions in operational effectiveness or military readiness, etc. RAMCAP Plus® estimates economic losses to the infrastructure owner and to the community served, respectively, and can readily be extended to state, multi-state regions or the nation.

A second, closely related concept – resilience – is not an element in the risk equation, but is central to the purposes of risk management for critical infrastructures. Resilience is defined as the ability of an asset, system or facility to withstand an adverse event while continuing to function at acceptable levels or, if functioning is diminished, the speed by which an asset can return to the acceptable level of function (or a substitute function or service provided) after the event. ***Resilience*** as a concept is still being formalized, but candidate metrics include reductions in the duration and severity of service denial and/or economic losses to the community due to service denial. For the purposes of this article, resilience is defined in different ways for the asset owner and community, respectively.

For the asset owner, the level of resilience for a particular asset/threat combination is:

Resilience $_{\text{Owner}}$ **= Lost Net Revenue x Vulnerability x Threat**
(Eq. 3.2)

For the community, the level of resilience for a particular asset/threat combination is:

Resilience $_{\text{Community}}$ **= Lost Community Economic Activity x Vulnerability x Threat**
(Eq. 3.3)

Where

Lost revenue = the product of the duration of service denial (in days) and the severity of service denial (in physical units per day) and pre-event price of the service less variable costs avoided (in dollars per unit), all of which are essential parts of estimating the owner's financial loss, i.e.:

Lost net revenue = Duration of Denial x Severity of Denial x (Unit Price - Variable Costs)
(Eq. 3.4)

and

Lost Economic Activity in the Community = the amount of decreases in both the losses of income, both direct and the indirect throughout the economy of the metropolitan region due to denial of service. It is usually estimated as a function of the asset's lost revenue and the duration of the service denial using a static application of basic regional economic data and an input-output model, modified to reflect the resilience of the respective business sectors. Impacts on the number of jobs and employment level are also

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[14] U.S. Department of Homeland Security, National Infrastructure Protection Plan, (Washington, D.C., DHS, 2006).

[15] ASME-ITI, All-Hazards Risk and Resilience: Prioritizing Critical Infrastructure Using the RAMCAP Plus® Approach (Washington, DC., ASME Press, 2009).

often estimated in the same model.[16]

The constituent elements of risk and resilience are treated as independent, single-point, "best" estimates. They are not means of underlying distributions of the estimates. More complete treatment of uncertainty and dependencies is being considered for the future.

3.3 The Seven Steps of the RAMCAP Plus® Process

The RAMCAP Plus® process is comprised of seven steps. Taken as a whole, these steps provide a rigorous, objective, replicable and transparent foundation for data-collection, interpretation, analysis, and decision-making. The figure also shows the iterative nature of the RAMCAP® process. The feedback arrows imply that the assessment of risk reduction and resilience enhancement benefits is a reiteration and modification of some or all of the same logical steps as the initial, baseline risk estimate. Enhancing security and resilience requires that the options being considered reduce consequences, including duration of service denial, vulnerability, and/or the likelihood of occurrence. The process estimates the changes attributable to a countermeasure or mitigation option.

Benefits are defined as the change in risk and/or resilience (the result of changing the elements in equations 3.1, 3.2 and 3.3). Costs include the investment and operating costs of the option. With these estimates, the net benefit (benefit less costs) and benefit-cost ratio can be used to rank the options by the magnitude and efficiency of security or resilience improvement per dollar of cost. Reductions of other consequences (e.g., fatalities) can be either converted to dollar values using the value of a statistical life, or can be maintained as a separate indicator.

The feedback arrows also imply that the process is iterated for three additional concepts:
(1) for each relevant threat for a given asset;
(2) for each asset critical to the mission of the organization; and

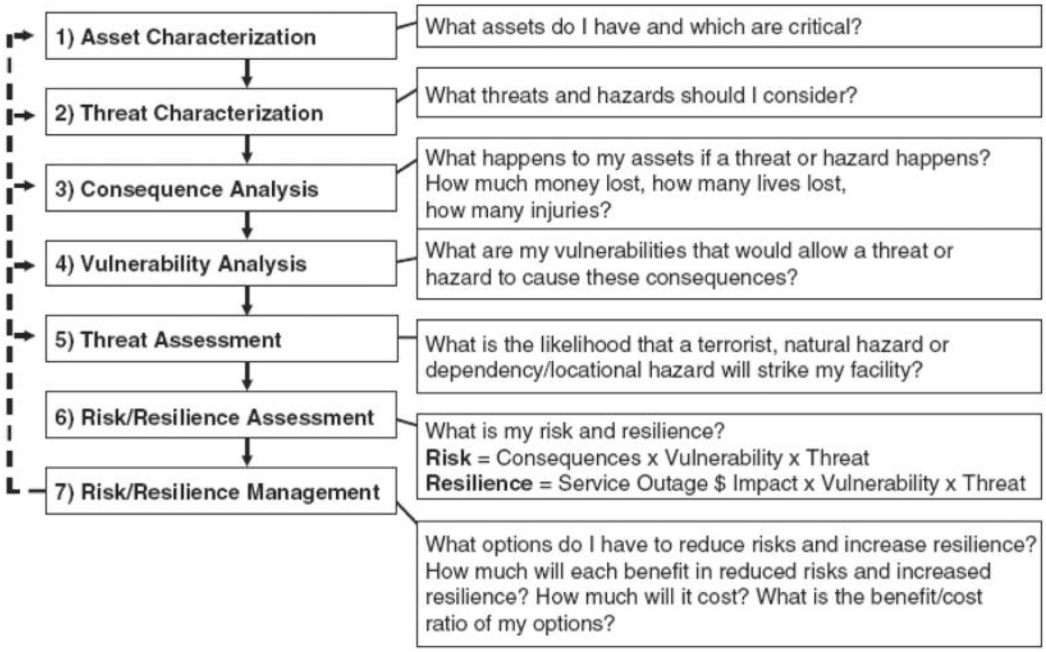

Figure 1. The RAMCAP® Plus Process

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[16] 1. Rose, A. "Economic Resilience to Disasters: Toward a Consistent and Comprehensive Formulation," in D. Paton and D. Johnston (eds.), Disaster Resilience: An Integrated Approach, Springfield, IL: Charles C. Thomas, 2006, pp. 226-48.
2. Rose, A. "Economic Principles, Issues, and Research Priorities in Natural Hazard Loss Estimation," in Y. Okuyama and S. Chang (eds.) Modeling the Spatial Economic Impacts of Natural Hazards, Heidelberg: Springer, 2004, pp.13-36.
3. Rose, A. and S. Liao. "Modeling Regional Economic Resilience to Disasters: A Computable General Equilibrium Analysis of Water Service Disruptions," Journal of Regional Science, Vol. 45, No. 1, 2005, pp. 75-112.
4. Rose, A., G. Oladosu, and S. Liao. "Business Interruption Impacts of a Terrorist Attack on the Water System of Los Angeles: Customer Resilience to a Total Blackout," in H. Richardson, P. Gordon, and J. Moore (eds.) Economic Costs and Consequences of Terrorist Attacks, Cheltenham, UK, 2007, pp. 291-316.

(3) over time as part of continuous improvement and evaluating periodic progress (e.g., annually) or as needed based on changing threat circumstances.

Step 1. Asset Characterization analyzes the organization's mission and operational requirements to determine which assets, if damaged or destroyed, would diminish the facility's ability to meet its mission. Critical assets are identified and a preliminary estimate is made of the gross potential consequences from various threats or hazards, in ordinal terms (e.g., "very small" to "very large" in five to seven intervals). The assets evaluated include those that are directly engaged in performing the most important missions or functions, the assets that support these, and the infrastructures on which they depend. These assets may include physical plant, cyber systems, knowledge base, human resources, customers, or critical off site suppliers.

Since the number of assets owned by an organization can be substantial, the assessment team conducts an initial ranking to identify the high priority assets, screening out the rest. The term "asset" means components of an organization's system.

The assets that directly perform the organization's mission are usually fairly obvious, but the assets and systems on which they depend may be less so. For example, a water plant has systems through which water flows for treatment and distribution and many of these are critical, but these systems require electricity, chemicals, automated monitoring, water testing, skilled labor, etc., which can also be critical because the assets directly performing the mission cannot operate without them.

The supporting assets, in turn, may be dependent on yet other assets, which are then seen as critical, e.g., the electricity substation from which the plant draws its power. Whenever an alternative source of critical support is independently available, the supporting asset may not be critical, e.g., an emergency generator with sufficient fuel to last through an event would make the substation non-critical. Non-critical assets are not considered further.

Step 2. Threat Characterization is the identification and description of reference threat scenarios in enough detail to estimate vulnerability and consequences. As summarized in Table 1, there are a wide variety of threat scenarios. Each is specified in more detail in actual application.[17]

One key to comparability of results is the use of a common set of reference threats. These threat scenarios are not "design basis threats," which imply that the organization must take steps to withstand the threat to continue operations. Rather, these are "benchmark" or "reference" threats that span the survivable range of possible threats across all critical infrastructure sectors. Five distinct types of reference threats have been defined:

1. Terrorism – attacks by enemies, as suggested by the DHS based on analyses by the Department and others as an understanding of the means, methods, motivations and capacities of terrorists.

2. Natural hazards – currently includes hurricanes, floods, tornadoes and earthquakes, based on the physical location of the facility and federal data.

3. Product or waste stream contamination – suggested by the water sector and also applicable to food and pharmaceuticals, to address concerns of intentional or accidental contamination.

4. Supply chain hazards – immediate dependencies, mostly supply chain issues such as suppliers, labor, customers, etc., included as an initial step toward dealing with dependencies on other organizations for critical elements of the organization's mission.

5. Proximity hazards – potential to become collateral damage from events at nearby sites.

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[17] Ibid. ASME-ITI, All-Hazards Risk and Resilience.

Table 1. Summary of RAMCAP *Plus*® Reference Threat Scenarios

Attack Type	Tactic/Attack Description			
Marine	**M1** Small boat	**M2** Fast boat	**M3** Barge	**M4** Deep draft shipping
Aircraft	**A1** Helicopter	**A2** Small Plane (Cessna)	**A3** Medium, Regional Jet	**A4** Large Plane Long-Flight Jet
Land-based Vehicle	**V1** Car	**V2** Van	**V3** Mid-sized Truck	**V4** Large Truck (18 wheeler)
Assault Team	**AT1** 1 Assailant	**AT2** 2-4 Assailants	**AT3** 5-8 Assailants	**AT4** 9-16 Assailants
Sabotage	**SP(PI)** Physical-Insider	**SP(PU)** Physical-Outsider	**SP(CI)** Cyber-Insider	**SP(CU)** Cyber-Outsider
Theft or Diversion	**T(PI)** Physical-Insider	**T(PU)** Physical-Outsider	**T(CI)** Cyber-Insider	**T(CU)** Cyber-Outsider
Product Contamination	**C(C)** Chemical	**C(R)** Radionuclide	**C(B)** Biotoxin	**C(P)** Pathogenic
	C(W) – Weaponization of waste disposal system			
Natural Hazards	**N(H)** Hurricanes	**N(E)** Earthquakes	**N(T)** Tornadoes	**N(F)** Floods
Dependency & Proximity Hazards	**D(U)** Loss of Utilities	**D(S)** Loss of Suppliers	**D(E)** Loss of Employees	**D(I)** Loss of Customers
	D(T) – Loss of Transportation		**D(U) –** Proximity to other targets	

The organization decides which of the defined scenarios represent physically possible or improbable threats for the facility. For those threats which are possible, the organization should summarily assess the consequences of a successful attack by each threat against each asset defined as critical earlier. A convenient way to do this is to array a matrix of the critical assets identified in the first step versus the possible threats and estimating ordinally according to a five- or seven-point ordinal scale (e.g., very low, low, moderate, high and very high). The sequence by which asset/threat pairs will be analyzed is to examine the highest ranked pairs and proceed to lower ranked pairs until the consequences are acceptable.

Step 3. Consequence Analysis is the identification and estimation of the *worst reasonable consequences* generated by each specific asset/threat combination. This step examines facility design, layout and operation in order to estimate fatalities, serious injuries and economic impacts. RAMCAP Plus® defines "economic impacts" for risk management at two levels: (1) the financial consequences to the organization; and (2) the economic consequences to the regional metropolitan community the organization serves. Economic consequences for communities larger than the metropolitan area, e.g., the state, multi-state region or the nation, may also be estimated, using the same methods, as needed by decision-makers. For many critical infrastructures and facilities, interdependencies make the metropolitan region most relevant to decision-makers.

Financial consequences to the organization include all necessary costs to repair or replace damaged buildings and equipment, abandonment and decommissioning costs, site and environmental clean-up, net revenue losses (including fines and penalties for failing to meet contractual production levels, but excluding avoided variable costs) while service is reduced, direct liabilities for casualties on and off the property, and environmental damages. These costs are reduced by applicable insurance or restoration grants and must be corrected to account for tax effects for tax-paying organizations.

The primary concern for the public or community is the length of time, quantity and sometimes quality of critical service denied, and the direct and indirect economic consequences of service denial.[18] When the service denial is short and/or customers are able to cope by such actions as conservation, substitution, redundancies, making up lost production later, the region is said to be "resilient".[19] The public's objective is to enhance the resilience of critical infrastructures on which they depend.

RAMCAP Plus® estimates the direct and indirect losses to the regional community by a modified input-output algorithm. While recognizing the classical critiques of input-output modeling of a major disruption of critical infrastructures, it remained necessary to quantify at least roughly the community impact to guide public choices. To minimize the methodological problems without adding inordinate complexity, RAMCAP Plus® adopted a model originally developed to fill a gap in the computational ability of Hazards United States - Multi-Hazard (HAZUS-MH),[20] the Federal Emergency Management Agency's (FEMA) loss estimation software referred to as a "HAZUS patch."[21] The algorithm can be applied to any estimate of infrastructure service disruption to compute direct and indirect losses of regional output, income and jobs.

Other consequences are identified and described qualitatively and include impact on iconic structures, governmental ability to operate, military readiness, citizen confidence in the organization, product, or the government.

Step 4. Vulnerability Analysis estimates the conditional likelihood that the estimated consequences will occur, given the occurrence of the specific threat or hazard. Vulnerability analysis involves an examination of existing security capabilities and structural components, as well as countermeasures and their effectiveness.

A variety of rigorous tools can be used to estimate vulnerability, such as those described in Table 2. In some RAMCAP® sector-specific applications, direct elicitation often seems to be easier and less time-consuming, but the time to reason through each threat/asset pair can lead to long discussions and it is difficult to maintain logical consistency across a number of such judgments. Some RAMCAP® sector-specific guidance documents provide pre-specified structure of vulnerability logic, and event or decision trees for users to populate with estimates of the required elements to enhance comparability and reliability.

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[18] Ibid. Rose "Economic Resilience to Disasters" and "Economic Principles, Issues, and Research Priorities in Natural Hazard Loss Estimation."

[19] Ibid. Rose and Liao, "Modeling Regional Economic Resilience to Disasters: A Computable General Equilibrium Analysis of Water Service Disruptions."

[20] Ibid. Rose, Oladosu, Liao. "Business Interruption Impacts of a Terrorist Attack on the Water System of Los Angeles: Customer Resilience to a Total Blackout."

[21] FEMA, "HAZUS-MH: Multi-Hazard Loss Estimation Methodology," (Washington, D.C., National Institute of Building Sciences, 2006) and Multi-Hazard Mitigation Council, "The Benefits of FEMA Hazard Mitigation Grants," (Washington, D.C., National Institute of Building Sciences, 2005).

Table 2. **Frequently Used Vulnerability Tools**

Method	Description
Direct Expert Elicitation	Members of the evaluation team discuss the likelihood of success and their reasoning for their estimates; in its more formal form, a statistical "Delphi" processor Analytical Hierarchy Process can be used to establish a consensus
Vulnerability Logic Diagrams (VLDs)	Plot of the flow of events from the time an adversary approaches the facility to the terminal event in which the attack is foiled or succeeds, considering obstacles and countermeasures that must be surmounted, with each terminal event associated with a specific likelihood estimate. This is frequently complemented with an estimate of the reaction time of a counterforce once the attack has been detected
Event Trees (also called "failure trees")	Tree with branches representing the sequence of events between the initiation of the attack and the terminal events The evaluation team estimates the probability of each outcome. Multiplying the probabilities along each branch, from the initiating event to each terminal event, calculates the probability of each unique branch, while all branches together sum to 1.0. The sum of the probabilities of all branches on which the attack succeeds is the vulnerability estimate.
Decision Trees	Very similar to event trees except that the decisions by the adversary are modeled at each node in the unfolding tree to capture the adaptive behavior of the adversary; a sophisticated variant is to conceive the tree as a two-player game
Hybrids of These	Often used by the more sophisticated assessment teams

Step 5. Threat Assessment estimates the probability that a particular threat – terrorist, natural, contamination, dependency, or proximity – will occur in a given timeframe (usually one year). The approach differs depending on the type of hazard, as characterized in Table 3.

Terrorism likelihood (and its contribution to contamination, proximity, and even dependency hazards) is the most difficult to estimate and is still being refined. In its most advanced formulation, it recognizes that terrorists are cognizant, near-optimizing adversaries in a contest perhaps best modeled by game theory. Because of RAMCAP's® specification to keep the process simple and brief, however, simpler techniques of approximation based on observable or previously estimated factors are used. RAND Corporation has contributed relative likelihood of attack based by metropolitan region and asset type.[22]

The previously estimated conditional risk (consequences times vulnerability) aptly characterizes the expected value to the terrorist of the asset/threat pair, while the asset's size and prominence relative to other assets of the same type in the region can indicate attractiveness. The adversary might also consider the likelihood of pre-attack detection and the "cost" in resources.

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[22] Willis, H., LaTourrett, T., Kelly, T., Hickey, S., Neil, S., "Terrorism Risk Modeling for Intelligence Analysis and Infrastructure Protection, (RAND Center for Terrorism Risk Policy, 2007).

Table 3. Estimation of Hazard Likelihood

Hazard Type	Likelihood/Probability Estimation
Terrorist Attack	Based on the terrorists' objectives and capabilities, generally (provided by intelligence and law enforcement agencies), and the attractiveness of the facility relative to alternative targets, the asset's expected value (vulnerability x consequences), and the cost/effectiveness of the attack.
Natural Hazards	Based on the historical federal frequency data for various levels of severity at the specific location of the asset. Can be adjusted if there is reason to believe that the future frequency or severity will differ from the past.
Dependency Hazard	Based on local historical records for the frequency, severity and duration of service denials as a baseline estimate of "business as usual," incrementally increased if they may be higher due to terrorist activity or natural events on required supply chain elements. Confidential conversations with local utilities and major suppliers can inform these estimates.
Product Contamination	Treated the same as terrorism and dependency likelihood, except additional consideration is given to accidental contamination of inputs and the vulnerability of critical processes to accidents.
Proximity Hazard	Based on asset's location relative to other assets that may incur adverse events leading to collateral damage, using the same logic in estimating terrorist and natural hazard threats.

Two additional analyses can assist in appraising the realism of this approach to terrorism likelihood:

1. *Comparison of terrorism risk with natural hazard risk* uses a natural hazard risk that is accepted by the organization to deduce a terrorism threat likelihood equating the two risks. The analyst and decision-maker then judge whether the deduced likelihood is reasonable or not. If the likelihood in the deduced risk is equal to or less than the judged reasonable level, then the terrorism risk is as tolerable as the natural hazard risk and the likelihood is moot. If, on the other hand, the likelihood in the deduced risk is greater than the accepted level, the judgment of the reasonable level sets a minimum and the asset/threat pair's risk justifies taking the next steps.
2. *Investment break-even* assumes the decision-maker's choices are simple "go/no-go" on individual options. This method can only be applied as part of Step 7 because it requires the calculation of a baseline risk, conceptual design and cost estimation of an investment option to materially reduce the risk, and an assessment of the risk with the option in place. Given the re-estimated consequences and vulnerability and the option cost, the calculated "break-even" likelihood is the one that yields a net benefit of exactly zero and a benefit-cost ratio of 1.0. The decision-maker can then judge whether the "break-even" likelihood is plausible or not. If the decision-maker believes the actual likelihood exceeds the break-even, the option has value and results in a "go" decision, and vice versa.

Step 6. Risk and Resilience Assessment creates the foundation for prioritizing and selecting among risk-reduction and resilience enhancement. The risk assessment step is a systematic and comprehensive evaluation of the previously developed estimates. The risk for each threat for each asset is calculated from the risk relationship expressed in Equation 3.1, above.

Resilience, the ability to function despite and during a traumatic event or to restore functionality in a very short time, is defined in different ways for the asset owner (Equation 3.2) and community (Equation 3.3), respectively, for each asset/threat pair.

Step 7. ***Risk and Resilience Management*** is the step that actually reduces risk and increases resilience. Having determined the risk and resilience of each important asset/threat pair, this step defines new security countermeasures and consequence mitigation resilience options and evaluates them to achieve a portfolio that yields an acceptable level of risk and resilience at an acceptable cost. The ten actions described in Table 4 constitute this crucial step.

In essence, the value or benefit of the options is estimated by re-visiting Steps 3, 4 and/or 5 and re-estimating the (reduced) threat likelihood, vulnerability or consequences to calculate a new risk and resilience with the option in place. The reduction

Table 4. Risk and Resilience Management Actions

Act. No.	Activity
1. Acceptance Level	Establish whether the risk/resilience level is acceptable.
2. Design	Design potential countermeasures and consequence-mitigation options that would reduce risk and/or enhance resilience.
3. Cost	Estimate the investment and operating costs of each option.
4. Re-estimation	Re-estimate consequences, threat likelihood and/or vulnerability, whichever is affected by the option.
5. Benefits	Re-calculate risk and resilience, given the option, and subtract it from the risk without the option (the “do nothing” baseline option) to define the benefit of the option.
6. Combinations	Combine the options that affect multiple asset/threat pairs, e.g., if a higher fence changes the vulnerability for an attack by one assailant, it may do the same for two to four. Add the benefits of the asset/pairs to be the total benefit of the option.
7. Key Metrics	Calculate the net benefits (less costs) – value – and the benefit/cost ratio – efficiency – of the option.
8. Rank & Select	Select the options that have the highest net benefits and/or benefit/cost ratios and the lives saved and injuries avoided, considering both risk and resilience until resources are fully committed (less any reserved amounts).
9. Manage	Manage the implementation and operation of the selected options, evaluate their effectiveness and make mid-course corrections for maximum effectiveness.
10. Recycle	Repeat the risk analysis cycle periodically or as needed given intelligence or changing circumstances, e.g., new technologies, new facilities.

in risk and the increase in resilience are the benefit or value of the option, which can be compared to the cost of implementing it and to the benefits of other options. Taking no action is always a baseline option against which all others are compared.

Net benefits measure the magnitude of the value added by the option, while the benefit/cost ratio measures of the amount of risk reduction per unit of cost, an efficiency test. For fatalities and serious injuries, examine the gross reductions and the expected number required to make the needed trade-offs. The full set of options should be as a portfolio to establish if equity and balance are maintained. Allocate the resources – financial, human and other resources are allocated to implement and operate the selected options.

Choices among the options are virtually never made with a single metric, but rather a set of difficult trade-off decisions must be made. Some organizations apply explicit preferences to establish an initial portfolio of options and then adjust the selections as needed to balance the portfolio or program of risk-reduction and resilience-enhancement measures. It is common to estimate a "value of statistical life" to roll human casualties into the dollar-denominated benefits. When this is done, RAMCAP Plus® calls for displaying the casualty estimates separately as well for decision-makers to consider.

Once these decisions are made, risk management extends to implementation of the chosen options, monitoring their effectiveness and taking corrective actions as needed. The risk management process is the essential part of continuous security and resilience improvement, repeated periodically (e.g., annual budget process) or as necessitated by changes in the threats, vulnerabilities, consequences, technologies or the evolving development of the organization's systems.

In addition to investing in these options, risk can also be managed by acquiring insurance, entering into cooperative agreements, or simply accepting the calculated risk when it compares favorably with other risks such as financial or investment alternatives. Ideally, the organization would consider all these risk-reduction and resilience enhancement options collectively as a mixed portfolio of risk and resilience management.

3.4 Benefits of Using the RAMCAP Plus® Process

Use of the RAMCAP Plus® process generates a number of benefits or advantages to the organization using it, the sector or industry that adopts it, the communities served, and the public policy toward infrastructure security and resilience. These are summarized in Table 5.

Several of the entries in the table mention benefits that occur if the process becomes a voluntary consensus standard. As this report is being written, two voluntary consensus American National Standards based on RAMCAP Plus® have been approved for water systems and higher education institutions and a third overarching standard applicable to any asset-based industry is under review. These standards and others that will follow provide for continuous improvement of the process – while maintaining consistency and comparability. They cost the federal government little or nothing other than perhaps development because they are maintained by volunteers in officially designated standards development organizations, of which ASME and ASME-ITI are recognized. These benefits result in dynamic, effective risk and resilience management – driven by the private and public infrastructure organizations in true partnership with all other stakeholders' interests, including public and non-profit concerns. In summary, use of the RAMCAP Plus® process yields significant benefits to the asset owners and industries who use it, to the communities they serve, and to the local, regional and/or national economies to which they contribute.

Table 5. Benefits of Using RAMCAP Plus®

Beneficiaries	Benefits
Infrastructure Organizations	• Cost-effective enhancement of security and resilience • Rational allocation of resources across assets, facilities, sites, and lines of business • More efficient management of capital and human resources • Consistently quantified risk and resilience levels, potential net benefit and benefit-cost ratios of investment options • Repeated application over time measures progress and trends while enabling accountability for execution • Enhanced reliability in performance of the mission • Ability to define risk and resilience levels quantitatively at the community level enables partnering with other firms and public agencies for large-scale solutions • If adopted as industry voluntary consensus standard, it becomes the vehicle for incentives, such as preferred supplier status, lower insurance costs, higher credit ratings and lower liability exposure

Whole Industry or Sector	• Ability to identify the assets with the greatest need and value of improvement
	• Cross-facility comparisons reveal industry-wide vulnerabilities for collective action (e.g., R&D, new technology, standards)
	• Direct comparison of the sector's risk and resilience level to other sectors for higher level resource allocation and policy-making
	• If sector-specific guidance becomes a consensus standard, additional benefits can be incurred, e.g.:
	    • preferential treatment by insurers, financial rating services and customers
	    • potential affirmative defense in liability cases
	    • able to substitute self-regulation by standards for bureaucratic regulation, and direct participation in federal regulatory, procurement or other federal actions

The Metropolitan Regional Community	• Able to estimate value of security and resilience investments to the region, a salient criterion in both private and public decisions • Consistent terminology provides common language for meaningful dialogue between private organizations and government agencies • Identification and valuation of "public goods" and shared-benefit programs; encourages public-private partnerships • Cooperative decision-making based on comparability of risk, resilience and benefit estimates for rational regional trade-offs • If consensus standards become available, communities can designate the standards as the local codes of expected practice • Repeated application over time measures progress and trends while enabling accountability for regional execution

Table 5 (cont'd). **Benefits of Using RAMCAP Plus®**

Beneficiaries	Benefits
State, Multi-State Regions and/or Federal Agencies	• All the metro regional community benefits, above • Consistency, transparency, and direct comparability needed to evaluate major public infrastructure and program investments • Methods used to estimate economic losses to metropolitan regions can be extended to whatever scales are relevant to the decisions to be made – states, multi-state regions or the national economy – in the same, directly comparable terms • Allocate resources rationally to maximize the security and resilience enhancement within a finite budget • If consensus standards are developed, the industry can self-regulate with public compliance audits; maintenance of the standards costs government nothing – *for as long as there is demand for the standard*

4. MIAN Risk Methodology

4.1 Basic Approach

The use of the RAMCAP Plus® methodology for the MIAN project requires some modification of the basic seven-step process for many scenarios of interest. RAMCAP® was originally developed in response to the need for critical infrastructure protection. Initial applications of RAMCAP® were designed for assessing the risk due to terrorist attack on infrastructure targets, i.e., infrastructure such as nuclear power plants, chemical plants, dams, navigational locks, water treatment plants, and other fixed assets.

In some cases, for example nuclear plants, a successful attack on the plant could result in consequences to surrounding population and other infrastructure components. However, the destruction associated with damage outside the fence was included as part of the consequences of an attack on the primary target or as a continuation of the initiating event. Cascading effects, such as loss of revenue, deprivation of plant output, or loss of use of the affected adjacent real estate were included in the overall assessment, but these effects emanated from the initiating event. The asset or the plant/ infrastructure component, however, was the target of the attack. MIAN facilities, on the other hand, may not necessarily be the primary target. MIAN facilities simply maintain the materials that could be sought for use at a different location or target.

Another significant difference between the MIAN procedure and RAMCAP Plus® is that the probability of an event occurring in a given year is assumed to be unity (1.0). The primary purpose of this current project, however, is to evaluate the relative risk resulting from the acquisition and deployment of radioactive materials. Presumably, a terrorist would attempt to maximize the consequences of his/her actions and decide to perpetrate an event that would pose the highest risk to the adversary. Rather than attempt to assign a value for likelihood to each event considered for analysis, it is more convenient to assume all events have the same likelihood of being attempted and calculate the conditional risk for comparison. Thus, MIAN risk assessments are “normalized” by initially assuming equal likelihood. Once all events of interest are evaluated (assuming that is actually possible given the almost infinite number of permutations), then a “true” risk can be estimated by multiplying the conditional risk by the probability of occurrence. The “true” risk can then be compared to other risk assessment results.

The MIAN assessment methodology requires additional steps to determine both the consequence and the probability of success for a terrorist attack. (Operational accidental incidents and natural hazards will be discussed later.) In many of the terrorist scenarios that are considered, the location or facility that contains the radioactive material is not the “target” of the attack. For example, radioactive material used for well logging or radiography may be located in a relatively rural area, remote from high population areas or extensive infrastructure. The terrorist “attacks” the facility only to obtain the radioactive material with intent to utilize it at another location that will produce higher monetary consequences, human fatalities, serious injuries, or psychological effects. Thus, the initial “attack” is only a first step in the overall scenario. It is necessary to capture the overall risk for a scenario, thus, the additional steps must be included in the risk assessment. This is accomplished by including additional terms in the basic risk equation. These include the probability of interdiction and the probability of success of deploying the material to achieve the assumed worst-case consequences.

Consider the term for interdiction. For the purposes of this analysis, it is assumed that the probability of obtaining the material at the initial attack location includes the potential for interdiction at the initial site of the attack. For example, if the terrorist attempts to steal material from a laboratory and mounts an armed attack using firearms, it is assumed that the probability of success of obtaining (Po) includes the probability of finding the material, defeating all security measures, including armed guards and gaining egress from the building with possession of the material. Once out of the building, the process of formal interdiction assessment begins.

Interdiction probability is defined as the probability of stopping the attacker(s) before they can reach the site of the planned attack with the material and the opportunity to deploy. There is a remaining question of whether the attackers are captured, the material is recovered, or both. However, for the purpose of calculating the probability of interdiction for a particular scenario and estimating the overall risk for that scenario, it is sufficient to determine only the probability of stopping the perpetrators from reaching the attack site with the material and the opportunity for deployment. Thus, the "stopwatch" on the interdiction continuum begins when the attackers leave the site after successfully obtaining the material and stops when they reach the target site "with opportunity to deploy." Further, a "dirty bomb" or RDD, may not be the intended deployment. The terrorists may decide to hide the material, use it to contaminate food/water supplies, or deploy it in public places for exposing members of the public to dangerous, perhaps fatal, levels of radiation.

The assessment of accidents and incidents caused by natural events, such as hurricane, tornado, flood, fire and earthquake, will not include a term associated with interdiction. Further, in these cases, the storage site of the material becomes the "target" of the event. Since radioactive materials are almost always contained in protective containers that are very robust, there is only a small probability of causing high consequences that are of the same order of magnitude as those caused in terrorist events. Another ameliorating effect inherent in natural and accidental events is that the form of the material is normally unaltered by the event; thus, the material remains intact, is easy to detect, and is readily removed from the site.

Since the storage or use site is the "target" of the accidental/natural hazard event, the consequences are normally expected to be quite low. Further, the public risk tolerance toward such events, and even release of small quantities of radioactive materials, is expected to be much higher than if the event were caused by a terrorist, especially when the threat of additional attacks cannot be ruled out. The psychological effect of a premeditated release of radioactive material cannot be overstated. Since there have been few major releases of such material, the only examples that might be used to gauge public reaction are the Chernobyl and Three Mile Island events. Both events had a profound effect on the acceptance of nuclear power. Chernobyl, of course, was far worse regarding physical consequences. However, the Three Mile Island event arguably changed the course of the nuclear power industry in this country.

Given the relatively small amount of material actually released, it is conceivable that a terrorist attack that utilized radioactive material could have an effect at least as great as Three Mile Island and perhaps even greater. It is difficult to predict public reaction to such an event. It would be interesting to calculate the cost of September 11, 2001, considering the additional security worldwide, the loss of time associated with security checks at the airport and other cascading costs including airline losses, bankruptcies, and other services. Would an attack on public transportation such as subways, for example, result in passenger security screening?

When considering accidents or natural hazards, the site where the material is stored is the focus of the risk assessment. The standard RAMCAP Plus® methodology is employed. Natural hazard assessment is preformed in exactly the same way as the methodology is used for all other target or asset-based assessments. The asset considered is the facility at which the material resides and the attack scenarios are the various natural or accidental events that can occur at that location. The radioactive material is considered to be the focus of the event.

Consequences of these events primarily involve release of material and/or exposure to personnel. Clean-up costs and loss of use of the facility are included in the consequences. Secondary or cascading effects are considered. However, natural or accidental hazard events are not likely to result in or create undue panic or concern outside of the local area.

A terrorist event has the potential to create panic and disrupt the conduct of business as usual, thus resulting in far higher consequences than a naturally-occurring or accidental event. A terrorist event involving MIAN materials typically requires several steps to achieve. The terrorist must obtain an appropriate form of material, avoid interdiction, and deploy the material at a different site in order to achieve a high-consequence event. A major difference between a natural/accidental event and a terrorist event is that the site at which the radioactive material resides is seldom the target of a terrorist attack. Thus, it is necessary to consider terrorist risk assessment in three distinct steps.

Step 1 consists of acquisition of the material from a source. Radioactive materials are available from thousands of possible sites throughout the United States, as well as from sites in foreign countries, especially those that may support terrorist activities.

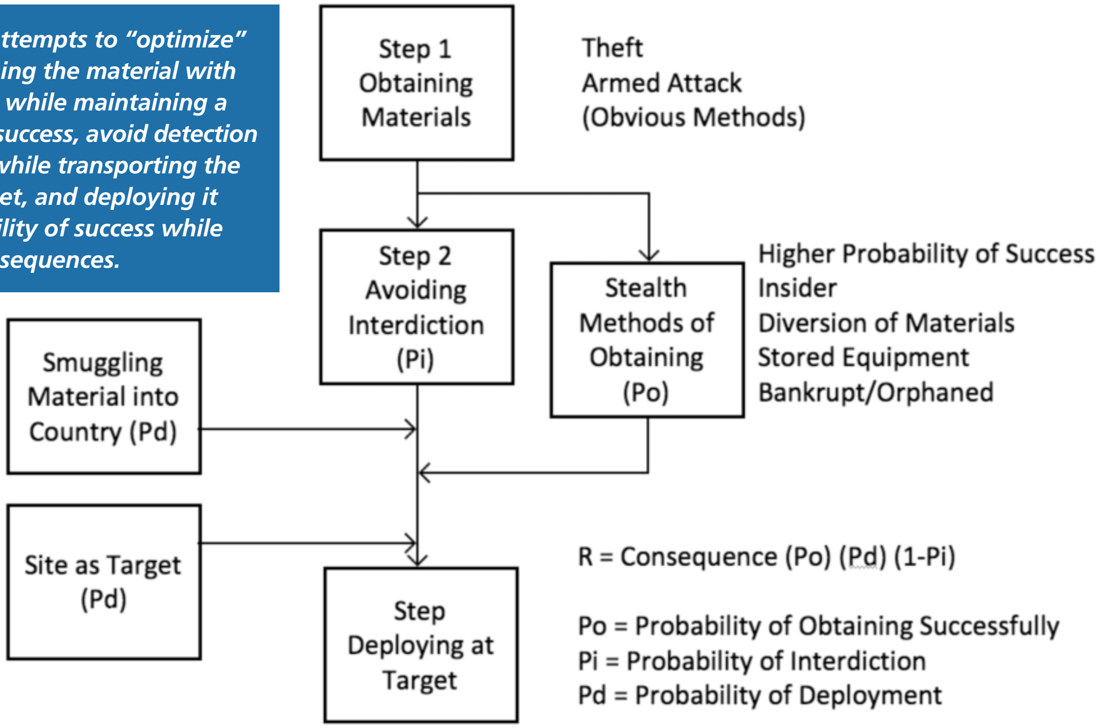
Table A-2 in Appendix A provides a list of materials that are considered to rise to the level of concern and a discussion of how these materials can be obtained. Historically, it has been assumed that some materials were "self protected," since the material itself would cause significant injuries or death if handled without proper shielding. However, it has recently been demonstrated that religious zealots are willing to risk bodily injury or death to carry out their terrorist missions. Thus, it must be assumed that danger to the perpetrator will not deter a terrorist organization.

If material is obtained without the knowledge of law enforcement, then the terrorist has a much higher probability of successfully deploying the material and achieving the maximum possible consequence. If theft or unauthorized removal of radioactive material is discovered immediately, law enforcement agencies have a much greater probability of interdicting the terrorist. Thus, the overall probability of success for the terrorist is greatly increased by stealthy acquisition. Materials obtained from sources that are not monitored frequently, such as storage locations or university repositories, may be deployed before the theft is discovered. Smuggled materials likewise pose an increased threat. Another scenario that must be considered is accumulation of material from more than one source. IC is required when the amount of material exceeds the limits defined by the NRC. The same materials can be obtained from two or more sites that have much less security and combined to achieve a quantity that exceeds the IC level.

Step 2 is to avoid interdiction by authorities before the material can be deployed. When material is obtained and the authorities are aware of the event, every effort will be made to apprehend the terrorist and recover the material. The probability of interdiction will reduce the overall probability of successful terrorist deployment. Once radioactive material is obtained and the law enforcement agencies are alerted, there is little that can be done by the general public to increase the probability of interdiction before the material is deployed. Alerting the public that material is missing and that a terrorist plot to deploy the material is suspected may result in large economic consequences. The terrorist ends can be achieved through the use of credible threats to deploy the material and expose the public to radiation.

Step 3 is to deploy the material in a DRD in such a manner as to have the maximum reasonable consequence. Table B-3 provides a discussion of how various isotopes can be deployed and an estimate of consequences.

Thus, the terrorist attempts to "optimize" the event by obtaining the material with minimum resources while maintaining a high probability of success, avoid detection and apprehension while transporting the material to the target, and deploying it with a high probability of success while maximizing the consequences.



Securing an amount of radioactive material that is large enough to be of concern is tantamount to obtaining a weapon for a contemplated attack. Clearly, multiple groups can be employed in such an operation. One group obtains the material, one transports it to the target, and another deploys.

Another possible scenario that must be considered is the case in which the radioactive material residence site would be the target of the attack. Consider a site containing radioactive materials that could be weaponized by an explosion at the site. For example, assume an irradiation facility attack using a truck bomb in order to cause release of the material in the explosion or a subsequent conflagration. This attack scenario can be addressed by the existing RAMCAP Plus® methodology. The facility is the asset and the attack scenarios are contained in the standard threats considered by RAMCAP Plus®.

Additionally, in an attack on an existing facility, the direct consequences are limited to the area near the facility. Of course there will be cascading effects because of the attack. However, it can be reasoned that cascading effects are proportional to the consequences of the initiating event and all events will have cascading effects. The highest overall risks will result when a device is deployed in locations that have the potential for causing the greatest consequences. This is seldom, if ever, the location of sources of radioactive materials. Additionally, RAMCAP Plus® considers all hazards when calculating risk. The site containing the material should also be evaluated for natural hazards to determine the total risk.

The MIAN Risk Assessment Methodology (RAM) begins with selecting a facility for evaluation that contains radioactive material. It is assumed that the user of MIAN RAM is the owner or operator of the facility. MIAN RAM is a self-assessment tool for the owner/operator. Nine potential sources of material have been identified.

1. Field Sources - Radiography sources, well logging sources, etc.
2. Nuclear Pharmacy - Locations that provide stores of radioactive materials for legitimate buyers.
3. Medical Facility - Used for treatment or diagnosis.
4. Irradiation Facility - Medical and food and packaging sources.
5. Universities - Research materials, test reactors,
6. Research Laboratory - Research materials
7. Stored Equipment - Any type from above that has been taken out of service.
8. Bankrupt/Abandon - Sites that have no viable owner or caretaker.
9. Industrial Facilities - Large gauging and radiography devices.

Table A-2 of Appendix A provides a discussion of radioactive materials of concern, the use and location of the material, and typical scenarios that should be considered for obtaining the material.

Table A-3 of Appendix A provides a discussion of how each material of concern could be used in a terrorist attack and the probability of success.

4.2 Detailed Assessment Methodology

As stated above, the site owner/operator will be responsible for assessing the location where radioactive materials are used and/or stored. The first step is to determine if the site contains one or more materials that are listed in Table A-1 of Appendix A and in quantities that rise to the level of concern. This step is essentially a screening tool that will provide the assessor with a list of materials that should be considered for further assessment. Additional guidance is available in IAEA-EPR-D-Values, "Dangerous Quantities of Radioactive Material."[24] This report defines a D value as the quantity of radioactive material which is considered a dangerous source. A dangerous source is one that, if uncontrolled, could result in death or a permanent injury which decreases the affected person's quality of life.[25]

Having compiled this list of site materials, the next step is to determine all possible methods that could be employed by a terrorist to obtain the materials. For this evaluation, it should be assumed that the terrorist is willing to risk his/her life to achieve the goals. The fact that the material could be harmful to the perpetrator should not be assumed a sufficient deterrent. The most likely methods of obtaining the material (Po) should be listed in the spreadsheet starting with the highest probability of success and considering all reasonable scenarios. For example, material could be obtained by armed attack, theft, or insider diversion. Each of the possibilities should be listed of each material on site. If it is assumed that an armed attack provides the highest probability for success, this will have the highest ranking for the site for that material.

An armed attack, however, will undoubtedly trigger an extensive search for the terrorists and attempts to recover the material. A stealth attack, such as theft by an insider, could go unnoticed for enough time that the terrorists could transfer the material to the target and execute the attack. This scenario could therefore have the highest overall probability of success since the probability of interdiction would be minimal and there would be no warning that could prevent the attack on the target. It is important to consider all modes of obtaining the material.

The above processes are repeated for all materials of interest. The site owner/operator is not responsible for determining the probability of success of interdicting the terrorist or the consequence level. This is beyond the scope of the facility assessor. The risk assessment for this scenario can be continued by law enforcement, homeland security, or any other knowledgeable evaluator as necessary. Having determined that a specific material or quantity of materials can be obtained from the particular site being evaluated, the risk to the public can now be estimated. The information obtained from the site operator is used to estimate the maximum reasonable consequence that could be caused by the deployment of the material. The remaining parameters in the risk equation are determined by the risk assessor.

References to consequences from exposure to radioactive materials normally emphasize the health effects. When considering the use of radioactive materials for terroristic activities, other considerations would be distraction and long-term denial of access or infrastructure. The terrorists' plans may include all outcomes. When outcomes are viewed separately, it becomes apparent that some radionuclides can be more damaging when used for one activity than the other.

As a general rule, the alpha-emitting radionuclides, when inhaled, ingested or otherwise incorporated into the body, will deliver higher doses than the same activity of gamma- or beta-emitting radionuclides. Some high-energy, beta-emitting radionuclides may also deliver very high doses when taken into the body. The reader is advised that these are general rules of thumb and the dosimetric consequence of any intake of radioactive material should be routinely reviewed and verified before taking protective measures. In general, gamma- and beta-emitting

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[24] IAEA, "EPR-D-Values 2006, Dangerous Quantities of Radioactive Material (D-Values), (Vienna, 2006).

[25] Ibid., p. 12.

radionuclides pose a greater hazard as an external source of radiation. Doses do increase if a gamma-emitting radionuclide is taken into the body due to beta and other radiations which are often emitted by them. These doses rarely rise to the dose levels that equal activities of internally deposited alpha-emitting radionuclides will produce.

Whether the intention of a terrorist is to cause injury to people or to deny access, the controlling parameter in recovery is dose. The magnitude of dose to an individual or group of individuals will determine the number of deaths and debilitating injuries. The levels of radioactive contamination in debris and on surfaces of still useful structures and equipment will determine the potential doses to the workers. The dose rates will limit the duration of exposure to the workers. This will increase the length of time and cost of recovery.

Numerous factors must be considered in determining the dose from a particular radionuclide:

- The quantity of radioactive material;
- The type(s) of radiation it emits;
- Whether it is inside or outside the body;
- If radioactive material is inside the body, the isotope's radiological and biological half-lives, the effective half-life, determine the length of time the radioactive material will remain inside the body and expose the individual;
- The radioactive isotope's specific activity (number of becqerels/curies per gram). As the specific activity of a radionuclide increases, the physical amount (grams) of that radionuclide that equals a Curie will decrease;
- If inside the body, route of entry (ingestion, inhalation, wound contamination, etc.) will also play a role in determining dose;
- The chemical form of the material and its solubility (transportability in extra-cellular fluids, plasma and blood) will determine in what organs or tissues it will tend to concentrate (pharmacokinetics);
- Mass of the organ or tissue can have significant dosimetric consequence since dose is directly proportional to the concentration of the radionuclide in units of radioactivity per unit mass of the organ, i.e., the same amount of radioactivity in a small organ will produce a higher dose to that organ than to a larger one;
- Function of the organ or tissue. The function of the organ determines what compounds or elements it may use. If an organ utilizes or concentrates a specific element or compound containing that element and the material introduced into the body contains a radioactive isotope of that element or compound containing a radioactive isotope of that element, then the organ could receive a significant dose; and
- Location of the organ or tissue. An organ located close to another that has incorporated a radioactive element will receive a higher dose than one more distant.

As is described in the discussion in Section 4.3 below concerning Alexander Litvenenko, the most desirable radioactive material for an attack with the purpose killing or injuring humans would be a radionuclide has a very high specific activity (becquerels/curies per gram) and emits a particle that deposits a large amount of energy. The material would have to get into the body by one of the mechanisms mentioned earlier. If stealth is also a consideration, another desirable property would be that the material would not emit other radiations which could be easily detected or could be easily shielded to prevent detection of other types of radiation it might emit.

Gamma-emitting radionuclides can be used to expose individuals with a source external to their person. With the exception of ^{226}Radium (Ra) and a few transuranic radionuclides, most alpha-emitting radionuclides do not emit gamma radiation of sufficient intensity or energy to pose an external radiation hazard. ^{226}Ra produces radioactive progeny within a short period of time that emit high-intensity gamma radiation and additional alpha-emitting progeny. It, therefore, represents a threat as both a significant external and internal contributor to dose. The most commonly available gamma emitting radionuclides are ^{137}caesium (Cs) and ^{60}cobalt (Co). If exposed to gamma radiation from either radionuclide, even from a source that is approximately a D-value (at a distance of one meter for one hour), a significant dose can be delivered. A dose of approximately 1 R can be delivered in one hour for each radionuclide. If exposed to the radiation for an 8-hour workday, doses can begin to approach those expected from a quantity of concern in one hour.

A gamma-emitting source, once removed from its shield, may be readily deployed as a radiation exposure device (RED). Because gamma rays may be easily detected remotely with more sophisticated detection equipment or within several tens of meters using more commonly available detection equipment, they have a much higher probability of early detection assuming a monitoring program is in place.

If the goal of the terrorist is to deny access or disable infrastructure, then he/she will most likely seek to contaminate facilities or areas with enough radioactive material to necessitate a long clean-up project. This activity will more than likely be conducted in a manner to also produce sufficient destruction to require rebuilding. In other words, it will involve the use of an RDD or bomb. Contamination by itself does not necessarily require an explosive device. An air conditioning system, fogger or any number of other methods may be used for dispersal if the radioactive material is already in a dispersible form. Alpha-emitting or beta-gamma emitting radionuclides could be used in this type of attack. A successful attack would require a lower activity of an alpha-emitting radionuclide than a beta-gamma emitting radionuclide. Much smaller quantities of alpha-emitting radionuclides that are inhaled will generally cause a greater dose per unit intake than small quantities from dispersed, beta-gamma emitting radionuclides, taking into consideration the contribution to dose from both external exposure and from inhalation.

Although alpha-emitting radionuclides are more effective weapons in terms of the amount of radioactivity necessary to produce a high dose weapon, ^{137}Cs and ^{60}Co are more readily available. The increased availability of the beta/gamma-emitting radionuclides increases the probability of their use in a radiological weapon.

Knowing the amount of material that could be obtained from a particular site and the worst-case consequences that could be reasonably expected to be produced by deployment, a consequence bin is determined from Table A-2. The consequence is measured in dollars, fatalities, and serious injuries. There is also a probability of successful deployment (Pd) associated with each bin. The more difficult the event is deemed to be, the lower the probability of success. The probabilities are subjective and the values provided in Table A-2 are suggestions only. If the assessor has additional information, the suggested value can be overridden.

The probability of interdiction (Pi) is estimated by others. This is an estimate of the probability that the perpetrators will be prevented from deploying the device assuming that the authorities know the material was obtained. Obviously many variables can affect the probability that the terrorist will be interdicted. It is logical to assume that the shorter the time between obtaining the material and deploying it, the more likely the terrorist will be successful. Additionally, it would be reasonable to assume that material obtained close to the target would increase the probability of successful deployment. If no information is available from law enforcement or other reliable sources, it is conservative to assume a value of zero (0.0).

Once these values are determined, the overall conditional risk is estimated as follows:

Risk = Po x Pd x (1 - Pi) (Consequence Values) (Eq. 4.1)

Where:

Po = Probability of Obtaining the Material
Pd = Probability of Deploying the Material
Pi = Probability of Successful Interdiction and Preventing Deployment

4.3 Materials Considered

A radionuclide is an isotope, one of two or more atoms of an element that have the same atomic number (the same number of protons) but a different number of neutrons, in which the nucleus is unstable. The instability is the result of excess energy. The primary mechanism for the atom to achieve stability is to change the number of protons or neutrons by emission of a particle. The emission of the particle is frequently accompanied by the emission of a gamma ray. The type of particle emitted is a function of the atomic number of the radionuclide and other factors. Larger atoms of a 200+ atomic mass units (AMU) emit alpha and beta particles. Lower atomic weight radionuclides will decay by emission of beta particles and likely a gamma ray. Interaction of these particles and gamma rays with other matter will transfer energy to that matter. The energy transferred often causes ionization of atoms and the ionization can result in a chemical change in the matter. Chemical change inside the cell can result in changes in critical molecules within the cell that in turn result in cell damage. The deposition of energy when described in terms of energy imparted per gram of target material is called the dose. This is a slightly different concept of dose than that used for chemical toxicology. Chemical dose refers to a quantity of a chemical that has been ingested, inhaled or otherwise incorporated into the body.

Radionuclides not only differ in the types of radiation they emit, but also the energy of the radiation they emit. Thus, some radionuclides are capable of delivering a higher dose per unit activity than others. Also, the different particles are capable of delivering different amounts of energy. Alpha particles, because they are capable of creating more ion pairs per unit distance traveled, deposit more energy. Beta particles create fewer ionizations per unit path length and consequently deposit less energy. Gamma rays will produce even fewer ionizations per unit path length and therefore, deposit the least energy of the three emissions discussed.

Because the alpha and beta particles interact with matter more frequently along a specified path length and transfer energy with each interaction, they lose energy faster than gamma rays and, as such, have shorter ranges. For instance, the range of an alpha particle in air is limited to 5 to 10 cm. A beta particle’s range in air may be a meter or two depending on the kinetic energy of the particle, usually expressed in megaelectron or kiloelectron volts (MeV or keV). The gamma ray has a much longer range in air and can penetrate through solid materials easily. As the material becomes denser, the range of its gamma rays rapidly decreases. Dense materials such as lead are very good shields for gamma rays.

Alpha particles cannot penetrate the layer of dead skin cells and therefore do not pose a radiation hazard as long as the radionuclide emitting them resides outside the body. If that radionuclide, however, is near or inside a cell, the alpha particles it emits can damage the cell internally and possibly the nucleus directly. Therefore, alpha-emitting radionuclides can deliver a dose, only if ingested, inhaled or otherwise incorporated into the body.

Beta particles can pose both external and internal dose hazards. Depending on their energy, beta particles can deliver a dose to shallow, subcutaneous tissues if close to the body. They can also deliver dose if incorporated into the body.

As many gamma-emitting radionuclides also emit beta particles, they can deliver dose from outside or inside the body. The gamma ray can deliver a dose from a significant distance (meters) outside the body to organs located deeper in the body.

Dose is also directly proportional to the particulate or electromagnetic (gamma ray) radiation’s energy. Therefore, higher energy beta particles are capable of delivering a higher dose than lower energy betas. Another key factor in dose is the pharmacokinetics (the body's reaction to drugs, including their absorption, metabolism, and elimination) of the particular radionuclide (element). Thus the chemical form of the radionuclide may dictate that it will be concentrated in a specific tissue or organ. The energy might then be concentrated in a small organ (low mass) and the dose (energy deposited per gram) to that organ can be much greater. Another factor that is directly proportional to dose is the half-life of the radionuclide. This is related primarily to radionuclides once incorporated into the body. Since the residence time for a particular chemical form of a radionuclide is a function of its biological half-life, the dose becomes a function of an expression of the combined radiological and biological half-lives (called the effective half-life). For a radionuclide with a long radiological half-live and a long biological half-life, the total dose delivered will be large. Decreasing the biological half-life, the radiological half-life, or both will result in a lower dose.

Specific activity is a property of a radionuclide that is generally inversely proportional to its half-life. Specific activity is defined as the amount of radioactivity associated with one gram of that radionuclide. In general, the shorter the half-life of the radionuclide, the higher its specific activity. This property may make the use of a particular radionuclide for an attack on an individual more efficacious than use of another radionuclide with a lower specific activity. The high specific activity means that a very small physical amount of material is all that would be required to provide a lethal dose to an intended victim. If the radionuclide produced only a type of radiation that is difficult to detect, such as alpha radiation, then it could be smuggled through a sophisticated security screen with little chance of discovery. Scans to detect alpha radiation could be easily defeated by packaging the material as a pill in a blister pack, commonly used for over the counter drugs. The assassination of Russian spy, Alexander Litvenenko, in 2006 demonstrates the efficacy of this approach. After his death scientists determined that Mr. Litvenenko had approximately 1.85 MBq (50 mCi) of Po-210 in his body at the time of his death. In terms of mass this would equate to 10 micrograms of material. In terms of toxicity it represents about 200 times the amount of Po-210 necessary to kill a person.

Thus, taking their individual properties into account, the dose from a given amount of one radionuclide can have a high consequence to exposed individuals. The dose from the same amount of another radionuclide has a much lower, possibly even negligible consequence to individuals.

Because some radionuclides do represent a greater hazard than others to humans, i.e., they are considered more radiotoxic, they are assigned much lower allowable contamination limits. Thus, any clean-up requiring decontamination of materials will be more expensive if the radionuclides involved are considered to have high radiotoxicity.

In view of the above, it is necessary to choose the isotopes and minimum quantities that need to be considered as "useful" for terrorist acts or dangerous in the event of an accident or natural disaster. As stated, the IAEA published IAEA-EPR-D-Values in 2006, with its list of isotopes and quantities that are considered dangerous. A more complete discussion of the IAEA D-values can be found in Appendix C of this document. The IAEA listed D-values are the threshold isotopes and quantities used in this study.

4.4 Description of MIAN Materials and Possible Malevolent Uses

Appendix A contains a listing of isotopes could be employed by terrorists or considered to be dangerous if released by natural hazard events. The first fourteen isotopes are related to materials that may be subjected to IC if possessed in sufficient quantity. For IC materials, a detailed discussion is provided that will assist the readers understanding of how this material can cause serious consequences to the public if released. Physical properties such as the half-life and principal emission and specific activity are provided. The relative hazard potential classification group provides a measure of the relative danger of the isotope.

A physical description of the material allows for better visualization when considering acquisition and deployment scenarios. Radioactive and chemical properties are provided for reference. For example, terrorists may dissolve the material in a liquid to facilitate dilution for easier deployment in the water or food supply. Internal and external exposure characteristics and health effects are included to aid in evaluation possible deployment scenarios. Principal uses are included to aid in determining the industries in which the material could be obtained. Finally, a brief discussion of how this material could be obtained as well as possible uses of the material to cause terrorism events. A few relevant definitions are also included for ready reference. The examples of how the materials could be obtained and used are in no way purported to be exhaustive. These are generally obvious to even a casual investigator. It should be assumed that a dedicated terrorist organization will be aware of these methods and others.

Additional information contained in Appendix A includes the following:

- Table A-1 - A summary sheet of the above mentioned isotopes for quick reference;
- Table A-2 - A discussion of how each of the aforementioned isotopes could be obtained and the probability of success of obtaining the material by the assumed scenario; and
- Table A-3 - Weaponizing scenarios for these materials, expected probability of success and consequence estimates.

4.5 Consequence Estimation

Appendix B contains a table for categorizing consequences of a terrorist event into bins. RAMCAP Plus® typically employs predefined bins to provide a range of consequences for cases in which the user does not have information that is more definitive. This approach is used to aid in comparing analyses of disparate risk events. If radioactive materials are utilized by a terrorist in a malevolent act there will, in all probability, be large monetary consequences. The denial of services caused by loss of use of facilities and transportation systems, for example, could result in severe financial consequences. Exposure to radioactive materials, especially if taken internally, could result is deaths and sickness. Public fear and cascading effects can further increase the financial consequences.

The literature lacks definitive information for accurate estimates of the consequences of a terrorist event involving radioactive materials. Example 5 in Appendix E proposes a range of monetary consequences that could result from an RDD in Long Beach or Los Angeles harbors. However, the range is quite large and covers several orders of magnitude. Further, it is not clear if the consequence estimates include secondary or tertiary effects, such as the possibility of closing other ports or imposing new and expensive inspection requirements that would greatly reduce throughput.

Appendix B contains a suggested range of consequence values for various events based on the current best estimates of the authors. These values can be used for comparison of various event scenarios, but are not purported to represent accurate estimates. The actual financial impact of a terrorist event may well be impossible to estimate. The cost, however, will be large and the residual effects of such an event will have a profound effect on commerce and public behavior. The suggested values in Appendix B may be overridden by the user if more detailed information is available.

4.6 Comparison of NRC Increased Controls Isotopes with the IAEA Dangerous Quantities Isotopes

In 2005, the NRC ordered certain radioactive materials (or isotopes) above certain quantities be provided with IC to prevent unauthorized removal for possible use as a terrorist weapon. IC applies equally to NRC and AS licensees. At a minimum, security systems which continuously monitor the materials and notify local law enforcement agencies of breached security, providing for an armed response, along with background checks and fingerprinting of persons authorized to deal with the materials, are now a requirement for storage and use of these materials. Enhanced security, such as alarmed vehicles, is also now required for transporting these materials. Nuclear power plants, certain sterilization irradiators, and manufacturers are under a higher level of safeguards.

If one compares the NRC IC list with the IAEA D-value list mentioned in 4.2, it becomes apparent that the NRC listed isotopes on the IAEA list are 10 times the basic D-value. For example, Cesium-137 is on the IC list with a threshold value of 1 Terabecquerel (TBq). It is also on the IAEA list with a D-value of .1 TBq (2.7 curies). When quantities are listed in units of curies, the IAEA rounds the values so they appear a little different than the curie amounts listed by the NRC. Appendix C contains a comparison of comparison of NRC increased controls isotopes with the IAEA dangerous quantities isotopes for reference by the users of this document.

4.7 Possible Scenarios and Sources for Obtaining and Deploying MIAN Materials

When performing a risk assessment of MIAN materials, it is necessary to create plausible scenarios that can be evaluated using the RAMCAP Plus® risk methodology. In fact, the “worst case” scenario must be conceived and analyzed by the user in order to achieve the correct assessment. It should be obvious to the user that there are an infinite number of detailed possibilities that could be evaluated. Appendix D contains information that will be useful in constructing possible scenarios for evaluation. The most likely sources for obtaining particular materials are discussed as well as ways that these materials could be deployed by a terrorist or terrorist organization.

4.8 Example Risk Assessment Exercises

Five example problems were developed to illustrate the RAMCAP Plus® MIAN risk assessment methodology. These examples are presented in Appendix E. The examples are purely hypothetical and do not represent information obtained from any particular location. The availability of Appendix E will depend upon assessment by government agencies and may be redacted from the report if they are deemed sensitive or classified information.

5. Conclusions

5.1 Summary of Results

In the course of this project the following items were developed:

1) Development of Risk Methodology for MIAN Materials

The MIAN risk methodology differs from other RAMCAP Plus® assessment tools, since the target of the malevolent event is not necessarily the asset from which the MIAN materials are obtained. Additional terms were added to the previous RAMCAP Plus® methodology equations to include obtaining the material, transporting the material to the site of the malevolent event, and dispersing the materials.

2) Comparison of Terrorist vs. Natural Hazard Events

It was shown that a premeditated event caused by terrorists results in much greater consequences than an event due to natural or accidental hazards. MIAN materials are contained in robust packaging and are difficult to disburse by naturally occurring or accidental events. A terrorist event can be much more dangerous to the public and the psychological ramifications are much greater than from natural or accidental hazards.

3) Compilation of MIAN Materials List with Relevant Properties That Could Contribute to Malevolent Uses

A detailed list of materials that could be used for terrorist purposes has been compiled. This compilation has proven to be extremely useful for constructing attack scenarios for risk assessment. This information will be even more important for law enforcement or homeland security personnel who may not be as familiar with these materials as the investigators.

4) Development of Current Security Status Screening and Assessment Tool

It was concluded that the licensees who are responsible for security of MIAN materials would benefit from a voluntary screening tool to determine if they were providing adequate security and to assess their programs. A prototype self-assessment tool was developed.

5) Investigation of Materials Related Terrorist Scenarios

The investigators compiled a list of possible deployment scenarios for MIAN materials. This list is provided to stimulate scenario construction by law enforcement, homeland security, and other users of the MIAN methodology. Creating plausible scenarios for assessment is a key element of the methodology.

6) Examples of Risk Assessments for Four Postulated Events

Appendix E contains examples which demonstrate how the MIAN methodology can be used to assess the overall risk of a terrorist event.

7) Site Visits and Pilots of the Methodology

The investigators visited a number of licensees that are currently using MIAN materials. The methodology was presented and licensees were made aware of the risk to the public if these materials were obtained by terrorists. The security self-assessment tool described above was explained and discussed with respect to how it would apply to their particular site or sites. Six questions were posed to security officers to assess their understanding of the tool, the usefulness of the tool, and whether they would voluntarily utilize the tool. Every licensee interviewed was of the opinion that the enhanced security tool would help them improve existing security. All interviewees preferred a voluntary program over a mandated program. The interviewees provided valuable feedback concerning how the security tools could be further enhanced. Detailed comments for each interview are included in Appendix F.

8) Peer Review

The MIAN methodology was reviewed by the FBI, the state of Texas Regulatory Radioactive Material Group, Radiation Licensing, Texas Department of Health Services, and informally by an employee of the Conference of Radiation Control Program Directors (CRCPD). These reviews provided many useful comments and suggestions that were incorporated into the methodology when possible.

5.2 Conclusions

The results of the site visits and the peer review comments indicate the need for enhancing current security practices and educating the licensees with respect to possible breaches in security. The risk posed by malevolent events has not been transmitted adequately to the licensees. While the licensees are diligent in protecting these materials, they are not fully aware of the extensive consequences that can result from the loss of material if employed by a terrorist. Most have not considered that armed terrorists willing to sacrifice themselves would present a threat that cannot be met with existing security measures. The need to report missing materials must be reinforced. If a terrorist plot is to be interdicted, law enforcement must be informed in time to apprehend the perpetrator before potential deployment.

During the pilot studies the interviewees indicated that they would utilize an enhanced security tool if it were available at little or no cost and not overly burdensome. There is a need to continue to develop a voluntary assessment tool that would be used to determine the current security status, compare the level of security to established benchmarks based on the materials and quantity of material on site, and suggest ways to further enhance security without incurring prohibitive costs. The interviewees suggested several ways to increase public awareness of the actual danger of a terrorist event as well as ways to reduce the psychological consequences. These suggestions should be implemented through an awareness and education program working with existing professional societies and industry organizations.

5.3 Recommendations

- Continue to develop the security enhancement tool. Include additional security measures suggested by the interviewees and provide guidance for enhancing security. Provide metrics to compare assessed site security to a range of scores that would be acceptable for sites storing materials of this type and quantity.

- Obtain feedback from licensees and regulators and other knowledgeable individuals regarding scoring and what acceptable levels are for different amounts and types of materials, including development of a table for comparison of program levels of security.

- Add suggestions for improving security and possibly create a handbook for security.

- Encourage adoption of the MIAN methodology on a voluntary basis.

- Work with states and organizations such as CRCPD, DHS and AS to adopt the process.

- Find ways to inform the public about the risk and the actual dangers of deployment of MIAN materials. Use existing organizations such as the Health Physics Society, the American Association of Physics Medicine and working committees to develop spokespersons and web sites. Inform media about the existence of these sources of information. Develop an information resource that can reduce the psychological impact in the event of a nuclear terrorism event.

Appendix A – NRC Increased Controls Isotopes and Possible uses by Terrorists

Isotopes that could be employed by terrorists are discussed in this appendix. The first fourteen isotopes are related to materials which may be subjected to Increased Controls (IC) if possessed in sufficient quantity. For these materials a detailed discussion is provided that will aid the reader in understanding how this material could be utilized in a malevolent fashion. Physical properties such as the half-life and principal emission and specific activity are provided. The relative hazard potential classification group provides a measure of the relative danger of the isotope.

A description of the material allows for better visualization when considering acquisition and deployment scenarios. Radioactive and chemical properties are given for reference. For example, terrorists may dissolve the material in a liquid to facilitate dilution for easier deployment in the water or food supply. Internal and external exposure characteristics and health effects are included to aid in evaluation possible deployment scenarios. Principal uses are included to aid in determining the industries in which the material could be obtained. Finally, a brief discussion of how this material could be obtained as well as possible uses of the material to cause terrorism events. A few relevant definitions are also included for ready reference.

The examples of how the materials could be obtained and used are in no way purported to be exhaustive. These are generally obvious to even a casual investigator. It should be assumed that a dedicated terrorist organization will be aware of these and other scenarios.

Additional information contained in Appendix A includes the following:

- Table A-1 - A summary sheet of the above mentioned isotopes for quick reference;
- Table A-2 - A discussion of how each of the aforementioned isotopes could be obtained and the probability of success of obtaining the material by the assumed scenario; and
- Table A-3 - Weaponizing Scenarios for these materials, expected probability of success and consequence estimates

As discussed above, the isotopes listed for 1 – 14 are IC-related and are discussed in detail. These include:

1. Am-241, Am(Be)-241
2. Cf-252
3. Cm-244
4. Co-60
5. Cs-137
6. Gd-153
7. Ir-192
8. Pm-147
9. Pu-238, Pu-239, Pu(Be)-239
10. Ra-226
11. Se-75
12. Sr-90 (Y-90)
13. Tm-170
14. Yb-169

The properties of the isotopes listed for 15 – 24 are briefly summarized in Table 1 of this appendix.

15. Au-198*
16. Cd-109*
17. Co-57*
18. Fe-55*
19. Ge-68*
20. Ni-63*
21. Pd-103*
22. Po-210*
23. Ru-106 (Rh-106)*
24. Tl-204*

The information for these isotopes (1 – 14) was excerpted (with little editing) from:

1 Radiological and Chemical Fact Sheets to Support Health Risk Analyses for Contaminated Areas, Argonne National Laboratory Environmental Science Division, John Peterson, Margaret MacDonell, Lynne Haroun, and Fred Monette, U.S. Department of Energy Richland operations Office, R. Douglas Hildebrand and Chicago Operations Office, Anibal Taboas, March 2007.
2 Classification Of Radionuclides According To Relative Hazard Potential, California Institute Of Technology, Radiation Safety Manual, August, 1997, 1200 E. California Boulevard, Pasadena, Ca 91125. http://safety.caltech.edu/documents/76-radiation_safety_manual.pdf, P. 45.
3 "Improved Separation and Purification Method for Gadolinium", Pacific Northwest National Laboratory; Operated by Battelle for the U.S. Department of Energy; June 2008.

4 Gadolinium-153 Production at the Oak Ridge National Laboratory; Oak Ridge National Laboratory; Oak Ridge, Tennessee 37531; operated by Martin Marietta Energy Systems, Inc. for the U.S. DEPARTMENT OF ENERGY under Contract No. DE-AC05-840R21400; D. W. Ramey
5 "Radionuclide Safety Data Sheet", Gd-153, Stanford University, 1990.
6 "Periodic Table of the Elements", Los Alamos National Laboratory, Chemistry Operations. Operated by the University of California for the US Department of Energy, UC 2003.
7 Chemistry Explained, Foundations and Applications, http://www.chemistryexplained.com/elements
8 International Isotopes Clearing House, Inc., Copyright © 2007 IICH Inc. All rights reserved. (Site is maintained by Zap Web Design)
9 Chemistry Explained, Foundations and Applications, Copyright © 2011 Advameg, Inc.
10 Computational Knowledge Engine, © 2011 Wolfram Alpha LLC—A Wolfram Research Company
11 "Ytterbium", Reference.com, HighBeam Research, Inc. © Copyright 2009.

Definitions:

Decay Mode - The radioactive decay modes addressed include beta-particle emission, alpha-particle emission, isomeric transition (IT), electron capture (EC), and spontaneous fission (SF).

Half-life - The radioactive half-life is the length of time for a given amount of radioactive material to decrease to one half its initial amount by radioactive decay.

Isotope - An isotope is a different form of an element that has the same number of protons in the nucleus but a different number of neutrons.

Metastable (atom) - An atom with its nucleus in an elevated energy state (typically a metastable isotope is designated by the letter "m") which releases excess energy by emitting a gamma ray. (The product of the decay is not a new isotope, but rather the same isotope in a reduced, more stable, energy configuration.)

Specific Activity - The specific activity is the activity per mass and is given in units of curies (Ci) per gram.

Materials which may be subjected to Increased Controls

1. **Isotope:** Americium-241 (241Am) and Am(Be)-241

   Half-life: 430 yrs

   Principal Emissions:
   α (5.5 MeV)
   β (0.52 MeV)
   γ (0.033 MeV)

   Specific Activity: 3.5 Ci/g

   Relative Hazard Potential Classification Group: Hazard Class I (Very High Hazard Potential)

   Description: Americium is a malleable, silvery white metal that tarnishes slowly in dry air at room temperature.

   Radioactive Properties: Americium does not occur naturally but is produced artificially by successive neutron capture reactions by plutonium isotopes. There are sixteen known isotopes of americium and all of them are radioactive, but only three have half-lives long enough to warrant concern: americium-241, americium-242m, and americium-243. Of these, americium-241 is generally the most prevalent isotope in use. It has a half-life of 430 years and decays by emitting an alpha particle with attendant gamma radiation.

   Chemical Properties: Americium is typically quite insoluble, although a small fraction can become soluble through chemical and biological processes.

   Internal Exposure: Americium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is a likely source of internally deposited americium in the general population. After ingestion or inhalation, most americium is excreted from the body within a few days and never enters the bloodstream; only about 0.05% of the amount taken into the body by ingestion is absorbed into the blood. After leaving the intestine or lung, about 10% clears the body.

The rest of what enters the bloodstream deposits about equally in the liver and skeleton where it remains for long periods of time, with biological retention half-lives of about 20 and 50 years, respectively.

External Exposure: The weak gamma emission of americium-241 decay offers a very low external exposure hazard.

Primary Health Effects: The major health concern is tumors resulting from the ionizing radiation emitted by americium isotopes deposited on bone surfaces and in the liver.

Principal Uses: Americium-241 is used extensively in industry. There is some use in academics, but currently little use in the medical community.

A very common use of americium is in smoke detectors where the alpha particle associated with the decay of americium-241 is used to ionize the air. Alpha particles from smoke detectors do not themselves pose a health hazard, as they are absorbed in a few centimeters of air or by the structure of the detector.

Americium is also used as a common neutron source by combining the americium-241 and beryllium. The alpha particle given off during the radioactive decay of americium-241 is absorbed by beryllium-9, producing carbon-12 and a neutron. Large americium-241 neutron sources are used extensively in well-logging (gas and oil industry) and smaller ones are used for gauging devices. Most use is probably in portable/mobile devices.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Free Americium-241 could be converted to a soluble form and introduced to water supplies or food to cause internal exposure. Large americium-241 neutron sources can be placed in areas where humans may spend a great deal of time to cause large external exposures.

Comments: Americium-241 could not readily be used to create immediate radiation exposure symptoms, such as “burns” – or even death. Its use would be to threaten cancers later in life.

2. **Isotope:** Californium-252 (^{252}Cf)

Half-life: 2.6 yrs

Principal Emissions:
α (5.9 MeV)
β (0.0056 MeV)
γ (0.0012 MeV)

Specific Activity: 540 Ci/g

Relative Hazard Potential Classification Group:
Hazard Class I (Very High Hazard Potential)

Description: Californium is a silvery-white or gray metal with a density somewhat greater than that of lead.

Radioactive Properties: Californium, which does not occur naturally, is produced artificially in nuclear reactors and particle accelerators. Ten isotopes of californium are known to exist and all are radioactive, however, only five have half-lives long enough to be of concern: californium-248, californium-249, californium-250, californium-251, and californium-252. The half-lives of these isotopes range from 0.91 to 900 years, while those of the other isotopes are less than two months. All five of these isotopes decay by emitting an alpha particle, and all but californium-248 also decay by spontaneous fission (SF). About 3% of the radioactive decays of californium-252 are by SF, while only a very small fraction of the decays of the other three isotopes are by SF. Californium-252 is a very strong neutron emitter, with one microgram emitting 170 million neutrons per minute.

Chemical Properties: Californium is typically quite insoluble.

Internal Exposure: Californium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is a likely source of internally deposited californium in the general population. After ingestion or inhalation, most californium is excreted from the body within a few days and never enters the bloodstream; only about 0.05%

of the amount taken into the body by ingestion is absorbed into the blood. After leaving the intestine or lung, about 65% of the californium that does enter the bloodstream deposits in the skeleton, 25% deposits in the liver, and the rest deposits in other organs or is excreted, primarily in urine. The biological half-lives in the skeleton and liver are about 50 and 20 years, respectively. (This information is per simplified models that do not reflect intermediate redistribution.) Californium in the skeleton is deposited on bone surfaces and slowly redistributes throughout the bone volume over time.

External Exposure: Californium-252, with about 3% of the decays by spontaneous fission, is a significant source of neutrons and gamma rays.

Primary Health Effects: Californium is generally a health hazard only if it is taken into the body, although there is an external risk associated with the gamma rays emitted by californium-249 and californium-251. The main means of exposure are ingestion of food and water containing californium isotopes and inhalation of californium-contaminated dust. Ingestion is generally the exposure of concern unless there is a nearby source of contaminated airborne dust. Because californium is taken up in the body much more readily if inhaled rather than ingested, both exposure routes can be important. The major health concern is cancer resulting from the ionizing radiation emitted by californium isotopes deposited on bone surfaces and in the liver.

Principal Uses: The only californium isotope that has a commercial use is californium-252. Because this radionuclide is only available in very small quantities its uses are quite limited. Californium-252 is a very strong neutron emitter, with one microgram emitting 170 million neutrons per minute. Thin foils containing californium-252 can be used as a source of fission fragments for research purposes. Californium-252 can also be used as a portable neutron source to identify gold or silver ores through neutron activation analysis, and it can be used in moisture gauges to locate water and oil-bearing layers in oil wells. Iridium has been used in trailered devices for highway/bridge evaluation. In addition, californium-252 is used in brachytherapy to treat various types of cancer.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use in the field.

Potential Uses by Terrorists: Californium-252 could be converted to a soluble form and introduced to water supplies or food to cause internal exposure. Large Californium-252 sources can be placed in areas where humans may spend a great deal of time to cause large external neutron exposures.

Comments: Californium-252 could not readily be used to create immediate radiation exposure symptoms, such as "burns" – or even death. Its use would be to threaten cancers later in life.

3. **Isotope:** Curium-244

Half-life: 18 yrs

Principal Emissions:
α (5.4 MeV)
β (0.086 MeV)
γ (0.0017 MeV)

Specific Activity: 82 Ci/g

Relative Hazard Potential Classification Group:
Not assigned to a hazard class.

Description: Curium is a hard, brittle, silvery metal that tarnishes slowly in dry air at room temperature.

Radioactive Properties: Curium does not occur naturally; it is typically produced artificially in nuclear reactors through successive neutron captures by plutonium and americium isotopes. There are sixteen known isotopes of curium and all are radioactive. Eight of the sixteen curium isotopes have half-lives greater than one month. Curium-243 and curium-244 are the two isotopes of most concern at Department of Energy (DOE) environmental management sites. Curium generally decays to plutonium by emitting an alpha particle; gamma radiation is associated with some of these decays. A relatively small percentage (14%) of curium-250 decays are by beta-particle emission to berkelium-250. Curium- 248 and curium-250 also decay by spontaneous fission (SF) and a very small fraction of curium-242, curium-244, and curium-246 decays are by SF.

Chemical Properties: Curium is typically quite insoluble.

Internal Exposure: Curium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is the most likely source of any internally deposited curium in the general population. After ingestion, most curium is excreted from the body within a few days and never enters the bloodstream; only about 0.05% of the amount ingested is absorbed into the bloodstream. Of the curium that reaches the blood, about 45% deposits in the liver where it is retained with a biological half-life of 20 years, and 45% deposits in bone where it is retained with a biological half-life of 50 years (per simplified models that do not reflect intermediate redistribution). Most of the remaining 10% is directly excreted. Curium in the skeleton is deposited mainly on the endosteal surfaces of mineral bone and only slowly redistributes throughout the bone volume.

External Exposure: A risk from external gamma exposure is associated with curium-243, curium-245, curium-247, and curium-250, but NOT with curium-244.

Primary Health Effects: People can be exposed by ingesting contaminated food or water or by inhaling contaminated dust. Ingestion is generally the exposure route of concern unless a nearby source of dust contamination exists. Because curium is absorbed within the body much more readily if inhaled rather than ingested, both exposure routes can be important. The main health concern is bone tumors resulting from ionizing radiation emitted by curium isotopes deposited on bone surfaces.

Principal Uses: Curium-244 has few uses outside of research activities, and it is only available in extremely small quantities. Curium isotopes can be used without heavy shielding as sources of thermoelectric power in satellites and crewless space probes.

Potential Acquisition by Terrorists: Theft from storage facilities or while in transport.

Potential Uses by Terrorists: Curium-244 could be converted to a soluble form and introduced to water supplies or food to cause internal exposure.

Comments: Curium-244 could not readily be used to create immediate radiation exposure symptoms. Its use would be to threaten cancers later in life.

4. **Isotope:** Cobalt-60

Half-life: 5.3 yrs

Principal Emissions:
β (0.097 MeV)
γ (2.5 MeV)

Specific Activity: 1100 Ci/g

Relative Hazard Potential Classification Group:
Hazard Class II (High Hazard Potential)

Description: Cobalt is a hard, silvery-white metal that occurs in nature as cobalt-59 is usually found in association with nickel, silver, lead, copper, and iron. Pure cobalt metal is prepared by reducing its compounds with aluminum, carbon, or hydrogen. It is similar to iron and nickel in its physical properties. Cobalt has relatively low strength and little ductility at normal temperatures and is a component of several alloys.

Radioactive Properties: There are nine major radioactive cobalt isotopes. Of these, only cobalt-57 and cobalt-60 have half-lives long enough to warrant concern. Cobalt-60 is the isotope of most concern at DOE for the cobalt-57 produced more than 20 years ago has long since decayed away. The two energetic gamma rays that accompany the radioactive decay of cobalt-60 make this isotope an external hazard. Cobalt-60 is produced by neutron activation of components in nuclear reactors; it can also be produced in a particle accelerator. When an atom of uranium-235 (or other fissile nuclide) fissions, it generally splits asymmetrically into two large fragments – fission products with mass numbers in the range of about 90 and 140 – and two or three neutrons. A number of reactor components are made of various alloys of steel that contain chromium, manganese, nickel, iron and cobalt, and these elements can absorb neutrons to produce radioactive isotopes, including cobalt-60. Cobalt-60 is a radionuclide of concern in spent nuclear fuel (as a component of the fuel hardware) and in the radioactive wastes associated with nuclear reactors and fuel reprocessing plants.

Chemical Properties: Cobalt is typically insoluble. It can be made soluble through chemical and biological processes.

Internal Exposure: Cobalt-60 poses both an internal and external hazard, and the main health concern is associated with the increased likelihood of cancer. Inside the body, cobalt presents a hazard from both beta and gamma radiation. Cobalt can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is the principal source of internally deposited cobalt in the general population. Estimates of the gastrointestinal absorption of cobalt range from 5 to 30%, depending on the chemical form and amount ingested; 10% is a typical value for adults and 30% for children. Of the cobalt that deposits in the liver and other tissues, 60% leaves the body with a biological half-life of 6 days and 20% clears with a biological half-life of 60 days; the last 20% is retained much longer, with a biological half-life of 800 days. On the basis of animal studies, retention of cobalt was determined to be the same for all age groups. Inhaled cobalt oxide moves from the lung to body tissues quite readily. Calculation of internal dose can be rather complicated. Inhalation poses a higher risk than ingestion.

External Exposure: External exposure is a concern because of the strong external gamma radiation, and shielding is often needed to handle wastes and other materials with high concentrations of the isotope. Calculation/measurement of doses due to external exposures is rather easy and straightforward.

Primary Health Effects: The major health concern is cancer, later in life, resulting from the exposure to the ionizing radiation.

Principal Uses: High-energy gamma rays emitted during the radioactive decay of cobalt-60 can be used to detect flaws in metal components and in brachytherapy to treat various types of cancer. (Brachytherapy is a method of radiation treatment in which sealed sources are used to deliver a radiation dose at a distance of up to a few centimeters by surface, intracavitary, or interstitial application.) Co-60 is also the principle isotope used in sterilization irradiators – wherein mega-curies of Co-60 sealed sources are situated to yield extremely high radiation fields.

Potential Acquisition by Terrorists: Theft from use and/or storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Co-60 could be chemically converted to a soluble form and introduced to water supplies or food to cause internal exposure. The more likely use would be to set large Co-60 sources in areas where humans may spend a great deal of time to cause large external exposures.

Comments: Co-60 can be used to create immediate radiation exposure symptoms, such as "burns" – even death. Its use would also threaten cancers later in life.

5. **Isotope:** Cesium-137

Half-life: 30 yrs

Principal Emissions:
β (0.19 MeV)
from the daughter Ba-137m (2.6 min half-life) for 95% of the decays:
β (0.065 MeV)
γ (0.60 MeV)

Specific Activity: 3.5 Ci/g (540 million for Ba-137m)

Relative Hazard Potential Classification Group:
Hazard Class III (Moderate Hazard Potential)

Description: Cesium is a soft, silvery white-gray metal that occurs in nature as cesium-133. The natural source yielding the greatest quantity of cesium is the rare mineral pollucite.

Radioactive Properties: There are 11 major radioactive isotopes of cesium. Only three have half-lives long enough to warrant concern: cesium-134, cesium-135 and cesium-137. Each of these decays by emitting a beta particle, and their half-lives range from about 2 to 2 million years. The half-lives of the other cesium isotopes are less than two weeks. Of these three, the isotope of most concern is cesium-137 which has a halflife of 30 years. Its decay product, barium-137m, with a half-life of about 2.6 minutes, stabilizes itself by emitting an energetic gamma ray. Cesium radionuclides are fission products, with cesium-135 and cesium-137 being produced with relatively high yields of about 7% and 6%, respectively. That is, about 7 atoms of cesium-135 and 6 atoms of cesium-137 are produced per 100 fissions. Cesium-137 is a major radionuclide in spent nuclear fuel, high-level radioactive wastes resulting from the processing of spent nuclear fuel, and radioactive wastes associated with the operation of nuclear reactors and fuel reprocessing plants.

Chemical Properties: Although it is a metal, cesium melts at the relatively low temperature of 28o C (82o F), so like mercury it is liquid at moderate temperatures. This most alkaline of metals reacts explosively when it comes in contact with cold water. In applications, Cesium-137 is often used as cesium-chloride (a water soluble material) in steel encapsulations.

Internal Exposure: Cesium can be taken into the body by eating food, drinking water, or breathing air, and behaves in a manner similar to potassium whereby it distributes uniformly throughout the body. Essentially all cesium that is ingested is absorbed into the bloodstream through the intestines. Cesium tends to concentrate in muscles because of their relatively large mass. Like potassium, cesium is excreted from the body fairly quickly. In an adult, 10% is excreted with a biological half-life of 2 days, and the rest leaves the body with a biological half-life of 110 days. Clearance from the body is somewhat quicker for children and adolescents. If someone is exposed to radioactive cesium and the source of exposure is removed, much of the cesium will readily clear the body along the normal pathways for potassium excretion within several months.

External Exposure: Cesium-137 presents an external as well as internal health hazard. The strong external gamma radiation associated with its short-lived decay product barium-137m makes external exposure a concern, and shielding is often needed to handle materials containing large concentrations of cesium.

Primary Health Effects: While in the body, cesium poses a health hazard from both beta and gamma radiation, and the main health concern is associated with the increased likelihood for inducing cancer.

Principal Uses: Cesium-137 is used in brachytherapy to treat various types of cancer. Brachytherapy is a method of radiation treatment in which sealed sources are used to deliver a radiation dose at a distance of up to a few centimeters by surface, intracavitary, or interstitial application. In industrial applications, Cs-137 is used in the same manner as Co-60. Often, one or the other will be selected for a given application based on its specific properties.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Cs-137 can be used to target both internal and external exposures. External exposure from large sources is probably more likely. Cs-137 in soluble form can be introduced to water supplies or food to cause internal exposure. Large Cs-137 sources can be placed in areas where humans may spend a great deal of time to cause high external exposures.

Comments: Cs-137 can be readily used to create immediate radiation exposure symptoms, such as "burns" – or even death. Its use could also be to threaten cancers later in life.

6. **Isotope:** Gadolinium-153

Half-life: 242 days (0.663 yrs)

Principal Emissions:
β 0.103 MeV maximum
γ 0.041 MeV (35.8 %)
0.042 MeV (64.7 %)
0.047 MeV (25.3 %)
0.070 MeV (2.57 %)

0.084 MeV (0.22 %)
0.097 MeV (31.3 %)
0.103 MeV (22.2 %)

Specific Activity: 60 Ci/g

Relative Hazard Potential Classification Group:
Not classified.

Description: Gd-153 is produced by the neutron irradiation of natural europium oxide targets followed by chemical separation of the gadolinium from the transmuted (and now radioactive) europium.

Radioactive Properties: Gadolinium-153 production involves the neutron irradiation of natural europium oxide (47.8% 151Eu, 52.2% 153Eu). The target material undergoes a series of neutron captures and radioactive decays to produce the desired 153Gd product. Several undesirable europium isotopes (152Eu, 154Eu, and 156Eu) are also produced during this irradiation process.

Chemical Properties: All forms are soluble. Internal Exposure: The annual limit on oral intake (ALI) of Gd153 corresponding to a whole-body guideline gamma exposure rate of 500 mrem/year is 540 uCi. Urine assays can be used for assessing internal exposures.

External Exposure: The gamma exposure rate at 1 cm from 1 mCi is 872 mR/hr. The exposure rate varies directly with activity and inversely as the square of the distance. The beta absorbed dose rate at 1 cm from 1 mCi is 157.5 R/hr. The range of the 0.103 MeV beta is 0.012 cm in lucite and 0.0057 cm in glass.

Primary Health Effects: Internal and/or external exposures would elevate the chance of cancer later in life.
Principal Uses: Gadolinium-153 is used in both the early detection and tracking of the crippling brittle bone disease of osteoporosis and as a calibration source for single photon emission computerized tomography (SPECT) cameras.

Potential Acquisition by Terrorists: Theft from storage/use facilities or while in transport.

Potential Uses by Terrorists: A soluble form can be introduced to water supplies or food to cause internal exposure. Large quantities could be placed in areas where humans may spend a great deal of time to cause large external exposures.

Comments: Due to the short half-life and relatively small individual quantities, Gd-153 would probably not be a good choice for terrorism.

7. Isotope: Iridium-192m

Half-life: 74 days.

Principal Emissions:
β (0.22 MeV)
γ (0.82 MeV)

Specific Activity: 9200 Ci/g

Relative Hazard Potential Classification Group:
Hazard Class III (Moderate Hazard Potential)

Description: Iridium is a silvery white metal. It is hard and brittle with low ductility, which makes it very difficult to machine and form. It is quite dense, about twice as dense as lead.

Radioactive Properties: There are 15 major radioactive iridium isotopes, but only three have half-lives longer than a month: Ir-192, Ir-192m, and Ir-194m. The half-lives of the other isotopes are less than 2 weeks. Iridium-192 has a half-life of 74 days, decaying to stable platinum-192 and osmium-192 by emitting a beta particle and by electron capture. Iridium-192 is the most commonly used of the iridium isotopes and it has a high specific activity and significant gamma radiation. Iridium-192 is the isotope of most concern based on general availability as it is used in a number of industrial and medical applications.

Chemical Properties: As a very corrosion-resistant metal, iridium is quite insoluble in water.

Internal Exposure: Iridium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is the likely source of internally deposited iridium in the general population. After ingestion or inhalation, most iridium is excreted from the body and never enters the bloodstream; only about 1% of the amount taken into the body by ingestion is absorbed into the blood. Twenty percent of the iridium that reaches the blood is excreted right away, 20% deposits in the liver, 4% deposits in the kidney, 2% deposits in the spleen, and the remaining 54% is evenly distributed among other organs and tissues of the body. Of the iridium that deposits in any organ or tissue, 20% leaves the body with a biological half-life of 8 days and 80% clears with a biological half-life of 200 days. On the basis of animal studies, retention of iridium was determined to be the same for all age groups. Most inhaled iridium compounds appear to clear the lungs quite rapidly. Iridium can concentrate in several organs depending on its chemical form, so while there is no dominant organ of health concern the liver is a main organ of deposition. Inside the body, these iridium isotopes can pose a hazard from both beta and gamma radiation.

External Exposure: External exposure is a concern because of the strong gamma radiation (especially for iridium-192 and iridium-194m), and shielding is needed to handle iridium-192 radiographic and medical sources.

Primary Health Effects: The iridium isotopes pose both an internal and external hazard, and the main health concern is associated with the increased likelihood of cancer.

Principal Uses: Iridium-192 is used extensively in industry. It is a major tool of industrial radiography, where 100+ curie sources are transported around the county for X-raying dense objects. There is some use in medicine and academics.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Large Iridium-192 sources can be placed in areas where humans may spend a great deal of time to cause large external exposures, such as populated areas like shopping malls and transportation devices like subways, buses, etc. It would have to be converted into "dust" size particles to introduce to water supplies or food to cause internal exposure. Iridium-192 could be a "choice tool" for terrorism.

Comments: Iridium-192 can be used to create immediate radiation exposure symptoms, such as "burns" – or even death. Exposure would also threaten cancers later in life.

8. **Isotope:** Promethium 147

Half-life: 2.62 yrs

Principal Emissions:
β (0.225 MeV, max)

Specific Activity: 930 Ci/g

Relative Hazard Potential Classification Group:
Hazard Class III (Moderate Hazard Potential)

Description: Promethium is a silver-white metal. Promethium is not found in the Earth's surface.

Radioactive Properties: Seventeen isotopes of promethium, with atomic masses from 134 to 155 are now known. Promethium-147, with a half-life of 2.6 years, is the most generally useful. Promethium-145 is the longest lived, and has a specific activity of 940 Ci/g. Promethium-147 is a soft beta emitter. Although no gamma rays are emitted, X-radiation can be generated when beta particles impinge on elements of a high atomic number, and great care must be taken in handling it. Promethium salts luminesce in the dark with a pale blue or greenish glow, due to their high radioactivity.

Chemical Properties: Promethium has a melting point of 1,160°C (2,120°F) and no measured boiling point. Its density is 7.2 grams per cubic centimeter. Little is yet generally known about the properties of metallic promethium. Ion-exchange methods led to the preparation of about 10 g of promethium from atomic reactor fuel processing wastes in early 1963.

Internal Exposure: Promethium can be taken into the body by eating food, drinking water, or breathing air. Since Promethium-147 is a soft beta emitter, exposure would only be internal.

External Exposure: The soft beta emission of the Promethium-147 offers a very low external exposure hazard.

Primary Health Effects: The major health concern is tumors resulting from the internal exposure of tissues.

Principal Uses: Promethium has limited uses. It can be used as a source of power. The radiation it gives off provides energy, similar to that from a battery. A promethium battery can be used in places where other kinds of batteries would be too heavy or large to use, as on satellites or space probes. Such batteries are far too expensive for common use, however.

Promethium is also used to measure the thickness of materials. For example, suppose thin sheets of metal are being produced on a conveyor belt. A sample of promethium metal is placed above the metal and a detector is placed below. The detector counts the amount of radiation passing through the metal. If the metal sheet becomes too thick, less radiation passes through. If the sheet becomes too thin, more radiation passes through. The detector reports when the sheet of metal is too thick or too thin. It can automatically stop the conveyor belt when this happens.

Some compounds of promethium are luminescent. Luminescence is the property of giving off light without giving off heat. The light of a firefly is an example of luminescence. Promethium compounds are luminescent because of the radiation they give off.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Free Promethium-147 could be converted to a soluble form and introduced to water supplies or food to cause internal exposure.

Comments: Promethium-147 could not readily be used to create immediate radiation exposure symptoms, such as "burns" – or even death. Its use would be to threaten cancers later in life.

9. **Isotope:** Pu-238 (238Pu), Pu-239 (239Pu), Pu(Be)-239

Half-life:
Pu-238 - 88 yrs
Pu-239 – 24,000 yrs

Principal Emissions:
Pu-238 - α (5.5 MeV)
β (0.011 MeV)
γ (0.0018 MeV)
Pu-239 - α (5.1 MeV)
β (0.0067 MeV)
γ (< 0.001 MeV)

Specific Activity:
Pu-238 – 17 Ci/g
Pu-239 – 0.063 Ci/g

Relative Hazard Potential Classification Group:
Hazard Class I (Very High Hazard Potential)

Description: Plutonium in its pure form is a very heavy, silver-colored, radioactive metal about twice as dense as lead.

Radioactive Properties: Essentially all the plutonium on earth has been created within the past six decades by human activities involving fissionable materials. Several plutonium isotopes exist, all of which are radioactive. Except for plutonium-241, these isotopes decay by emitting an alpha particle. Plutonium-241 decays by emitting a low-energy beta particle to americium-241, an alpha emitting radionuclide with a half-life of 430 years that is much more radiotoxic than its parent. The maximum activity of americium-241 is about 3% of the initial activity of plutonium-241 and occurs 73 years later. An extremely small fraction of the decays of plutonium-236, plutonium-238, plutonium-240, and plutonium-242, are by spontaneous fission (SF), as are about 0.1% of the plutonium-244 decays. Plutonium-242 and plutonium-244 are generally present in relatively minute activity concentrations.

Chemical Properties: The most common form in the environment is plutonium oxide. Plutonium is typically very insoluble, with the oxide being less soluble in water than ordinary sand (quartz). It adheres tightly to soil particles and tends to remain in the top few centimeters of soil as the oxide. In aquatic systems, plutonium tends to settle out and adhere strongly to sediments, again remaining in upper layers. Typically one part of plutonium will remain in solution for every 2,000 parts in sediment or soil. A small fraction of plutonium in soil can become soluble through chemical or biological processes, depending on its chemical form. While plutonium can bioconcentrate in aquatic organisms, data have not indicated that it biomagnifies in aquatic or terrestrial food chains.

Internal Exposure: When plutonium is inhaled, a significant fraction can move from the lungs through the blood to other organs, depending on the solubility of the compound. Little plutonium (about 0.05%) is absorbed from the gastrointestinal tract after ingestion, and little is absorbed through the skin following dermal contact. After leaving the intestine or lung, about 10% clears the body. The rest of what enters the bloodstream deposits about equally in the liver and skeleton where it remains for long periods of time, with biological retention halflives of about 20 and 50 years, respectively, per simplified models that do not reflect intermediate redistribution. The amount deposited in the liver and skeleton depends on the age of the individual, with fractional uptake in the liver increasing with age. Plutonium in the skeleton deposits on the cortical and trabecular surfaces of bones and slowly redistributes throughout the volume of mineral bone with time.

External Exposure: The weak beta and gamma emissions of the Plutonium-238 and Plutonium-239 offer a very low external exposure hazard.

Primary Health Effects: Plutonium generally poses a health hazard only if it is taken into the body because all of its isotopes except plutonium-241 decay by emitting an alpha particle, and the beta particle emitted by plutonium-241 is of low energy. Minimal gamma radiation is associated with these radioactive decays. However, there is an external gamma radiation hazard associated with plutonium-244 from it short-lived decay product neptunium-240m. Inhaling airborne plutonium is the primary concern for all isotopes, and cancer resulting from the ionizing radiation is the health effect of concern. The ingestion hazard associated with common forms of plutonium is much lower than the inhalation hazard because absorption into the body after ingestion is quite low. Laboratory studies with experimental animals have shown that exposure to high levels of plutonium can cause decreased life spans, diseases of the respiratory tract, and cancer. The target tissues in those animals were the lungs and associated lymph nodes, liver, and bones. However, these observations in experimental animals have not been corroborated by epidemiological investigations in humans exposed to lower levels.

Principal Uses: The nuclear properties of plutonium-239, as well as our ability to produce large amounts of nearly pure plutonium-239, led to its use in nuclear weapons and nuclear power. The fissioning of uranium-235 in the reactor of a nuclear power plant produces two to three neutrons, and these neutrons can be absorbed by uranium-238 to produce plutonium-239 and other isotopes. Plutonium-239 can also absorb neutrons and fission along with the uranium-235. Plutonium fissions provide about one-third of the total energy produced in a typical commercial nuclear power plant. The use of plutonium in power plants occurs without it ever being removed from the nuclear reactor fuel, i.e., it is fissioned in the same fuel rods in which it is produced. Another isotope, plutonium-238, is used as a heat source in radiothermal generators to produce electricity for a variety of purposes including unmanned spacecraft and interplanetary probes. The United States recovered or acquired about 110,000 kilograms (kg) of plutonium between 1944 and 1994, and about 100,000 kg remains in inventory. Of this amount, over 80% is in the form of weapons-grade plutonium, primarily plutonium-239. Plutonium was generated in production reactors at DOE's Hanford and Savannah River sites, and weapons components were produced at the Rocky Flats facility. Surplus plutonium is currently stored at the Pantex Plant and other sites. Plutonium-239 has been combined with beryllium to create neutron sources, in the same manner as the americium-241/beryllium neutron sources.

Potential Acquisition by Terrorists: The chance of removal from nuclear power plants or weapons facility is probably very remote. More likely would be theft from Pu-239/Be sources – found at educational facilities and some industrial operations. Fortunately, most of these have been removed from public use and secured by DOE. Otherwise, Plutonium would probably have to be imported from other countries with less rigorous controls. Theft from storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Plutonium could be converted to a soluble form and introduced to water supplies or food to cause internal exposure. Large Pu-239/Be neutron sources can be placed in areas where humans may spend a great deal of time to cause large external exposures.

Comments: Plutonium-239/Be sources could not readily be used to create immediate radiation exposure symptoms, such as "burns" – or even death. Its use would be to threaten cancers later in life.

10. Isotope: Radium-226

Half-life: 1600 yrs

Principal Emissions:
α (4.8 MeV)
β (0.0036 MeV)
γ (0.0067 MeV)

Specific Activity: 1.0 Ci/g

Relative Hazard Potential Classification Group:
Hazard Class I (Very High Hazard Potential)

Description: Radium is a radioactive element that occurs naturally in very low concentrations (about one part per trillion) in the earth's crust. Radium in its pure form is a silvery-white heavy metal that oxidizes immediately upon exposure to air.

Radioactive Properties: Radium was first discovered in 1898 by Marie and Pierre Curie, and it served as the basis for identifying the activity of various radionuclides. One curie of activity equals the rate of radioactive decay of one gram (g) of radium-226. Radium-226 is a radioactive decay product in the uranium-238 decay series and is the pre cursor of radon-222. Radium-228 is a radioactive decay product in the thorium-232 decay series. Both isotopes give rise to many additional short-lived radionuclides, resulting in a wide spectrum of alpha, beta and gamma radiations. Lead-210, which has a 22-year half-life, is included in the list of short-lived radionuclides associated with radium-226 for completeness, as this isotope and its short-lived decay products are typically present with radium-226. Radium-226 decays slowly (half-life of 1,600 years) by emitting an alpha particle. Radium-228 has a much shorter half-life (5.8 years) and decays by emitting a beta particle. While radium-226 poses a hazard due to its long half-life, radium-228 poses a long-term hazard only if its parent (thorium-232) is present.

Chemical Properties: Radium has a density about one half that of lead and exists in nature mainly as Radium-226, although several additional isotopes are present. It is present in all uranium and thorium minerals; its concentration in uranium ores is about one part radium to 3 million parts uranium. The chemical properties of radium are similar to those of barium, and the two substances are removed from uranium ore by precipitation and other chemical processes. Originally, radium was obtained from the rich pitchblende ore found in Bohemia. The carnotite sands of Colorado furnish some radium, but richer ores are found in the Republic of Zaire and the Great Lake Region of Canada. Radium is a major contaminant in mine and milling wastes, such as uranium mill tailings, and is present in various radioactive wastes associated with past uranium processing activities.

Internal Exposure: Radium can be taken into the body by eating food, drinking water, or breathing air. Most of the radium taken in by ingestion (about 80%) will promptly leave the body in feces. The remaining 20% enters the bloodstream and is carried to all parts of the body. Inhaled radium can remain in the lungs for several months and will gradually enter the bloodstream and be carried throughout the body. The metabolic behavior of radium in the body is similar to that of calcium. For this reason, an appreciable fraction is preferentially deposited in bone and teeth. The amount in bone decreases with time from the exposure, generally dropping below 10% in a few months to 1% and less in a few years. Release from the bone is slow, so a portion of inhaled and ingested radium will remain in the bones throughout a person's lifetime. The inhalation risk is associated primarily with radium decay products, i.e., radon and its short-lived daughters. Each of the two radium isotopes decays into a gaseous radon isotope. Radon-222 is a short-lived decay product of radium-226, and radon-220 is a short-lived decay product of radium-228. The primary hazard associated with radon arises from the inhalation of its short-lived decay products, which are charged ions that readily attach to dust particles. These particles can be inhaled into the lungs and deposited on the mucous lining of the respiratory tract. Unattached decay products tend to be inhaled deeper into the lungs where the residence time is longer. When alpha particles are then emitted within the lung, the cells lining the airways can be damaged, potentially leading to lung cancer over time.

External Exposure: The strong external gamma radiation associated with several short-lived decay products of radium-226 and radium-228 makes external exposure a concern, and shielding is often needed to handle waste and other materials containing large concentrations of these radionuclides.

Primary Health Effects: The majority of epidemiological data on the health effects of radium-226 and radium-228 in humans comes from studies of radium dial painters, radium chemists, and technicians exposed through medical procedures in the early 1900s. These studies, as well as studies on experimental animals, indicate that chronic exposure to radium can induce bone sarcomas. The minimum latency period is seven years after the first exposure, but tumors can continue to appear throughout a lifetime.

Principal Uses: Radium-226 is the only radium isotope used commercially. Historically, the main use of radium has been as a component in luminous paint used on the dials of watches, clocks, and other instruments, although it is no longer used for this purpose. While Radium was often used in brachytherapy to treat various types of cancer, there is probably little such use, today. Brachytherapy is a method of radiation treatment in which sealed sources are used to deliver a radiation dose at a distance of up to a few centimeters by surface, intracavitary, or interstitial application. Radium was also used in gauging devices and oil field activities, but these uses, too, have been greatly reduced. Most Radium today is probably stored and waiting for disposal resources to develop.

Potential Acquisition by Terrorists: Theft from use or storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Ra-226 could be converted to a soluble form and introduced to water supplies or food to cause internal exposure. Large Radium-226 gamma sources can be placed in areas where humans may spend a great deal of time to cause large external exposures.

Comments: Although Radium is in a state of slowly being removed from society, it would make a good weapon for both internal and external exposure. Radium-226 can also be extracted from the environment by a person knowledgeable in chemistry.

11. Isotope: Selenium-75

Half-life: 119.8 days

Principal Emissions:
γ (0.280 MeV average, 0.800 max)

Specific Activity: 20 – 45 Ci/g

Relative Hazard Potential Classification Group:
Not Assigned

Description: Selenium is a non-metallic mineral that resembles sulfur and can exist as a gray crystal, red powder, or vitreous black form.

Radioactive Properties: It occurs in nature as six stable isotopes. Selenium-80 is the most prevalent, comprising about half of natural selenium. The other five stable isotopes and their relative abundances are selenium-74

(0.9%), selenium-76 (9.4%), selenium-77 (7.6%), selenium-78 (24%), and selenium-82 (8.7%). There are nine major radioactive selenium isotopes. The half-life of selenium-75 is 120 days and the half-lives of all other isotopes are less than eight hours. Selenium-75 decays by electron capture with a half-life of 119.8 days to stable arsenic-75, emitting an average of 1.75 gamma rays with an average energy of 215 keV each, and a peak energy of 800 keV.

Chemical Properties: Selenium-75 exists as an elemental or metal compound. It is a volatile, reactive, and corrosive element chemically resembling sulfur and forming extremely toxic compounds. It has moderate density (4.3 g/cm3 to 4.8 g/cm3) and melts at 217°C. Selenium has several natural isotopes: selenium-74 (0.89 percent), selenium-76 (9.36 percent), selenium-77 (7.63 percent), selenium-78 (23.78 percent), selenium-80 (49.61 percent), and selenium-82 (8.73 percent).

Internal Exposure: Selenium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption is the principal source of internally deposited selenium in the general population. About 80% of selenium incorporated in food and soluble inorganic compounds are absorbed from the gastrointestinal tract into the bloodstream. However, elemental selenium and selenides are relatively inactive biologically, and only about 5% of these forms are absorbed from the intestines. After reaching the blood, selenium selectively deposits in the liver (15%), kidneys (5%), spleen (1%) and pancreas (0.5%). The remainder is deposited uniformly throughout all other organs and tissues. Of the selenium deposited in any organ or tissue, 10% is retained with a biological half-life of 3 days, 40% is retained with a biological half-life of 30 days, and 50% is retained with a biological half-life of 150 days. As a gamma emitter, internal exposure caused by ingested selenium would be minimal.

External Exposure: External exposure is a concern because of the strong external gamma radiation, and shielding is needed to handle high concentrations of the isotope. Calculation and measurement of doses due to external exposures is rather easy and straightforward.

Primary Health Effects: The major health concern is cancer, later in life, resulting from the exposure to the ionizing radiation. Sources used in radiography are large enough to cause serious injury, even death.

Principal Uses: It is used in radiography cameras for thin-walled structures and, until recently, was not commonly used in the United States. With Ir-192 shortages, Se-75 has seen increased use.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: The best use of Se-75 as a terror weapon is to use it as a source of external radiation – such as hiding large sources in public places or on transportation systems.

12. Isotope: Strontium-90 (Yttrium-90)

The main health concerns for strontium-90 are related to the energetic beta particle from yttrium-90, thus they will be discussed together.

Half-life:
Sr-90 – 29 yrs
Y-90 - 64 hrs

Principal Emissions:
Sr-90 - β (0.20 MeV)
Y-90 - β (0.94 MeV)
Y-90 - γ (negligible)
Specific Activity:
Sr-90 - 140 Ci/g
Y-90 - 550,000 Ci/g

Relative Hazard Potential Classification Group:
Hazard Class I (Very High Hazard Potential)
Description: Strontium is a soft, silver-gray metal that occurs in nature as four stable isotopes.

Radioactive Properties: Sixteen major radioactive isotopes of strontium exist, but only strontium-90 has a half-life sufficiently long (29 years) to warrant concern. The half-lives of all other strontium radionuclides are less than 65 days. Strontium-90 decays to yttrium-90 by emitting a beta particle, and yttrium-90 decays by emitting a more energetic beta particle with a half-life of 64 hours to zirconium-90. The main health concerns for strontium-90 are related to the energetic beta particle from yttrium-90. While four stable isotopes of strontium occur naturally, strontium-90 is produced by nuclear fission. When an atom of uranium-235 (or other fissile nuclide) fissions, it generally splits asymmetrically into two large fragments – fission products with mass numbers in the range of about 90 and 140 – and two or three neutrons. (The mass number is the sum of the number of protons and neutrons in the nucleus of the atom.) Strontium-90 is such a fission product, and it is produced with a yield of about 6%. That is, about six atoms of strontium-90 are produced per 100 fissions. Strontium-90 is a major radionuclide in spent nuclear fuel, high-level radioactive wastes resulting from processing spent nuclear fuel, and radioactive wastes associated with the operation of reactors and fuel reprocessing plants.

Chemical Properties: Strontium is a reactive metal typically found as an oxide or a salt.

Internal Exposure: Strontium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is the principal source of internally deposited strontium in the general population. On average, 30 to 40% of ingested strontium is absorbed into the bloodstream. The amount absorbed tends to decrease with age, and is higher (about 60%) in children in their first year of life. Adults on fasting and low-calcium diets can also increase intestinal absorption to these levels, as the body views strontium as a replacement for calcium. Strontium behaves similarly to calcium (although it is not homeostatically controlled, i.e., the body does not actively regulate levels within the cells), but living organisms generally use and retain it less effectively. For adults, about 31% of the activity entering the blood (plasma) from the gastrointestinal tract is retained by bone surfaces; the remainder goes to soft tissues or is excreted in urine and feces. Much of the activity initially deposited on bone surfaces is returned to plasma within a few days based on an updated biokinetic model that accounts for redistribution in the body. About 8% of the ingested activity remains in the body after 30 days, and this decreases to about 4% after 1 year. This activity is mainly in the skeleton. Strontium-90 concentrates in bone surfaces and bone marrow, and its relatively long radioactive half-life (29 years) make it one of the more hazardous products of radioactive fallout. The health effects associated with strontium-90 were studied concurrent with development of the atomic bomb during World War II by the Manhattan Engineer District. Bone tumors and tumors of the blood-cell forming organs are the main health concern. These tumors are associated with the beta particles emitted during the radioactive decay of strontium-90 and yttrium-90.

External Exposure: External gamma exposure is not a major concern because strontium-90 emits no gamma radiation and its decay product yttrium-90 emits only a small amount.

Primary Health Effects: Strontium is a health hazard only if it is taken into the body. Strontium-90 concentrates in bone surfaces and bone marrow, and its relatively long radioactive half-life (29 years) make it one of the more hazardous products of radioactive fallout. The health effects associated with strontium-90 were studied concurrent with development of the atomic bomb during World War II by the Manhattan Engineer District. Bone tumors and tumors of the blood-cell forming organs are the main health concern. These tumors are associated with the beta particles emitted during the radioactive decay of strontium-90 and yttrium-90.

Principal Uses: Strontium-90 has been used as an isotopic energy source in various governmental research applications, including in radiothermal generators to produce electricity for a variety of purposes including devices to power remote weather stations, navigational buoys, and satellites. Strontium-90 has been used in medical plaques for certain eye treatments.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use.

Potential Uses by Terrorists: The "best" use for terrorism might be to put Strontium-90 in a form to be introduced to food and water supplies.

13. Isotope: Thulium-170

Half-life: 130 days

Principal Emissions:
β (0.315 MeV, avg; 0.967 MeV, max)
γ (0.084 MeV)

Specific Activity: 40-400 kBq/g

Relative Hazard Potential Classification Group:
Hazard Class II (High Hazard Potential)

Description: Thulium is a silvery metal so soft it can be cut with a knife. It is easy to work with and is both malleable and ductile. Its melting point is 1,550°C (2,820°F) and its boiling point is 1,727°C (3,141°F). Its density is 9.318 grams per cubic centimeter.

Radioactive Properties: Only one naturally occurring isotope of thulium exists, thulium-169. At least 16 radioactive isotopes of thulium are known also.

Chemical Properties: Thulium is relatively stable in air. That is, it does not react easily with oxygen or other substances in the air. It does react slowly with water and more rapidly with acids.

Internal Exposure: Most dose will occur in the lungs.

External Exposure: High external exposures can be experienced.

Primary Health Effects: Burns and immediate death caused by high external exposures are possible. Long term prospect of cancer.

Principal Uses: Useful for a thickness gauge of metal, a density gauge, and a gamma radiography.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Can be used to cause high external exposures in the same manner as other sources used in radiography.

14. Isotope: Ytterbium-169

Half-life: 32 days

Principal Emissions:
γ (0.093 MeV - mean)

Specific Activity: 2.2x104 Ci/g

Relative Hazard Potential Classification Group:
Not listed – probably the same as Tm-170 (Hazard Class II).

Description: Ytterbium is a soft, malleable, ductile, lustrous silver-white metal.

Radioactive Properties: Naturally occurring ytterbium is composed of 7 stable isotopes, Yb-168, Yb-170, Yb-171, Yb-172, Yb-173, Yb-174, and Yb-176, with Yb-174 being the most abundant (31.83% natural abundance). Twenty-seven radioisotopes have been characterized, with the most stable being Yb-169 with a half-life of 32.026 days, Yb-175 with a half-life of 4.185 days, and Yb-166 with a half life of 56.7 hours. All of the remaining radioactive isotopes have half-lives that are less than 2 hours, and the majority of these have half-lives that are less than 20 minutes. This element also has 12 meta states, with the most stable being Yb-169m (t ½ 46 seconds).

The isotopes of ytterbium range in atomic weight from 147.9674 u (Yb-148) to 180.9562 u (Yb-181). The primary decay mode before the most abundant stable isotope, Yb-174 is electron capture, and the primary mode after is beta emission. The primary decay products before Yb-174 are element 69 (thulium) isotopes, and the primary products after are element 71 (lutetium) isotopes. Of interest to modern quantum optics, the different ytterbium isotopes follow either Bose-Einstein statistics or Fermi-Dirac statistics, leading to interesting behavior in optical lattices.

Chemical Properties: Although it is one of the rare-earth metals of the lanthanide series in Group 3 of the periodic table, in some of its chemical and physical properties it more closely resembles calcium, strontium, and barium. It exhibits allotropy; at room temperature a face-centered cubic crystalline form is stable. The metal tarnishes slowly in air and reacts slowly with water but rapidly dissolves in mineral acids. It forms numerous compounds, some of which are yellow or green. The oxide (ytterbia, Yb 2 O 3) is colorless. It is widely distributed in a number of minerals, e.g., gadolinite, and is recovered from monazite but has no commercial uses.

Internal Exposure: The gamma emission of Ytterbium-169 would make it more of an external exposure hazard.

External Exposure: While primarily an external exposure hazard, Ytterbium-169 exposures are rather simple to measure and calculate..

Primary Health Effects: The major health concern is cancer, later in life, resulting from the exposure to the ionizing radiation. However, external exposures can be high enough to cause burns and perhaps death.

Principal Uses: Ytterbium-169 is being examined for use in brachytherapy and there is some use in radiography.

Potential Acquisition by Terrorists: Theft from storage facilities, while in transport, or while in use in the field (usually remote areas).

Potential Uses by Terrorists: Large Ytterbium-169 sources can be placed in areas where humans may spend a great deal of time to cause large external exposures.

Comments: Metallic ytterbium dust poses a fire and explosion hazard.

Table A-1 – Isotope Data Summary

ISOTOPE	Dvalue (TBq)	Dvalue (Ci)	Avail	Emission Group *	Reference	Alpha Energy (MeV)	Beta Energy (MeV)	Gamma Energy (MeV)	Neutron Energy (MeV)	Neutron Flux (106 npm/Ci)	Form of Use **	Half-life, radiological	Time Units	Half-life, biological 4,✪	Time Unit	Half-life, effective	Time Unit	Hazard Group ***	Annual Limit on Intake (µCi) Inh or Ing^5	Dose Rate for 1 Ci at 1 meter (rem/hr)6
^{241}Am	0.06	2	H	α	1,3,4,5,	5.49		0.06			S,P	458	y	54.8	y	48.94	y	1	6.00E-03	0.314
^{241}Am/Be	0.06	2		αèn	1,3,4,5,	5.49		0.06	3.0-6.0	147	S	458	y	54.8	y	48.94	y	1	6.00E-03	0.317 ✜
^{198}Au*	0.2	5	H	β,γ	1,4,5,6		0.962	0.412			S,U	2.67	d	280	d	2.7	d	2	1.00E+03	0.292
^{109}Cd*	20	500	M	γ	1,4,5,6			0.088			S	453	d	200	d	138.74	d	3	4.00E+01	0.185
^{252}Cf	0.02	0.5	L	α & n	1, 3,5,6	6.12			0.01-18	1.44E8/g	S	2.2	y	100	y	2.15		1	4.00E-02	2450.000 ✜
^{244}Cm	0.05	1	L	α	1,4,5,6	5.81					P	17.6	y	65.7	y	13.88	y	1	1.00E-02	0.064
^{57}Co*	0.7	20	L	EC, x-ray	1,4,5,6			0.122			S	270	d	9.5	d	9.18	d	3	7.00E+02	0.151
^{60}Co	0.03	0.8	H	β,γ	1,4,5,6		0.314	1.17, 1.33			S	5.25	y	10	y	10	y	1	3.00E+01	1.365
^{137}Cs	0.1	3	H	β,γ	1,4,5,6		0.514	0.662			S	30	y	0.2	y	70	d	2	1.00E+02	0.377
^{55}Fe*	800	20000	L	EC	1,4,5,6						S	2.6	y	11.9	y	2.2	y	4	2.00E+03	0.000
^{153}Gd	1	30	M	EC, x-ray	1,4,5,6		0	0.1			S	242	d	550	d	168.06	d	3	1.00E+02	0.172
^{68}Ge(Ga-68)*	0.7	20	L	EC, nnih,β+	1,4,5,6		1.9	0.511			S	275	d	1	d	1	d	1	1.00E+02	0.710
^{192}Ir	0.08	2		β,γ	1,4,5,6		0.67	0.468			S,U	75	d	20	d	15.79	d	1	2.00E+02	0.592
^{63}Ni*	60	2000	M	β	1,4,5,6		0.067				S	93	y	1.83	y	1.79	y	4	2.00E+03	0.000
^{103}Pd*	90	2000	L	EC, x-ray	1,4,5,6			insig			S	17	d	5	d	3.86	d	3	4.00E+03	0.229
^{147}Pm	40	1000	L	β	1,4,5,6		0.224				U	2.6	y	1.8	y	1.06	y	4	1.00E+02	0.000
^{210}Po*	0.06	2	L	α	1,4,5,6	5.3					S	138	d	30	d	42	d	1	6.00E-01	0.000
^{238}Pu	0.06	2	M	α	1,4,5,6	5.5					S	86.4	y	178	y	58.17	y	1	1.00E-02	0.079
^{239}Pu/Be	0.06	2	L	αèn	1,4,5,6	5.16			4.5	3.84/g	S	24390	y	200	y	200	y	1	1.00E-02	0.034 ✜
^{226}Ra + progeny	0.04	1	M	α,β,γ	1,4,5,6	4.76	111	0.8			S	1625	y	44	y	44	y	1	6.00E-01	0.825
^{106}Ru (^{106}Rh)*	0.3	8	L	β	1,4,5,6		0.039				P	368	d	7.3	d	7.16	d	3	1.00E+01	0.014
^{75}Se^{i}	0.2	5	M	EC, x-ray	1,4,5,6						S	120	d	11	d	10.08	d	2	5.00E+02	0.858
^{90}Sr (^{90}Y)	1	30	M	β	1,4,5,6		0.546,				P	28	y	49.3	y	18.6	y	2	4.00E+00	0.000
^{204}Tl*	20	500	M	β	1,4,5,6		0.766				S	3.8	y	10	y	9.9	d	4	2.00E+03	0.001
^{170}Tm	20	500	M	β	1,4,5,6		1.0				S	134.0	d	675.0	d	111.8	d	4	2.00E+02	0.006
^{169}Yb^{i}	0.3	8.0	H	EC, x-ray	1,4,5,6						S	31.0	d	685.0	d	29.66	d	2	2.00E+03	0.327

For Availability, H means high, M means medium, and L means low.

Table 1 Key

* Assigned by the values following	i xrays are significant
** S-solid or encapsulated, P-plated, U-unsealed	✪ Biological half-life for whole body
*** Assigned by values following	✣ Gamma plus neutron doses

Table 1 Key, Continued

[1] RADIOLOGICAL HEALTH HANDBOOK, Revised Edition, January 1970: U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, Public Health Service, Consumer Protection and Environmental Health Service, Rockville, Maryland 20852

[2] Nuclear Energy Institute: 1776 I Street NW, Suite 400, Washington, D.C. 20006 (web page)

[3] Guidelines on Calibration of Neutron Measuring Devices, Technical Report Series No. 285, IAEA, Vienna, 1988.

[4] Handbook of Radioactive Nuclides, Y. Wang, M.D.,D.Sc.(Med.), Chemical Rubber Co., Cleveland, OH, 1969.

[5] 10 CFR 20, Appendix B, Annual Occupational Limits on Intake of Radionuclides

[6] Specific Gamma Ray Dose Constants for Radionuclides Important to Dosimitry and Radiological Assessment, ORNL-118(5-82), May 1982.

Table 1 Key, Continued

Hazard Groups: In order of decreasing hazard based on D-values in terabecquerels, and slightly modified by data for dose rate at one meter.

Group 1- 0.01 ≥ value < 0.1

Group 2- 0.1 ≤ value < 1

Group 3- 1 ≤ value < 10

Group 4- 10 ≤ value

Table 1 Key, Continued

Form of Use:

(S)- Solid{usually metal}, Sealed Source{generally doubly encapsulated in stainless steel capsule, or Special Form Source{usually doubly encapsulated in stainless steel}

(U)-Unsealed{dissolved in liquid, liquid, or fine powder and unencapsulated}

(P)- Plated usually on a stainless steel or gold foil backing

Table A-2 – Radioactive Material Weaponization Example Scenarios - Methods of Obtaining

Item	Device/Source	Minimum Security Level	Method of Obtaining	Probability of Success	Discussion Weight, forces, temperatures, etc., should be considered.
			Medical		
1.	1* Gamma Knife, Blood Irradiator(^{60}Co)	IC	Armed attack team overwhelms staff and LEA 6* sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.4	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.1	Security system causes armed LEA response.
			IED – armed attack team with target of hospital containing gamma knife or blood irradiator.	1.0	Explosive device can be set and detonated before armed response can occur.
2.	2* Brachytherapy sources (^{137}Cs)	4	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm staff.
			Diversion of shipment to site	0.8	Shipments not strictly monitored, although notices are exchanged.
			Inside employee removes	1.0	In most circumstances, a person/employee can carry off the relatively portable source containers.
			Theft	0.8	In most circumstances, the source containers can easily be carried off, if a perpetrator can reach them.
			IED – armed attack team with target of hospital containing sources.	1.0	Explosive device can be set and detonated before armed response can occur.
			Industrial		
3.	Radiography, In-house (^{192}Ir, ^{60}Co)	IC	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination. Companies often pick up own sources at supplier.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.2	Security system causes armed LEA response.
			IED – armed attack team with target radiography offices/plant.	0.1	Explosive device can be set and detonated before armed response can occur. Not likely, due to remoteness of radiography offices/plant.
4.	Radiography, Field Use (^{192}Ir,	IC	Armed attack team overwhelms radiography crew.	1.0	2 or more heavily armed perpetrators can overwhelm unarmed, 2 or 3 man crew.

Table A-2 (cont'd) – Radioactive Material Weaponization Example Scenarios - Methods of Obtaining

	^{60}Co) [Vehicles are alarmed]		Diversion of shipment to site	0.2	This circumstance would, most likely, be due to an employee's action.
			Inside employee removes	0.2	Fingerprint and background checks for employees having access.
			Theft	0.4	Security system alerts radiography crew. Portable devices must have two independent physical controls that form tangible barriers to secure the material from unauthorized removal when the device is not under direct control and constant surveillance.
			IED – armed attack team with target of radiography site.	0.9	Explosive device can be set and detonated before armed response can occur. This could be done when radiography crew is at or near target location for work.
5.	Well-logging, Station [Large source: Am(Be)-241 or ^{137}Cs ≥ 10 Dvalues]	IC	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.2	Security system causes armed LEA response.
			IED – armed attack team with target of logging site.	0.1	Explosive device can be set and detonated before armed response can occur. Not likely, due to remoteness of logging stations.
6.	Well-logging Site [Large source: Am(Be)-241 or ^{137}Cs ≥ 10 Dvalues] [Vehicles are alarmed]	IC	Armed attack team overwhelms logging crew.	1.0	2 or more heavily armed perpetrators can overwhelm unarmed, 2 man crew.
			Diversion of shipment to site	0.2	This circumstance would, most likely, be due to an employee's action.
			Inside employee removes	0.2	Fingerprint and background checks for employees having access.
			Theft	0.4	Security system alerts logging crew. Portable devices must have two independent physical controls that form tangible barriers to secure the material from unauthorized removal when the device is not under direct control and constant surveillance.
			IED – armed attack team with target of radiography site.	0.9	Explosive device can be set and detonated before armed response can occur. Not likely, due to remoteness of logging sites, although there are some logging sites in or near potential targets.
7.	Well-logging Station[Tool	4	Armed attack team overwhelms staff.	1.0	2 or more heavily armed perpetrators can overwhelm staff.

Table A-2 (cont'd) – Radioactive Material Weaponization Example Scenarios - Methods of Obtaining

	(source): Am(Be)-241 or ^{137}Cs <10 Dvalues]		Diversion of shipment to site	0.7	Shipments not strictly monitored, although notices are exchanged.
			Inside employee removes	0.8	In most circumstances, an person/employee can carry off the relatively portable source containers.
			Theft	0.8	The source containers can easily be carried off, if a perpetrator can reach them.
			IED – armed attack team with target of logging site.	0.1	Explosive device can be set and detonated before armed response can occur. Not likely, due to remoteness of logging sites.
8.	Well-logging Site [Large tool (source): Am(Be)-241 or ^{137}Cs < 10 Dvalues]	3	Armed attack team overwhelms logging crew.	1.0	2 or more heavily armed perpetrators can overwhelm unarmed, 2 man crew.
			Diversion of shipment to site	0.7	This circumstance would, most likely, be due to an employee's action.
			Inside employee removes	0.2	Fingerprint and background checks for employees having access.
			Theft	0.9	Security system alerts logging crew, at most.
			IED – armed attack team with target of logging site.	0.9	Explosive device can be set and detonated before armed response can occur. There should be no target of any value at a logging site.
9.	*3, *4 Large Gauging Device (^{137}Cs, ^{60}Co)	IC	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.2	Security system causes armed LEA response.
			IED – armed attack team with target of plant where gauge in use.	**0.3**	Explosive device can be set and detonated before armed response can occur. Many sites remote from valuable targets.
10.	*3, *4 Gauging Device	4	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm staff

Table A-2 (cont'd) – Radioactive Material Weaponization Example Scenarios - Methods of Obtaining

	(^{137}Cs, ^{60}Co)		Diversion of shipment to site	0.7	Shipments not strictly monitored, although notices are exchanged.
			Inside employee removes	1.0	In most circumstances, a person/employee can carry off the relatively portable source containers.
			Theft	0.8	The source containers can easily be carried off, if a perpetrator can reach them.
			IED – armed attack team with target of plant where gauge in use.	**0.4**	Explosive device can be set and detonated before armed response can occur. Many sites remote from valuable targets.
11.	Portable Gauge Facilities [Typically: 10 mCi ^{137}Cs 44 mCi Am(Be)-241]	4	Armed attack team overwhelms staff	1.0	2 or more heavily armed perpetrators can overwhelm staff. 300 gauges needed to accumulate 1 Dvalue (3.0 Ci) of ^{137}Cs. 46 or more gauges needed to accumulate 1 Dvalue (2.0 Ci) of ^{241}Am.
			Diversion of shipment to site	0.7	This circumstance would, most likely, be due to an employee's action.
			Inside employee removes	1.0	Fingerprint and background checks for employees having access.
			Theft	1.0	No particular security system. Simple locks used.
			IED – armed attack team with target of plant where gauge in use.	**0.4**	Explosive device can be set and detonated before any response can occur.
12.	Manufacturer/ distributor (any IC qualifying quantity)	IC	Armed attack team overwhelms staff	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.7	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	1.0	Fingerprint and background checks for employees having access.
			Theft	1.0	Security system causes armed LEA response.
			IED – armed attack team with target of plant where gauge in use.	**0.4**	Explosive device can be set and detonated before armed response can occur. Many sites remote from valuable targets.
			Armed attack team overwhelms staff	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
13.	Manufacturer/ distributor (any quantity < 10 Dvalues)	4	Armed attack team overwhelms staff	1.0	2 or more heavily armed perpetrators can overwhelm staff
			Diversion of shipment to site	0.2	This circumstance would, most likely, be due to an employee's action.
			Inside employee removes	1.0	Fingerprint and background checks for employees having access.
			Theft	0.8	No particular security system. Simple locks used.

Table A-2 (cont'd) – Radioactive Material Weaponization Example Scenarios - Methods of Obtaining

			IED – armed attack team with target of plant where gauge in use.	1.0	Explosive device can be set and detonated before any response can occur.
14.	Commercial carrier for RAM (any IC qualifying quantity)	IC	Armed attack team overwhelms staff	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.2	Security system causes armed LEA response.
			IED – armed attack team with target of plant where gauge in use.	1.0	Explosive device can be set and detonated before armed response can occur. Many sites remote from valuable targets.
15.	Commercial carrier for RAM (any quantity < 10 Dvalues)	4	Armed attack team overwhelms staff	1.0	This circumstance would, most likely, be due to an employee's action.
			Diversion of shipment to site	0.2	Fingerprint and background checks for employees having access.
			Inside employee removes	1.0	No particular security system. Simple locks used.
			Theft	0.8	No particular security system. Simple locks used.
			IED – armed attack team with target of plant where gauge in use.	1.0	Explosive device can be set and detonated before any response can occur.
			Academic		
16.	*5 Large quantity of alpha emitter ≥ 10 Dvalues	IC	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.2	Security system causes armed LEA response.
			IED – armed attack team with target of academic institution containing alpha source.	1.0	Explosive device can be set and detonated before armed response can occur.
17.	Quantity of alpha emitter < 10 Dvalues	4	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Shipments not strictly monitored, although notices are exchanged.

Table A-2 (cont'd) – Radioactive Material Weaponization Example Scenarios - Methods of Obtaining

			Inside employee removes	1.0	In most circumstances, an person/employee can carry off the relatively portable source containers.
			Theft	0.8	The source containers can easily be carried off, if a perpetrator can reach them.
			IED – armed attack team with target of academic institution containing alpha source.	1.0	Explosive device can be set and detonated before armed response can occur.
18.	*5 Large beta quantity/device ≥ 10 Dvalues	IC	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.2	Security system causes armed LEA response.
			IED – armed attack team with target of academic institution containing beta source.	1.0	Explosive device can be set and detonated before armed response can occur.
19.	Quantity/device of beta emitter < 10 Dvalues	4	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Shipments not strictly monitored, although notices are exchanged.
			Inside employee removes	0.1	In most circumstances, an person/employee can carry off the relatively portable source containers.
			Theft	0.2	The source containers can easily be carried off, if a perpetrator can reach them.
			IED – armed attack team with target of academic institution containing beta source.	1.0	Explosive device can be set and detonated before armed response can occur.
20.	*5 Large gamma quantity/device ≥ 10 Dvalues	IC	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.2	Security system causes armed LEA response.
			IED – armed attack team with target of academic institution containing gamma source.	1.0	Explosive device can be set and detonated before armed response can occur.
21.	Gamma quantity/device < 10 Dvalues	4	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Shipments not strictly monitored, although notices are exchanged.
			Inside employee removes	0.5	In most circumstances, an person/employee can carry off the relatively portable source containers.

Table A-2 (cont'd) – Radioactive Material Weaponization Example Scenarios - Methods of Obtaining

			Theft	0.8	The source containers can easily be carried off, if a perpetrator can reach them.
			IED – armed attack team with target of academic institution containing gamma source.	1.0	Explosive device can be set and detonated before armed response can occur.
22.	*5 Large neutron quantity/device ≥ 10 Dvalues	IC	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	0.2	Closely monitored transport. *7 May be armed LEA at point of origin and/or destination.
			Inside employee removes	0.1	Fingerprint and background checks for employees having access.
			Theft	0.2	Security system causes armed LEA response.
			IED – armed attack team with target of academic institution containing neutron source.	1.0	Explosive device can be set and detonated before armed response can occur.
23.	Neutron quantity/device < 10 Dvalues	4	Armed attack team overwhelms staff and LEA sent on alarm activation.	1.0	2 or more heavily armed perpetrators can overwhelm 1 armed LEA.
			Diversion of shipment to site	1.0	Shipments not strictly monitored, although notices are exchanged.
			Inside employee removes	0.5	In most circumstances, an person/employee can carry off the relatively portable source containers.
			Theft	0.8	The source containers can easily be carried off, if a perpetrator can reach them.
			IED – armed attack team with target of academic institution containing neutron source.	1.0	Explosive device can be set and detonated before armed response can occur.

*1 IC means Increased Controls and requires: employee fingerprinting and background check, escorted access, a security system which alerts and causes a Law Enforcement Agency response by an LEA armed officer, as a minimum.

*2 a numeric value for Minimum Level of Security is the sum of the methods employed to achieve security, i.e., 1 padlocked container in 1 padlocked cabinet, stored in 1 locked room, located in 1 locked building with (1) security guard would be 5 levels of security.

*3 Damage from an explosion at a petrochemical or chemical plant will be primarily from the chemical side, not radiological. Gauging devices are not usually located close to one another.

*4 Activities of isotopes in gauging devices are usually less than D-values.

*5 Although there may be an aggregate of a large quantity of material, it can be expected to be spread over campus, not all co-located.

*6 LEA means Law Enforcement Agency (IC's do not allow for private security – armed or not).

*7 Quantities ≥ 100 X IC quantity require 90 days notice to NRC – which issues special order for shipping/transport/receiving. Order usually requires armed LEA at point of origin and destination.

Table A-3 – Radioactive Material Weaponization Scenarios - Methods of Dispersal

Item	Device/Source	Form	Method of Dispersal	Actual Effect	Terror Effect	Probability of Success	**Discussion** Weight, forces, temperatures, etc., needed to remove encapsulation, should be considered.
			Medical				
1	Gamma Knife, Blood Irradiator (^{60}Co) Gamma hazard	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, maybe fatal, radiation levels until discovery. Probably serious exposure to perpetrators.
		Unsealed	^{60}Co removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	^{60}Co removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion and removal by water treatment system minimizes concentration. If ingested, body would probably eliminate rapidly. Probably serious exposure to perpetrators.
		Unsealed	^{60}Co removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.
2	Brachytherapy sources (^{137}Cs) Gamma hazard	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, maybe fatal, radiation levels until discovery. Probably serious exposure to perpetrators.

Table A-3 (cont'd) – Radioactive Material Weaponization Scenarios - Methods of Dispersal

		Unsealed	^{137}Cs removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	^{137}Cs removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Fair	Fair	0.2	Rapid dispersion. ^{137}Cs usually in water soluble form - removal by water treatment system unknown. If ingested, body would probably eliminate slowly. Probably serious exposure to perpetrators.
		Unsealed	^{137}Cs removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.
			Industrial				
3	Radiography (^{192}Ir) Gamma hazard	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, maybe fatal, radiation levels until discovery. Probably serious exposure to perpetrators.
		Unsealed	^{192}Ir removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	^{192}Ir removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion. Removal by water treatment system unknown. If ingested, body would probably eliminate slowly. Probably serious exposure to perpetrators.
		Unsealed	^{192}Ir removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.

Table A-3 (cont'd) – Radioactive Material Weaponization Scenarios - Methods of Dispersal

		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.
4	Radiography (^{60}Co) Gamma hazard	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, maybe fatal, radiation levels until discovery. Probably serious exposure to perpetrators.
		Unsealed	^{60}Co removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	^{60}Co removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion and removal by water treatment system minimizes concentration. If ingested, body would probably eliminate rapidly. Probably serious exposure to perpetrators.
		Unsealed	^{60}Co removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.
5	Well-logging (^{137}Cs) Gamma hazard	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, maybe fatal, radiation levels until discovery. Probably serious exposure to perpetrators.
		Unsealed	^{137}Cs removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.

Table A-3 (cont'd) – Radioactive Material Weaponization Scenarios - Methods of Dispersal

		Unsealed	^{137}Cs removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion. ^{137}Cs usually in water soluble form - removal by water treatment system unknown. If ingested, body would probably eliminate slowly. Probably serious exposure to perpetrators.
		Unsealed	^{137}Cs removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.
6	Well-logging [Am(Be)-241] Neutron hazard	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, radiation levels until discovery. Probably serious exposure to perpetrators. Possible fatalities long term (years).
		Unsealed	^{241}Am removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	^{241}Am removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Moderate dispersion. Removal by water treatment system unknown. If ingested, body would probably eliminate slowly. Probably serious exposure to perpetrators.
		Unsealed	^{241}Am removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere, at any time.

Table A-3 (cont'd) – Radioactive Material Weaponization Scenarios - Methods of Dispersal

7	Gauging Device (^{137}Cs) Gamma hazard	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, maybe fatal, radiation levels until discovery. Probably serious exposure to perpetrators.
		Unsealed	^{137}Cs removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	^{137}Cs removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion. ^{137}Cs usually in water soluble form - removal by water treatment system unknown. If ingested, body would probably eliminate slowly. Probably serious exposure to perpetrators.
		Unsealed	^{137}Cs removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere, at any time.
8	Gauging Device (^{60}Co) Gamma hazard	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, maybe fatal, radiation levels until discovery. Probably serious exposure to perpetrators.
		Unsealed	^{60}Co removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	^{60}Co removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion and removal by water treatment system minimizes concentration. If ingested, body would probably eliminate rapidly. Probably serious exposure to perpetrators.

Table A-3 (cont'd) – Radioactive Material Weaponization Scenarios - Methods of Dispersal

		Unsealed	^{60}Co removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.
9	Portable gauge [Typically: 10 mCi ^{137}Cs 44 mCi Am(Be)-241]	Note: 300 gauges needed to accumulate 1 Dvalue (3.0 Ci) of ^{137}Cs. 46 or more gauges needed to accumulate 1 Dvalue (2.0 Ci) of ^{241}Am.					
		Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to radiation levels until discovery. Possibly serious exposure to perpetrators, but passenger exposure minimal due to low activity of individual sources.
		Unsealed	Radioactive material removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Possibly serious exposure to perpetrators, but minimal exposure to public members. Restriction of area during decon.
		Unsealed	Radioactive material removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion and removal by water treatment system minimizes concentration. Possibly serious exposure to perpetrators.
		Unsealed	Radioactive material removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Possibly serious exposure to perpetrators, but little exposure to public members.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.

Table A-3 (cont'd) – Radioactive Material Weaponization Scenarios - Methods of Dispersal

Academic							
10	Quantity of alpha emitter	Since alphas cannot penetrate dense materials, would not be a sealed source. If Beryllium etc. present for neutrons, would then be sealed.					
		Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to neutron radiation levels until discovery. Possibly serious exposure to perpetrators. Probably no deaths for typical quantities.
		Unsealed	Radioactive material removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Possibly serious internal exposure to perpetrators. Restriction of area during decon.
		Unsealed	Radioactive material removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion and removal by water treatment system minimizes concentration. Possibly serious internal exposure to perpetrators.
		Unsealed	Radioactive material removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Possibly serious internal exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.
11	Beta quantity/ device	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious radiation levels until discovery. Possibly serious exposure to perpetrators. Possible deaths for typical quantities if long exposures.

Table A-3 (cont'd) – Radioactive Material Weaponization Scenarios - Methods of Dispersal

		Unsealed	Radioactive material removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Possibly serious internal exposure to perpetrators. Restriction of area during decon.
		Unsealed	Radioactive material removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion and removal by water treatment system minimizes concentration. Possibly serious internal exposure to perpetrators.
		Unsealed	Radioactive material removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Possibly serious internal/external exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere at any time.
12	Large gamma quantity/device	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious, maybe fatal, radiation levels until discovery. Probably serious exposure to perpetrators.
		Unsealed	Gamma emitter removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	Gamma emitter removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Rapid dispersion. If gamma emitter in water soluble form - removal by water treatment system unknown. If ingested, body would probably eliminate slowly. Probably serious exposure to perpetrators.
		Unsealed	Gamma emitter removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere, at any time.

Table A-3 (con't) – Radioactive Material Weaponization Scenarios - Methods of Dispersal

13	Large neutron quantity/device	Sealed	Explosive dispersal of sealed sources.	Poor	Fair	1.0	Sealed sources would be scattered in explosion area. Minimal exposure as area cleared of people. Cleanup would be easy. Short time restriction of area during decon.
		Sealed	Placement of individual or clustered sources in transportation system (bus, subway) under seats. Schools, universities, and government offices could also be targeted.	Good	Excellent	0.9	Many exposed to serious radiation levels until discovery. Probably serious exposure to perpetrators. Possible fatalities long term (years).
		Unsealed	Neutron emitter removed from cladding and placed in dispersible condition. Dispersed by explosion.	Fair	Fair	0.3	Widespread contamination of property, facilities in area of explosion. Expensive, long term decontamination probable. Probably serious exposure to perpetrators. Restriction of area during decon.
		Unsealed	Neutron emitter removed from cladding and placed in dispersible (water soluble) condition. Dispersed into water supply.	Poor	Poor	0.2	Moderate dispersion. Removal by water treatment system unknown. If ingested, body would probably eliminate slowly. Probably serious exposure to perpetrators.
		Unsealed	Neutron emitter removed from cladding and placed in dispersible (water soluble) condition. Dispersed into food supply. Schools, universities, and government offices could be targeted.	Fair	Fair	0.6	Much higher exposure than water contamination. Higher concentrations ingested by persons. Probably serious exposure to perpetrators.
		Sealed or Unsealed	Perpetrators hide material in unknown location.	None	Excellent	1.0	Population afraid that material will be dispersed among them, anywhere, at any time.

Appendix B - Estimating Maximum Reasonable Consequence from Terrorist Events Involving MIAN Materials

Consequence analysis consists of estimating the "worst *reasonable* case" results of each relevant threat scenario using a common set of metrics. Consequences of interest include both those that can be quantified and losses that can only be described in qualitative terms.

For estimating terrorist consequences, the "worst reasonable case" assumption serves two purposes: (1) it reflects the fact that, in the case of terrorist attacks, the assailants are knowledgeable about the facility and its technologies and intend to inflict the maximum damage; and (2) where threat scenario could be considered in multiple locations, it permits the evaluation team to decide which to use in the assessment.

The worst reasonable case consequence should consider that the adversary is intelligent, well-informed about the facility and its technologies and work-flows, and adaptive and will attempt to optimize or maximize the consequences of a particular attack scenario. However, it is not appropriate to assume that all uncontrollable variables that could exacerbate the damages (such as wind speed, direction, and unpredictable events) occur simultaneously. Judgment is necessary in defining the worst reasonable case.

The following discussion provides more detailed guidance on estimating and reporting consequences:

Fatalities and Serious Injuries. Human safety and health consequences should be expressed in number of fatalities and number of serious (acute) injuries that occur immediately or within a short period of time, as opposed to health problems revealed over the span of more than a few weeks. "Serious" injuries are those that result in lost work time or disability. However, long-term injuries such as cancer caused by exposure to radioactive materials will contribute to public terror and psychological impacts. These effects may be very significant and should be included in consequence estimates.

While it is generally desirable to estimate a discrete number of fatalities and injuries, it is difficult to estimate exactly. For this reason, the RAMCAP Plus® process provides pre-specified ranges for estimating fatalities (Table A2-2) and injuries (Table A2-3), respectively, for a particular attack scenario. Here, the analyst can assign the consequence to one of fourteen ranges, or 'bins," each with a range of fatalities or injuries. In Tables A2-2 and A2-3, the range in each bin increases by a factor of two over the next smaller bin. The use of a constant scaling factor produces a logarithmic scale, in this case one at base 2.

Table B-1. **RAMCAP Plus® Consequence Parameters**

1. Human Health & Safety Impacts
   a. Fatalities – on site/off site*
   b. Serious injuries – on site/off site*
   c. Acquisition of dangerous materials/ weapons of mass destruction
   d. Contamination to water, food or pharmaceutical products

2. Financial & Economic Impacts
   a. Asset replacement costs*
   b. Remediation costs*
   c. Business interruption costs*
   d. Negligence liability costs*
   e. National/regional economic losses/multiple sector impacts*
   f. Loss of critical data
   g. Loss of reputation or business viability

3. National Security & Government Functionality Impacts
   a. Military mission importance and readiness
   b. Delivery of public health services
   c. Contamination/disruption to critical potable water or sanitation services
   d. Interruption of governance, public safety or law enforcement

4. Environmental Impacts
   a. Permanent or long-term damage to the ecosystem
   b. Pollution of air, water or soil

5. Psychological Impacts
   a. Impact to iconic/symbolic assets
   b. High profile and/or symbolic casualties
   c. Loss of consumer confidence
   d. Loss of confidence in governmental institutions

* Quantitative estimates; all others are quantitatively described.

Table B-2. Consequence Scale for Fatalities

	CONSEQUENCE SCALES – FATALITIES													
Number of Fatalities														
RAMCAP Consequence Criteria ("Bin Numbers")	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Ranges in Number of Fatalities	0 – 25	26 – 50	51 – 100	101 – 200	201 – 400	401 – 800	801 – 1,600	1,601 – 3,200	3,201 – 6,400	6,401 – 12,800	12,801 – 25,600	25,601 – 51,200	51,201 – 102,400	102,401 +

Table B-3. Consequence Scale for Serious Injuries

	CONSEQUENCE SCALES – INJURIES													
Number of Injuries														
RAMCAP Consequence Criteria ("Bin" Numbers)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Ranges in Number of Injuries	0 – 25	26 – 50	51 – 100	101 – 200	201 – 400	401 – 800	801 – 1,600	1,601 – 3,200	3,201 – 6,400	6,401 – 12,800	12,801 – 25,600	25,601 – 51,200	51,201 – 102,400	102,401 +

Financial and Economic Losses. "Economic impacts" are widely recognized as key indicators of consequences in analyzing risks from terrorism and natural disasters. Specifically defining the meaning of "economic impacts" is necessary for risk management. Estimating financial and economic losses requires specification of the stakeholders and their decisions. Different stakeholders bring different perspectives and use different metrics for their decisions. The perspectives of a variety of stakeholders could be relevant, depending upon the decisions, but the perspectives of the following two groups of stakeholders are particularly germane to virtually all decisions pertaining to security, reliability, and resilience:

- *The owners/operators of the critical infrastructures,* who are responsible for maintaining the security of their facilities, the reliability of their services and their financially sustainable operation. They must address issues of risk and risk management for their facilities and networks, such as how to reduce the vulnerabilities, threat likelihood, or consequences of attack. They must also address the facility's resilience, or how to maintain continuity of operations through an attack or, if operations are interrupted by the attack, how quickly the organization recovers its ability to provide the basic services and quality demanded of it.

- *The general public of the regional community* (or "the regional economy," "the community," "the metropolitan area," etc.), particularly, but not limited to, the suppliers and customers served by the facility, usually represented or overseen by public authorities or by public/private partnerships. The public is generally more concerned with reliability, quality and resilience – how often service is interrupted and how quickly service is restored after an interruption at the quality they expect (so they can resume their own normal functioning), as well as how best they can cope with the lack of services during an interruption.

These perspectives differ, in part, because of "externalities" – impacts on the community not included in the usual revenue-and-cost decision context of facility operators. Such externalities are the economic consequences of direct and indirect ("ripple effect") to customers and their customers, suppliers and their suppliers (*ad infinitum*) and to the general economy caused by the denial of lifeline services. These are not included in the facility's economics, so generally are not included in the facility's decision-making, but these considerations can be central to the decisions of the relevant public and public/private organizations responsible for the well-being of the community. The existence of externalities is indicative of market failures" to allocate resources optimally. Utilities providing essential lifeline services should always examine both perspectives in their risk/resilience management decision-making. Others providing infrastructure services would generally be well served to examine both in security and continuity investment decision-making.

Other stakeholders, e.g., neighbors of major facilities, suppliers, customers, etc., also have relevant issues and perspectives that may need to be analyzed separately. Similarly, higher order communities (e.g., state, multi-state regions, the nation as a whole) are also relevant stakeholders. Additionally, the effect of having a terrorist attack in which radioactive materials are used will in all probability have a profound effect on public awareness of such events and significant increases in security will undoubtedly result. These effects may result in paradigm shifts and could result in large expenditures that cannot be predicted accurately. Thus, for the purposes of scenario consequence assessment and comparison consequences should be limited to the parameters listed in Table A2-1.

Owners' financial losses. In estimating owners' losses, the principle is that value, whether gain or loss, is the incremental (decremental in losses) discounted net present value of future cash flows. Net present value implies that only future cash flows are relevant, prior cash flows are "sunk," and inflation is treated (choosing real or nominal) consistently for all estimates. The owner's net loss is estimated as a decrement from a "business-as-usual" base case, in which there is no incident. If the owner/operator is a taxable entity, the estimates are adjusted to an after-tax basis in a later chapter. The elements of the owner's loss are:

- Repair and replacement costs for assets damaged or destroyed in the attack, estimated with an "emergency premium," when relevant, to reflect the higher costs of "urgent" construction compared to "business as usual" construction;
- Business interruption costs, including revenue net of avoidable variable costs, emergency operations costs, plus any penalties for service interruption;
- Environmental remediation and personal liability costs (after any insurance payments);
- Abandonment costs, if any; and
- Other costs directly attributable to the attack.

The time-weighted present value of the sum of these losses should be used. A single, discrete estimate may be used or the provided ranges may be used.

Table B-4. **Consequence Scale for Financial Losses to the Owner/Operator**

	CONSEQUENCE SCALE — FINANCIAL LOSSES TO THE OWNER/OPERATOR ($-million)													
Owner's Financial Loss ($-million)														
RAMCAP Consequence Criteria ("Bin Numbers")	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Owner's Financial Loss (in $-million)	0 – 25	26 – 50	51 – 100	101 – 200	201 – 400	401 – 800	801 – 1,600	1,601 – 3,200	3,201 – 6,400	6,401 – 12,800	12,801 – 25,600	25,601 – 51,200	51,201 – 102,400	102,401 +

The following discussion contains examples of scenarios considered and the bins suggested to represent the consequences of employing radioactive materials by terrorists. These are examples only and are presented to illustrate the binning procedure. When considering an actual scenario it is recommended that financial analysts provide estimates of consequences based on modeling of the actual commerce in the region considering the disruption caused by the event.

Description of Scenario and Example of Consequence Bin

1) Material is stolen or otherwise obtained but not deployed. This consequence is primarily due to the unsettling effect the event will have on the general public that knows that material is in the hands of terrorists and could be used. This scenario is not expected to produce fatalities or injuries and the financial impact is relatively low.
   Estimate financial consequence bins 0 to 3.

2) Small explosion spreads material in local area of low population density. No serious injuries are expected and no fatalities. No major disruption of services is expected. Consequences are primarily due to general unease of the public and cost of cleanup of materials.
   Estimate financial consequence bins 3 to 8.

3) Acquisition of large amount of material such as pencils for radiation facility. No dispersal or attack. This consequence is primarily due to the unsettling effect the event will have on the general public that knows that material is in the hands of terrorists and could be used.
   Estimate financial consequence bins 1 to 5 depending on the location.

4) Explosion at a facility that contains radioactive materials that has the potential for spreading the material through the explosion of an ensuing fire. Examples of this include using improvised explosive devices at radiation facilities, or a nuclear pharmacy, etc. The damage will be limited to the area near the facility. Consequences could include fatalities and serious injuries due to the explosion. Costs include clean-up costs and the loss of the facility. Possible adverse effects to other similar facilities, such as shutdown and ladditional security requirements are also considered.
   Estimate financial consequence bins 4 to 8 depending on the location. Fatalities and serious injuries are estimated based on the facility and the attack scenario.

5) Dispersing material at public location such as subway or other public transportation (including major airports) to deny service and cause alarm.
   Estimate financial consequence bins 3 to 6 depending on the location. No fatalities and serious injuries are expected.

6) Dispersing material in a public place such as subway or other public transportation (including major airports) in more than one place simultaneously.
   Estimate financial consequence bins 4 to (?) depending on the locations and number of locations attack. No fatalities and serious injuries are expected.

7) Deploying material at iconic or critical locations (Wall Street, Washington, DC governmental buildings, communications centers, etc.)
   Estimate financial consequence bins 4 to (?) depending on the locations and number of locations attack. No fatalities and serious injuries are expected.

8) Ingestion of material by public official or iconic figure. (Material must be capable of causing extreme injury or fatality to individuals that ingest it.)
   Estimate financial consequence bins 4 to (?) depending on the individual attack and whether the/she is fatally injured.

9) Food/Medicine/water contamination that can be obtained by general public. Material is consumable and could be distributed by normal distribution channels.
   Estimate extreme financial consequence. Number of fatalities and serious injuries depends on the extent of the attack.

10) Dispersal of radioactive materials at public site at gatherings of large numbers of people such as sports events or concerts. The material can be dispersed by explosion or other methods.
   Estimate extreme financial consequence.

Number of fatalities and serious injuries depends on the extent of the attack.

11) Major explosion in highly populated area such as Times Square in New York. Consequences include major news coverage, disruption of services, fatalities, serious injuries, and high propaganda value to terrorists.

    Estimate extreme financial consequence.
    Number of fatalities and serious injuries depends on the extent of the attack.

12) Multiple simultaneous explosions at sites similar to those described above.

    Estimate extreme financial consequence.
    Number of fatalities and serious injuries depends on the extent of the attack.

Appendix C - Comparison of NRC Increased Controls Isotopes with the IAEA Dangerous Quantities Isotopes

In 2005, the U.S. Nuclear Regulatory Commission (NRC) ordered that certain radioactive materials (or isotopes), above certain quantities, be provided with special, enhanced security arrangements to prevent unauthorized removal for possible use as a terrorist's weapon. The new requirement is called "Increased Controls (IC)" and applies equally to NRC and Agreement State (AS) licensees. As a minimum, security systems which continuously monitor the materials and notify local law enforcement agencies of breached security, providing for an armed response, along with background checks and fingerprinting of persons authorized to deal with the materials, are now a requirement for storage and use of these materials. Enhanced security, such as alarmed vehicles, is also now required. Nuclear power plants, certain sterilization irradiators, and manufacturers are under a higher level of security called "safeguards."

Prior to the above, the International Atomic Energy Agency (IAEA) had distributed a list of isotopes that it had reviewed and were deemed"Dangerous Quantities of Radioactive Materials." The isotopes and quantities listed are addressed as "D-values."

According to the IAEA, the D-value is "that quantity of radioactive material that, if uncontrolled, could result in the death of an exposed individual or a permanent injury that decreases that person's quality of life."[26]

If one compares the NRC IC list (attached below) with the IAEA D-value list, it becomes apparent that the NRC listed isotopes are on the IAEA list, but are 10 times the basic D-value. For example, cesium-137 is on the IC list with a threshold value of 1 Terabecquerel (TBq). It is also on the IAEA list with a D-value of .1 TBq (2.7 curies). When quantities are listed in units of curies, the IAEA rounds the values so they appear a little different than the amounts listed by the NRC.

The NRC IC list shows 16 isotopes ranging from 0.2 TBq to 400 TBq. The IAEA[27] list shows approximately 373 isotopes, with about 17 being unlimited. Listed isotopes indicated as "unlimited" have special circumstances that reduce their health threat.

There are over 350 isotopes for which the IAEA has established D-values. The NRC has identified 16 of those isotopes which require more stringent security when the quantities exceed 10 times the IAEA D-value. While the NRC and the IAEA selected the most commonly used radionuclides, the D-values have not been restricted on that basis. A large number of those radionuclides listed in the D-values table are not normally found in common use and, therefore, are far less likely candidates for terrorist use or accidental release.

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[26] IAEA, "EPR-D-Values 2006, Dangerous Quantities of Radioactive Material (D-Values), (Vienna, 2006).

[27] Ibid., p. 3

Table C-1. Radionuclides of Concern

Radionuclide		Quantity of Concern[1] (TBq)	Quantity of Concern[2] (Ci)	IAEA D-value (TBq)[28]
^{241}Am	Am-241	0.6	16	0.06
^{241}Am(Be)	Am-241/Be	0.6	16	0.06
^{252}Cf	Cf-252	0.2	5.4	0.02
^{244}Cm	Cm-244	0.5	14	0.05
^{60}Co	Co-60	0.3	8.1	0.03
^{137}Cs	Cs-137	1	27	0.1
^{153}Gd	Gd-153	10	270	1.0
^{192}Ir	Ir-192	0.8	22	0.08
^{147}Pm	Pm-147	400	11,000	40
^{238}Pu	Pu-238	0.6	16	0.06
^{238}Pu(Be)	Pu-238/Be	0.6	16	0.06
^{226}Ra	Ra-226[5]	0.4	11	0.04
^{75}Se	Se-75	2	54	0.2
^{90}Sr (^{90}Y)	Sr-90 (Y-90)	10	270	1
^{170}Tm	Tm-170	200	5,400	20
^{169}Yb	Yb-169	3	81	0.3
Combinations of radioactive materials listed above[3]		See Footnote Below[4]		

[1] The aggregate activity of multiple, collocated sources of the same radionuclide should be included when the total activity equals or exceeds the quantity of concern.

[2] The primary values used for compliance with this Order are TBq. The curie (Ci) values are rounded to two significant figures for informational purposes only.

[3] Radioactive materials are to be considered aggregated or collocated if breaching a common physical security barrier (e.g., a locked door at the entrance to a storage room) would allow access to the radioactive material or devices containing the radioactive material.

[4] If several radionuclides are aggregated, the sum of the ratios of the activity of each source, i of radionuclide, n, **A(*i*,*n*)**, to the quantity of concern for radionuclide n, **Q(*n*)**, listed for that radionuclide equals or exceeds one. [(aggregated source activity for radionuclide A) ÷ (quantity of concern for radionuclide A)] + [(aggregated source activity for radionuclide B) ÷ (quantity of concern for radionuclide B)] + etc..... >1

[5] On August 31, 2005, the NRC issued a waiver, in accordance to Section 651(e) of the Energy Policy Act of 2005, for the continued use and/or regulatory authority of Naturally Occurring and Accelerator-Produced Material (NARM), which includes 226Ra. The NRC plans to terminate the waiver in phases, beginning November 30, 2007, and ending on August 7, 2009. The NRC has authority to regulate discrete sources of 226Ra, but has refrained from exercising that authority 2 until the date of an entity's waiver termination. For entities that possess 226Ra in quantities of concern, this Order becomes effective upon waiver termination. For information on the schedule for an entity's waiver termination, please refer to the NARM Toolbox website at http://nrcstp.ornl.gov/narmtoolbox.html

The NRC has issued orders to its licensees to institute IC for radioactive sources which meet the definition of a Category 2 quantity as described in IAEA Tech-Doc 1344. These orders are currently being replaced by rule (proposed 10 CFR 37). The orders/rules add a further constraint that each licensee must meet the quantity limits for the aggregate of all sources listed on their licenses. Use of the sum of the fractions rule is required to be applied for each radionuclide listed on the license.

These orders, soon to be rule, because of regulatory constraints can only address individual licensees. The orders/rules cannot address multiple licensees in a given area. Certainly, there will be numerous licensees in metropolitan areas. Most of them will likely not individually possess quantities of radionuclides requiring IC. Groups of these licensees, however, may together possess considerably more than Category 2 quantities of certain radionuclides. None of these licensees could be required by existing orders or the proposed rule to employ the additional security requirements imposed under IC.

RAMCAP Plus® is a voluntary program providing the licensees who are not subject to IC a mechanism to evaluate their potential liabilities. The evaluation assumes that the licensees' radioactive sources might be used as part of a radioactive dispersal device or put to some other malicious use and calculates potential costs in lives and dollars for such an event. This tool could be used by the radiation safety professional as a means to justify voluntarily increases in security for radioactive sources at his facility.

Just as the NRC established a trigger for initiating increased controls at the Category 2 level, a minimum amount of radioactive material needs to be determined for use as a trigger for conducting the RAMCAP Plus® self-evaluation. The D-value or lower limit of a Category 3 source was adopted as that minimum value. It is the smallest amount of a radioactive material, based on the adopted scenarios, "which, if uncontrolled, could result in the death of an exposed individual or a permanent injury that decreases that person's quality of life." The activity of Category 3 sources start at the D-value and increase to just under 10 times the D-value, which is the starting activity for Category 2 sources. Put another way, in order to have a Category 2 quantity of radioactive material, one must have at least 10 D-values of that radionuclide. Smaller sources could be aggregated to produce the Category 2 quantity of material, but the likelihood of that occurrence diminishes as the activity of sources decreases. The number of sources required to add up to a D-value would increase in the following manner: 10 divided by the fraction of the D-value.

Appendix D - Possible Scenarios and Sources for Obtaining and Deploying MIAN Materials

1. Field Sources – Radiography, well logging sources, gauges, etc.

Description of Application:

Many sources of radiation are taken out of their facility of storage for use in other areas. For industrial radiography, gamma sources are taken in their shielded containers (called cameras) to X-ray various dense structures, such as steel pipe/objects, building structures, bridges, etc. In well logging, neutron sources are taken to field sites to evaluate oil and gas wells and their geology. Unsealed short-lived materials are also used in small quantities for tracer studies. Many types of gauges are used in the field to evaluate soils, concrete, and asphalt, as a minimum. Gauges are also outfitted on vehicles for checking the density of cement. The use of the radioactive material can be from within a few feet of a residence to many miles out in the country under very isolated conditions.

Radionuclides most commonly utilized:

Industrial Radiography (gamma):
^{192}Ir, 60Co, 75Se, ^{169}Yb.
Well logging (neutron and gamma):
^{241}Am(Be), ^{137}Cs, ^{60}Co, ^{59}Fe.
Tracer studies (unsealed gamma):
^{131}I, ^{46}Sc, ^{124}Sb, ^{110m}Ag, ^{3}H, ^{192}Ir.
Portable gauges (neutron and gamma):
^{241}Am(Be), ^{137}Cs, ^{60}Co, ^{59}Fe.
Mobile gauges (gamma):
^{137}Cs, ^{60}Co.

Form of Material:

All of the sources used in radiography and in gauges will in the form of a metallic powder or pellets doubly encapsulated in stainless steel. The quantities can range from millicuries to curies. The same is true for the well logging sources. Tracer materials will be in liquid form, or absorbed by "sand." The materials, usually of millicurie quantities, are generally mixed with sand or similar man-made material which is pumped down-hole. The radiography and most gauge source shielding containers can be lifted by one person. Some of the well logging neutron source containers will require two persons to handle them. Tracer materials containers are very light. Industrial radiography sources will be dangerous to handle outside of their shielding. Most of the other sources can be handled by using "remote handling tools".

Security and gap analysis:

The radiography sources will all fall under NRC required Increased Controls (IC). The Americium sources used in the well-logging industry generally are found in quantities of 1, 3, 5, and 20 curies. A 20-curie source by itself falls under IC's. A large ^{137}Cs or ^{60}Co gauge could fall under IC's, but large gauges are not common. IC quantity materials are required to be transported in vehicles with alarm systems manned by persons who have had background checks.

Possible Scenarios for obtaining material:

Since transportable devices are designed to be carried/moved by one or two persons, they are somewhat more vulnerable to unauthorized removal. They are most vulnerable when they are in transport. The transport vehicle, although alarmed for IC materials, may be parked at a restaurant, motel, or even a work site with the authorized personnel not present. Theft would be relatively easy. A person could follow a crew from the storage location to a remote work site and use force to remove the radioactive material. When stored in its usual secure storage location, IC materials are far more difficult to acquire. Non-IC materials would be relatively easy to acquire in either situation.

Deployment potential:

The ^{192}Ir, ^{60}Co, and very large ^{137}Cs sources would probably be most useful for external exposure of individuals, such as placement on a bus or subway system with many persons being within a foot or so of the source for a half an hour. ^{241}Am would probably be better used by removing it from encapsulation and putting it into an ingestible form where it could be introduced to air (by explosion), water, or food. Portable gauges are numerous, but contain very small quantities. They could, however, be stolen and accumulated to collect a serious quantity of material.

2. Nuclear Pharmacies - Provide medical radioactive materials for legitimate buyers.

Description of Application:
Nuclear pharmacies receive curie quantities of radioactive material that are redistributed as radiopharmaceuticals to medical facilities in their area for diagnostic studies and therapy. They may also distribute check and calibration sources (small quantities), depending on how their radioactive material license is set up. The most common isotope is Technetium-99m (^{99m}Tc). It is received in a container (commonly called a cow) which contains Molybdenum-99 (^{99}Mo) which decays to ^{99m}Tc. Periodically, the 99mTc is extracted ("milked") from the container. It is then either sent to a medical facility as bulk quantities (large, millicurie quantities) or tagged to an agent which is then sent to the facility as a unit patient dose. Other isotopes are used, depending on the medical procedure. Some hospitals have their own nuclear pharmacies.

Radionuclides most commonly utilized:
In general, isotopes used in nuclear medicine are very short-lived (half lives of hours to days):

Diagnostic:
^{99}mTc, ^{99}Mo, ^{111}In, ^{201}Th, ^{18}F, ^{67}Ga, ^{11}C, ^{82}Rb.

Therapeutic:
^{131}I, ^{90}Y, short-lived α-emitters (^{111}At, ^{223}Ra, ^{212}Bi)

Form of Material:
Diagnostic radiopharmaceuticals are in liquid form for injection while therapeutic radiopharmaceuticals can be in the form of a capsule for oral administration or injected. Check and calibration sources are generally encapsulated in anything from plastic to steel.

Security and gap analysis:
All entities must have a radioactive material license. There should not be any circumstances involving IC quantities for nuclear pharmacies. However, the large quantities of radioisotopes are in a form that is useful for intake and are under minimum security arrangements, so they should be a large cause for concern.

Possible Scenarios for obtaining material:
Forced entry and theft/burglary would be relatively easy as pharmacy staff are not equipped to address force and pharmacies usually have no special security arrangements – other than an alarm system. An insider could easily arrange for unauthorized removal of materials. There have been a number of cases in Texas in which radiopharmaceuticals were redirected to unauthorized locations, or in an unauthorized manner, simply "to make a profit." An organized group could easily do the same for malevolent purposes.

Deployment potential:
The radiopharmaceuticals are generally in readily dispersible form. Their best use would probably be to introduce the materials to food or water supplies. They could probably only be used on small scale assaults – say cafeterias, or local water bottles. A water system would rapidly disperse the material and make it ineffective for providing any significant doses. Adding radiopharmaceuticals to food, could have serious consequences – particularly large quantities of therapeutic materials. For example, I-131, which accumulates in the thyroid, could be added to food in large quantities and seriously injure or destroy the thyroids of those who consumed the food. These radionuclides have short half-lives and, therefore, to be used effectively would have to be deployed quickly. This would make them less desirable as a terrorist weapon. They could be used if in sufficient quantity. However, they would not be effective for denial of service as their short half-lives would assure that the facilities they contaminated would be back in service after a relatively short time.

3. Medical Facility - Used for treatment or diagnosis.

Description of Application:
Radioactive material is used in medical facilities for either diagnosis or therapy. Most medical facilities now receive the radioactive material from a nuclear pharmacy in the form of unit doses (the dose is prepared by the pharmacy to be directly used by the medical facility). A few hospitals, usually very large ones, still obtain the radioactive material in bulk quantities and prepare their own doses. The unsealed radioactive mate-

rials, whether diagnostic or therapeutic, are in a form that is readily absorbed into the body. Diagnostic quantities are very small (microcurie and millicurie) amounts. Therapeutic unsealed quantities are millicurie amounts. Sealed sources (for therapy) range from millicuries to curies, although some sealed sources are small and used for instrument calibration.

In diagnostic procedures, the radiopharmaceutical is injected or introduced into the patient's body where, after a measured time period, a device called a camera picks up and records the radiation being emitted by "targeted" organs in the patient – providing a 2 or 3 dimensional image of internal structures. In therapy, the radioactive material is either inserted into an organ (Brachytherapy) or a beam of radiation is "focused" onto the area of treatment (teletherapy). Some devices are used to provide a large radiation field rather than a beam. Devices commonly used are the gamma knife (brain), blood irradiator, and teletherapy units (these have mostly been replaced by accelerators).

Radionuclides most commonly utilized:
While there are many short-lived radionuclides that are used for radiopharmaceuticals and therapy, the most common are:

Diagnostic:
^{99m}Tc, ^{99}Mo, ^{111}In, ^{201}Th, ^{18}F, ^{67}Ga-67, ^{11}C, ^{82}Rb.

Therapeutic:
^{131}I, ^{125}I, ^{60}Co, ^{137}Cs, ^{226}Ra, ^{90}Y, and short-lived α-emitters (^{111}At, ^{223}Ra, ^{212}Bi).

In therapy, the gamma knife, the blood irradiator, and teletherapy units usually use curie quantities of ^{60}Co. Brachytherapy usually uses millicurie amounts of ^{137}Cs or ^{226}Ra.

Form of Material:
Diagnostic radiopharmaceuticals are in liquid form for injection while therapeutic radiopharmaceuticals will normally be in the form of a capsule for oral administration or injection. Check and calibration sources are generally encapsulated in anything from plastic to steel. The devices using 60Co will use metallic ^{60}Co doubly encapsulated in stainless steel . Most brachytherapy sources are stainless steel encapsulations of ^{137}Cs. Although, ^{226}Ra sources are being replaced by ^{137}Cs sources, some facilities still use them for brachytherapy. "Seeds" consisting of small tubes containing ^{125}I are used by insertion into an organ, usually the prostate. From time-to-time experimental devices appear for testing. For example, a Texas licensee received a license authorization for testing the use of neutron radiation from ^{241}Am(Be) well logging sources on cancer patients as a therapeutic means.

Security and gap analysis:
None of the diagnostic materials fall under NRC's IC requirements and will be maintained in a low security manner. However, the security for radioactive materials in a medical facility is usually much greater than for other items due to radiation regulatory requirements. The gamma knife, blood irradiator, and teletherapy unit contain sufficient quantities of ^{60}Co to require IC security measures. Brachytherapy devices will probably not be required to have IC level security; however, theft of Brachytherapy sources from several facilities could allow accumulation of a serious quantity of materials.

Possible Scenarios for obtaining material:
Medical facilities are generally found in populated areas and are integral components of societal infrastructures; thus, a medical facility could easily be made the target of its own radioactive material used as radioactive dispersal device (RDD). For large therapy sources, theft or armed assault could result in removal of the material, but serious, perhaps fatal, exposure of the perpetrators is probable. For diagnostic and unsealed therapeutic materials, theft would be reasonably easy by determined individuals.

Deployment potential:
If large therapeutic sources are removed, the encapsulated sources could be separated out and used to expose the population in transport scenarios. There would be injury and fatalities. The best use of a large quantity of ^{131}I, which can be stolen fairly easily, would be to introduce it into food or water supplies, thereby threatening irreparable damage to the thyroids of a large number of the population.

4. **Irradiation Facility - Medical and food and packaging sources.**

Description of Application:
Radiation allows for the sterilization of the contents of medical and food packages after packaging, thereby reducing the potential of contamination that is found in "sterilization before packaging" systems. However, the elimination of bacteria requires the use of extremely high radiation fields to effect extraordinarily high doses – doses that would be instantly fatal to a human. The systems using radioactive material are contained in steel-reinforced concrete structures to provide shielding. The structures have racks of radioactive material (usually in long, slender rods, "pencils",) which are normally stored in large water pools – perhaps 20 feet or so deep. In the sterilization process, the racks are mechanically lifted above the pool of water and the packages to be sterilized are run through the shielded room on a conveyor belt. Bacteria and viruses within the sealed packages are destroyed. There are some systems which use electrically generated radiation fields and these would not need to be included in a security program. There are also "self-contained" irradiators where a large radioactive materials source is used to sterilize within a shielded container. These are quite small scale, but the source(s) usually requires IC level security.

Radionuclides most commonly utilized:
^{60}Co, in megacurie quantities, has been the "isotope of choice" used for the pool type of sterilization facilities. At least one such facility used ^{137}Cs. This facility had to be closed because one of the cesium sources began to leak. The loose cesium contaminated the water used to shield the sources. The self-contained irradiators can use either ^{60}Co or ^{137}Cs (no water involved) in tens, hundreds, or perhaps thousands of curies. Any gamma emitter with a reasonably long half-life and relatively high gamma ray output could be used.

Form of Material:
In pool irradiators, the radioactive material is usually contained in small cylinders that are loaded, end-to-end, in larger, long cylinders called "pencils". The form of the material can be in metallic powder form, solid, or as a compound. ^{60}Co sources are generally in "pencil" form, whereas ^{137}Cs is usually in the form of cesium chloride incorporated into ceramic microspheres to make them less soluble in liquids. In other irradiators, such as the self-contained ones, the smaller cylinders can be loaded into one or several cylinders to build the desired total quantity designed to provide a given radiation field and remain shielded by the designed shield.

Security and gap analysis:
All irradiators using radioactive material should have sufficient quantities to require implementation of IC's. Pool-type irradiators currently operate under NRC required "safeguards" – a higher security level than IC's (safeguards are similar to those employed at nuclear power plants). The other irradiators will operate under standard IC's.

Possible Scenarios for obtaining material:
The removal of radioactive material from a pool-type irradiator can perhaps be done, but it would require careful planning to overcome both the security arrangements and the high radiation exposure hazard. Most likely, any perpetrator would be facing potential death. One would probably more successful in obtaining the radioactive material from a self-contained irradiator. The material could be carried to another location if the internal shielding was removed and carted off, or if the material was removed and placed into a portable device providing for shielding.

Deployment potential:
If a pool-type irradiator is located in a populated area, then explosions could be used to make the facility a weapon. One explosive device could be used to move aside the ceiling/roof over the pool, and a second device could be used to propel the radioactive material out of the pool. This would probably affect only a small area – perhaps not even off of the irradiator's grounds. If one were able to remove some of the pencils from the facilities, then the pencils could be divided up into individual sources and used to expose persons unknowingly, such as in a transportation system. This would cause serious numerous deaths and could result in serious health effects in those who survived irradiation. The same could be done using a source from a self-contained

irradiator. Neither would be very useful as RDDs without investing a good deal of time in preparation. If the sources were ^{137}Cs in a soluble form (for example the salt cesium-chloride), then the encapsulations could be crushed and placed in a liquid suitable for dissolution. The material could then be introduced to food and/or water supplies. However, this would probably not be very effective for actually causing serious health effects – but it would be very effective as a scare tactic.

5. Universities - Research materials, test reactors.

Description of Application:
Educational (college level) facilities pose a rather unique problem in the use of radioactive materials: specific uses are unpredictable from facility to facility. Many colleges, even large ones, have very little use of radioactive material. "From the outside" one would have difficulty in determining whether a facility possessed radioactive materials that could be dangerous. For colleges with radioactive material, the isotopes are generally used for either teaching/training purposes, or for research and/or development. Sources used for research can range from extremely small (picocurie) to very large (megacurie) quantities. Their uses can range from research with inanimate objects to living entities: animals, plants, and humans.

Radionuclides most commonly utilized:
There are too many isotopes used in educational facilities to be listed here. However, there will probably be at least alpha, beta, and gamma emitters; and often there will be neutron emitters.

Form of Material:
The sources used for teaching purposes are usually very small, but they can be solid, gaseous or liquid form and can be spread throughout many labs. The radioactive materials used for research and development can be of any form: solid, powder, liquid, gaseous, encapsulated, or plated. The isotopes may soluble or insoluble.

Security and gap analysis:
Radioactive material that meets the criteria for IC security will have such implemented. All of the other materials will have typical lab security: storage in a locked container, stored in a locked lab, located in a locked building, with campus security/police. An insider, a very determined thief, or an armed contingent could easily acquire materials with or without the knowledge of officials. Usually, there are students from many countries participating in normal activities. It would be difficult to predict insider diversion.

Possible Scenarios for obtaining material:
The "open atmosphere" and the arrangement of buildings on a college campus would seem to allow for rather easy access by determined persons. Insider access should be very easy, while theft would probably be fairly easy at any time of the day or week, and an armed party could take whatever they wanted at any time. The method employed would probably depend on how easily the material could be moved. Materials under IC requirements would be a more difficult to deal with, but probably not significantly.

Deployment potential:
Deployment of radioactive material removed from a college campus as a weapon would depend on its form and type of radiation. Large sealed gamma sources would be best used as a source of external exposure to members of the public. This can be accomplished by placing them in locations where members of the public spend some time. Placement on transport systems, in movie theater seats, etc., could cause individuals to receive very harmful, even fatal, exposures. Soluble, or solubilized, alpha- and beta- emitters could be placed in food or water supplies. They could also be spread in areas where human hand contact is common, facilitating ingestion.

6. Research Laboratory - Research materials

Description of Application:
Radioactive materials are utilized in research laboratories in any number of applications including tracers for biological studies, chemical studies, and medical studies; high dose studies involving high activity sealed sources for materials testing, polymerization studies, activation analysis, and physics experimentation. In a research facility just about any radionuclide can be used.

Most of these types of facilities will maintain broad licenses in order to have the flexibility to order whatever radionuclide and activity a researcher may need.

Radionuclides most commonly utilized:

Biological Tracers:
Tritium, ^{14}C, ^{32}P, ^{45}Ca, ^{35}S, etc.

Chemical Tracers:
^{85}Br, ^{36}Cl, ^{54}Mn, ^{57}Co, etc.

High activity sources:
^{60}Co, ^{137}Cs, ^{241}Am, ^{252}Cf, ^{239}PuBe, etc.

Form of Material:
Biological tracers will be in curie quantities for tritium, the others will usually be in microcurie or millicurie quantities. The radioactive material will be most commonly in a liquid form.

Chemical tracers will also be in microcurie or millicurie quantities depending on the size of the experiment. Radioactive material will most likely be a liquid or solid powder or gas.

High activity sources will most commonly be in millicurie to multi-curie quantities. When very high dose rates are required the sources could be in the kilocurie range. These sources will be sealed or encapsulated sources.

Security and gap analysis:
The biological and chemical tracers can be expected to be in too small a quantity in each lab to be of use as a weapon of terror. Although the license may allow possession of a large quantity of material, it will be spread throughout the facility (campus) in multiple laboratories. Also notable is that the radionuclides normally used for biological and chemical tracer work are not listed in the NRC list of quantities of concern.

Larger sealed sources will most likely be of sufficient activity to invoke the IC security requirements.

Possible Scenarios for obtaining material:
Forced Entry and Theft/burglary
Inside assistance

Deployment potential:
Tracer materials would not be deemed sufficient to use for terroristic purposes as they normally have short half-lives and are stored in very small quantities.

Sealed sources could be used unshielded to expose unknowing victims or be converted to vapors by use of a thermite device and contaminate a large area and personnel occupying that area by use of an explosive device or an air handling system.

7. Stored Equipment - Any type from above that has been taken out of service.

Description of Application:
Stored equipment is, as the name implies, equipment or radioactive material that has been taken out of service for some reason. It could be that the equipment is obsolete and has been replaced by new equipment, the source has decayed below an activity that is necessary to perform the function, or the facility no longer performs the particular service that necessitated owning the equipment. A path for disposal is not available or affordable. Waste materials with intermediate half-lives may be stored for long periods of time for decay to a point where they may be disposed as non-radioactive in accordance with regulations.

Radionuclides most commonly utilized:
Items or materials can contain any radionuclide that is commonly available. If a quantity of concern is present, then security is required as specified under order for IC. Depending on availability of storage space, the materials may be stored at a remote location and inventoried infrequently. In general, the radionuclides of concern will most likely be those commonly used in sealed sources, i.e., gamma emitting radionuclides or neutron sources containing ^{241}Am. The expected gamma emitters are ^{60}Co, ^{137}Cs, ^{192}Ir, ^{75}Se, ^{63}Ni, ^{57}Co, ^{90}Sr, ^{59}Fe, ^{244}Cm, ^{109}Cd.

Form of Material:
The materials may be contaminated lab equipment, protective clothing, samples, etc. This material will most likely be very low concentration and not be attractive to a terrorist. The sealed sources could individually or in aggregate

comprise a quantity of concern. If so, then IC would be required. If less than a quantity of concern is present, then no additional security above that required by rule to protect health and safety is required to be provided.

Security and gap analysis:
Up to 9.9 D-values of a particular radionuclide could be available without IC being required. Therefore, the material could be of interest to a terrorist.

Possible Scenarios for obtaining material:
Theft or burglary
Inside assistance

Deployment potential:
Sealed sources could be used unshielded to expose unknowing victims or be converted to vapors by use of a thermite device and contaminate a large area and personnel occupying that area by use of an explosive device or an air handling system.

8. **Bankrupt/abandoned - Sites that have no viable owner or caretaker.**

Description of Application:
Well Logging
Pipe Spinning Gauges
Industrial Radiography

Generally, these facilities will be small to medium size companies, although a large company occasionally may fail. The most likely applications to fail are well logging, industrial radiography, moisture density gauge users, and spinning pipe gauge users. Well logging facilities may also use tracer materials such as liquid or sand tagged with any of a number of short-lived radionuclides. These radionuclides will generally be of low activity (millicurie quantities). And because of their short half-lives might be less attractive as weapons of terror. The logging sources may be attractive as they may contain curie quantities of material.

Small and medium sized radiography companies will also have fewer radiography sources. These companies may have from 1 or 2 to 10 or 20 radiography cameras.
Radionuclides most commonly utilized:
^{137}Cs- millicurie to a few curies activity- radiography, well logging and spinning pipe gauges
^{60}Co- millicurie to 100 Curies- radiography (larger sources), well logging
^{57}Co- millicurie quantities- well logging
^{75}Se- 100 Curies-radiography
^{241}Am- several Curies, possibly 20 Curies (max)- well logging
^{252}Cf- 2-3 Ci (spA=5.36 E+2 Ci/g) and assuming source is 4 mg. - well logging (low probability for small or medium size company)

Form of Material:
Tracer materials can be in liquid or solid (tagged sand or proppants). Gauges, well logging and industrial radiography sources will be doubly encapsulated metals or salts of metals.

Security and gap analysis:
Industrial radiography sources will be under IC. Any other sources most likely will not. However, in the case of small companies, especially, financial concerns may override security concerns at a time of impending foreclosure or bankruptcy. The owner may not provide the necessary notifications to the regulator in a timely manner or may dispose of assets by sale to unknown individuals. Inspection intervals may not be sufficiently short to assure the regulatory agency any notice of the licensee's situation until long after he has gone out of business.

Possible Scenarios for obtaining material:
Access may not require forced entry. Otherwise forced entry and theft or burglary.

Sale by bank or owner (if foreclosure not yet begun) to unlicensed individual.

Deployment potential:
Sealed sources could be used unshielded to expose unknowing victims or be converted to vapors by use of a thermite device and contaminate a large area and personnel occupying that area by use of an explosive device or an air handling system.

9. **Industrial facilities – Large gauging devices.**

Description of Application:
Gauges are used in petro-chemical plants,

cement plants, steel mills, pharmaceutical manufacturing plants, any plant that requires some kind of continuous process control or real-time density information.

Radionuclides most commonly utilized:
^{137}Cs- millicurie to several curie sources
^{60}Co- millicurie to several curie sources
^{241}Am- usually no more than a curie

Form of Material:
The material is normally in the form of a metal or metal salt doubly encapsulated in stainless steel, and inside a robust housing.

Security and gap analysis:
Individual sources will rarely exceed the quantities of concern, however, due to the size of the facilities a large number of devices will be located on site, and therefore, aggregate quantities may easily exceed a quantity of concern, esp. ^{137}Cs sources. Access controls to the plants are usually strict. However a contractor can obtain access relatively easily. He would not normally be escorted, since individual sources are generally not quantities of concern and, if careful in his selection could remove devices, from an area he is authorized to be in, without immediate detection. This approach would most likely be successful, if the area the contractor is in is undergoing maintenance or shut down for other reasons.

Possible Scenarios for obtaining material:
Insider from contractor's company gains access to area shut down for maintenance.
Imposter posing as a contractor doing the same.

Deployment potential:
Sealed sources could be used unshielded to expose unknowing victims or be converted to vapors by use of a thermite device and contaminate a large area and personnel occupying that area by use of an explosive device or an air handling system.

Appendix E - Examples of Application of the Present Risk Assessment Process Including Previous Risk Assessments for MIAN Sources

Previous examples of MIAN radiological material dispersal risk assessment caused by either malevolent (e.g., terrorist act) or non-malevolent (e.g., natural event or accidental acts) hazards are sparse, for at least two reasons. First, in terms of non-malevolent events, such as dispersal caused by an accident or a tornado, emergency responders generally have concerns about exposure to a wider variety of hazardous materials, other than radiological sources, with a much greater likelihood for dispersal during the event. However, in spite of the relatively lower concern, incidents that involve radiological source dispersal, such as an isotope used for medical purposes in a hospital that might be hit by a tornado, are carefully documented.

It should be noted that the large majority of such documented incidents were not attributable to natural hazards, but in fact were accidental or human-error related. Second, very few actual incidents involving intentional (including attempted) radiological source dispersal have occurred and the actual risks documented, whereas most of the hypothetical intentional dispersal event risk assessments that have been carried out are classified. The few radiological source dispersal risk assessments that are available in the open literature are generally documented only partially, again because of classification concerns. In the following these few risk assessments are examined relative to the MIAN risk methodology described in Section 4 of this report, and in particular relative to Equation 3.1.

Background and Previous Assessments

One of the earliest and most complete summaries of the risks associated with radiological source dispersal after September 11, 2001, was the report issued by the Center for Nonproliferation Studies at the Monterey Institute for International Studies.[30] This study was funded by the John D. and Catherine T. MacArthur Foundation. The summaries of previous studies in Reference 1 concentrate on potential consequences (see pages 19 to 24 in Reference 1), with very little information on the frequency of occurrence of the accidental or terrorist event, or on the likelihood that the event would be successful. However, it would appear that, essentially by default, the consequence studies have assumed a high probability that the event will occur (once per year or once every few years) and will cause some degree of dispersal. In spite of these assumed high probabilities, the information cited and contained in the supporting references provides useful data for comparison with future risk assessments.

A much more complete and classical risk assessment was carried out shortly thereafter by Rosoff and von Winterfeldt.[31] This study, funded by the U.S. Department of Homeland Security (DHS), identified the various steps that would be taken by the attackers prior to detonation of the device, including acquisition of the material by theft or other means, transport of the material to a storage site, storage for the period of time required to assemble the device, and transport of the device to the location of deployment. During each step, potential for detection and possible interdiction was considered in the probability that that step would be successful. A wide variety of possible attack scenarios were then considered and eventually narrowed down by expert judgment to two plausible scenarios for which consequences were estimated.

For what is referred to as the "medium reactivity" scenario, the likelihood of successful detonation was estimated to be between 15 and 40%, with limited public health consequences and substantial economic impact – primarily from the shutdown of port facilities for clean-up efforts. One of the interesting findings in this study concerned the likelihood of interdiction during transport of the radiological source into the United States, as the result of efforts in the past decade on such programs as the Container Security Initiative for examining a substantial fraction of containers in foreign ports prior to shipment to the United States or the radiation portal monitors used by Customs and Border Protection personnel at land and sea entry points into the United States. These efforts, combined with global non-proliferation activities such as the Off-Site Source Recovery

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[30] Ferguson, C., Kazi, T., and Perera, J., "Commercial Radioactive Sources: Surveying the Security Risks," Occasional Paper No. 11 (Center for Nonproliferation Studies, Monterey Institute of International Studies, 2003).

[31] Rosoff, H., and von Winterfeldt, D., "A Risk and Economic Analysis of Dirty Bomb Attacks on the Ports of Los Angeles and Long Beach," Risk Analysis, Volume 27, No. 3, 2007, pp. 533-546.

Program (OSRP), have changed the most likely dirty bomb scenarios from imported “orphan source” driven to domestic theft driven. This example is discussed further in Example 4.

More recently, the National Research Council – the research arm of the National Academy of Science, the National Academy of Engineering, and the Institute of Medicine – published a report, funded by the U.S. Nuclear Regulatory Commission (NRC), that included a Chapter 3 on “Radiation Source Risks.”[32] The risk concepts that were used in Chapter 3 coincide precisely with the risk concepts defined in Sections 3 and 4 of this report, so there is no concern about any differences in terminology. Also, since Reference 3 was developed under the auspices of the NRC, the study had access to classified information or at least briefings on regulatory risk assessments relative to radioactive source dispersal events. Chapter 3 refers to additional risk assessments that were carried out during the preparation of the study, but does not actually contain any quantitative results. However, the study does contain qualitative information on contamination clean-up costs, based on both actual clean-up costs from past events and estimates of clean-up costs for different dispersal conditions.

Because of these very high costs, the Academy panel came to their most important finding – replace long half-life and mobile isotopes (cesium chloride being the poster boy for that finding) with shorter half-life and less mobile substitutes. Another major finding was a criticism of previous NRC risk assessments, which apparently *did not* include “denial of access” consequences. The Academy panel found that, because of the very long half-lives of some of the source material involved, and the mobility of that material under either accidental or intentional dispersal conditions, the contamination clean-up consequences far outweighed the other potential consequences, such as the public health consequences. Although not explicitly stated in Reference 3, the implication is that the NRC regulations at the time (2007-2008) could be somewhat misguided because of the lack of consideration of "denial of access" consequences. Relative to any MIAN risk assessments, this finding means that establishing meaningful consequence cost estimates for contamination clean-up, including clean-up caused by widespread mobility to multiple sites, will be a challenge for any MIAN risk assessments.

It can also be inferred from the Chapter 3 discussion that the risk assessments carried out by both the NRC and the Academy panel, although not described in any detail, point out two major conclusions that affected the Academy report. First, that theft during transport of replacement sources for many of the facilities is apparently the weak link in the security chain, since diversion of the sources once they are installed was found to be much less likely to be successful. This low likelihood is due to both the potential lethality of the most desirable installed source quantities and the current level of protection required by the regulator for high risk installed sources. Second, most of the sources could be shown, whether using only the immediate human health consequences or using the complete range of decontamination and other economic consequences, to be inconsequential. Further, the Academy panel identified control of orphan sources as a very important security ingredient, and in particular the OSRP at the U.S. Department of Energy/National Nuclear Security Administration (NNSA) was found to be critical. The panel appeared to be concerned about continued NNSA funding of this program.

Examples illustrating the proposed MIAN Risk Assessment Process

The following *hypothetical* examples are provided to illustrate the detailed procedure used to determine the risk for a particular terrorist attack. Examples of events involving natural hazards are not included since it has been demonstrated that these events, while significant, result in much lower consequences. Further, there is a much higher risk tolerance for naturally occurring events than for premeditated, malevolent attacks.

In all of the examples that follow, only one overall scenario is discussed in detail. Presumably, this scenario results in the highest overall risk. The RAMCAP Plus® risk methodology is actually more comprehensive. Each step of the process consists of a number of possible sub-plots that should be evaluated. In example 1, for instance, the method of

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[32] U.S. NRC, “Radiation Source Use and Replacement,” (Washington, D.C., The National Academies Press, 2008).

obtaining the material could have been armed attack in which the guard was overpowered and forced to tell the terrorists where the blood irradiator was located. In this sub-plot the need for an "inside man" is eliminated but the probability of interdiction is more likely because the theft would more than likely be reported faster. There are other scenarios in which hostages could be taken, the irradiator is exploded in place without dismantling it, etc.

Every risk assessment should consider as many variations as possible, for each step of the scenario (obtaining material, transporting it to the site, and deploying it, consequence estimation) as well as interdiction scenarios. An event tree analysis can be used to document the variations and select the scenario that results in the greatest probability of overall success, i.e., produces the highest risk. Red teaming is recommended when evaluating complex scenarios. Access to intelligence concerning terrorist capabilities, tendencies, and activities would be highly desirable. Knowledge of security procedures and surveillance equipment is also necessary. Finally, expert elicitation, when available, cannot be overrated for obtaining useful and accurate information.

Example 1 considers a blood irradiator located in upper state New York. The contained radioactive material is stolen, transported to a site in downtown New York, and detonated. The explosion scatters cesium-137 into a large area of New York City resulting in extensive remediating of the area, denial of services and access and psychological trauma.

Example 1 - Blood Irradiator

Source: Gammacel 3000 Elan, located at a hospital in Upper State New York.

Isotope: Cesium-137, 3048 curies

Information from brochure:

The Gammacell® 3000 is shipped in two parts:

- The radiation shield and radiation sources are sent together as a Radioactive Materials (RAM) transport package which meets international transportation and safety regulations.
- A second package contains the cabinet, control system, and related parts.

CESIUM FACTS[33]

Naturally occurring cesium is the non-radioactive isotope, cesium-133. In addition, twenty radioactive isotopes ranging from cesium-123 to cesium-144 have been artificially prepared. Cesium-137 is useful in medical and industrial radiology because of its long half-life of 30.2 years. Cesium is the most electropositive and most alkaline element, and thus, it loses its single valence electron and forms electrovalent bonds more easily than all other elements and it does so with nearly all the inorganic and organic anions.

RADIATION CONTAMINATION

When cesium comes into contact with plants and animals, it is absorbed into the system by replacing potassium in tissues and cells. Radiation destroys the most rapidly dividing cells of the body, particularly skin, hair, gastrointestinal tract, and bone marrow. Because bone marrow gives rise to the blood cells, including those of the immune system and the platelets that staunch bleeding, radiation victims are susceptible to infections and hemorrhaging as well as long term effects.

An incident exhibiting the effects of radiation contamination from a cesium-137 sourced blood irradiator occurred in September 1987, in the state capitol of Goiana, Brazil. A group of scavengers raided an abandoned cancer center and found a small lead canister, later selling it to a junkyard. A junkyard employee opened the container to discover a radiant, blue, glowing dust. The dust was cesiusm-137, the same highly radioactive material used in blood irradiators throughout the world. Over the next week, children and adults rubbed the substance on themselves because of the sparkle and the dust passed from home to home eventually contaminating 244 people, 54 of which were hospitalized for serious injury. In addition, several medical personnel and emergency workers, as well as their clothing and instruments, were contaminated. Within one week,

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[33] Kirk, B., "Decommissioning and Disposal Options for Cesium-137 Blood Irradiators," 2001, (http://www.radjournal.com/articles/Cesium/Cesiumdisposal.htm, accessed January 2011.)

four of the first six people to handle the cesium had died from pneumonia, blood poisoning and hemorrhaging. The accident contaminated everything from people to homes, businesses, soil and water. Those objects and structures that could not be decontaminated were dismantled or collected and stored in concrete drums as nuclear waste.

Scenario:

1) Obtaining the material:

Terrorist number 1 (T1) obtained employment as an orderly working the eleven to seven shift. T1 made it a point to meet the armed night guards and befriend them, spending some time talking and bringing them coffee during his shift. He knew most guards did not usually sleep during the day before the first night back at work. On the night of the attack, he brings the guard coffee about two AM. The coffee is laced with three .25 mg Xanax (a strong muscle relaxer) and sugar substitute to mask the bitter taste. As the guard begins to nod off, the terrorist tells him he will watch the security monitors if he falls asleep. When the guard goes to sleep, he calls his accomplices and opens the side door to the facility. Two armed individuals, dressed in scrubs (hospital clothing), and caps enter the hospital at approximately 3 a.m. They are pushing a heavy-duty, wheeled dolly with a suitcase and a toolbox on it. T1 returns to the guard station to monitor the sleeping guard and serve as a lookout. The other two proceed directly to the blood irradiator facility. Using tools from the toolbox, they quickly dismantle the radiation shield and source from the cabinet and, with the help of T1, roll it onto the dolly. They wheel the shielded container to the side entrance, load it into a waiting van, and speed away.

Probability of success: 90% (estimated); $P_o = 0.5$

2) Transporting the material to the site of the attack:

Once inside the van, two of the individuals begin to pack explosives, which were previously procured and secreted in a self-storage unit, around the lead-shielded container while the third drives toward New York City. Once this task is completed, they shed their outer garments (scrubs). The van pulls off the road at a truck stop and two of the men exit the van and pick up their automobile, which had been previously parked at the truck stop; they follow the van at a safe distance. They are not stopped during the drive to Manhattan.

Probability of success: 90%; Probability of interdiction = 10%; $P_i = .10$

3) Deploying the material at the site:

The van pulls over to the curb on Wall Street. The driver exits the van and immediately enters the car containing the other two terrorists as it that pulls alongside the van. The car speeds away. When the car is several blocks away, a cell phone is use to explode the van. The car melds into traffic as sirens sound.

Probability of success: 80%; $P_d = 0.8$

4) Consequences:

The van explodes scattering radioactive material over a twenty-block area. The number of fatalities depends upon the time of day, but there are likely to be at least a few fatalities. Clean-up operations begin the next morning. The news media is on the scene within minutes. The area is cordoned off. Numerous businesses are shut down for several days. It is months before the area returns to normal. Many people refuse to return to the area. All large cities establish curfew hours. Security is greatly increased. The cost is conservatively estimated at tens of billions of dollars.[34]

Consequence = $\$30 \times 10^9$

The risk can be estimated as:

$R = P_o \times P_d \times (1-P_i)$ (Consequences)
(.5) x (.9) x (1-.1) x ($30 x 109) =
$12,500,000,000.00 = $12.5 billion dollars

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[34] In congressional testimony before the House Committee on Homeland Security, Kenneth Sheely, NNSA Associate Assistant Deputy Administrator Global Threat Reduction Initiative, testified on September 14, 2009 "Even without weponization of the radioactive materials or optimization of the device, the study found that the economic cost to the nation could be in the billions of dollars." Note: the study referred to was performed jointly by Los Alamos National Laboratory and Sandia National Laboratory. The author assumes the estimate of $30 billion used in the example for illustrative purposes.

Notes:

1) The site was selected because it had not yet had a protective system installed to protect the Cesium. (However, even with a protective system, the contingency plan would include carrying a cutting torch on the dolly.)
2) The explosive could have been obtained from a construction site or manufactured by the terrorists using information readily available from a number of sources.
3) The terrorists plan contained a number of abort points and alternative scenarios. These included:
    a) If the guard did not fall asleep or could not be neutralized quietly by T1, the attack would have been aborted until another night.
    b) The suitcase on the dolly contained part of the explosives that were in the van. If their plot had been discovered before they were able to move the radioactive material to the van, they would have exploded the suitcase inside the facility, releasing the radioactive material. The explosion and ensuing fire would have spread the cesium causing considerable consequences, but less than desired.
    c) If the terrorists had been interdicted by police or highway patrol while driving to New York City, the plan was to explode the van in a highly populated area or when police stopped them, killing as many officers as possible.

All of the above scenarios would result in extensive, worldwide, media coverage, greatly increase public fear, and have significant monetary consequences as well as possible fatalities and serious injuries.

Example 2 - Placement of Radioactive Material in Public Place

Background:

An employee of a radiography firm finishes work on a Friday afternoon, locks his radioactive sources in the back of his pickup truck, and heads back to his apartment. He drops off his partner on the way back to the shop to unload the sources, in a moment of weakness, decides to stop in for a quick beer at TexiAnn's Dew Drop Inn in Pasadena, Texas. He parks the pickup in the lot and goes into the establishment. He loses track of the time and when he returns to his truck at one o'clock in the morning, he fails to notice that the locks on the vehicle darkroom and the storage container have been replaced with new but similar locks. While in the noisy bar, he failed to hear his truck alarm and keychain alarm. Due to the lateness of the hour, he decides to drive his rig to his residence.

The next morning he realizes he did not return the sources to the company storage area. He calls his boss and tells him that an emergency came up and he failed to return his sources. They agree that he will return to the work site on Monday morning and bring them back to the office Monday afternoon after work, even though it may be a violation of radiation control rules. When he arrives at work Monday morning, he tries to open the locks and realizes they have been changed. After cutting the lock from the storage box, it is established that the sources checked out to him are missing. The time of the loss cannot be determined exactly, but it is assumed that the theft occurred Friday night. Local law enforcement and the state radiation control agency are contacted. The FBI is called in to investigate. The FBI traced the replacement padlocks to a major store on the west side of Houston, and the store's video surveillance cameras showed a suspected terrorist purchasing the padlocks.

It is determined that two sources are missing. The employee is disciplined. It is also found that similar case occurred in Corpus Christi, Texas on the same weekend, although it was a different company. None of the four sources were recovered.

Several weeks later, a call is received at the Washington DC Metro headquarters at six o'clock on a Monday morning. The caller states that radioactive material has been hidden on several cars on the Metro trains and people will die unless all trains are evacuated immediately. When pressed for more information, the caller tells the operator to look on car # 1020 on the Red Line.

A search of car # 1020 results in finding a single pellet of Iridium-192 material duct taped under a seat. The Metro is shut down and all lines are evacuated. Passengers are not told why they are being evacuated. The Washington Post, local television stations, and National Public Radio receive anonymous calls at seven o'clock that morning with a tip that radioactive material has been planted on all cars of the Metro. Everyone coming in close proximity to the material will incur severe doses of radiation that can lead to cancer or death. Further, this is a terrorist attack and all public transportation across the United States is targeted.

Over the next month, two other pellets are found on public transportation systems. Both incidents cause major disruption in public transportation. The Department of Homeland Security increases security at entrances to subways and other major public transportation systems. Ridership falls to record low levels. The cost of increased security is estimated to be in the billions of dollars. Traffic problems increase dramatically.

Notes:

1) It is determined that the terrorists use Stanley stainless steel thermos bottles with lead shielding to bypass radiation monitors. Empty containers are found in waste cans in the subway.
2) The terrorists concentrate on cold-weather cities because public transportation is more prevalent and cold-weather clothing can be used to conceal the containers.
3) The media is relentless in reporting the story. Members of congress vow to completely eliminate the possibility of future attacks. Foreign press, including Al Jazeera, airs the story worldwide. Several terrorist organizations issue press releases claiming responsibility.
4) The terrorists are not apprehended.

Risk calculation:

The probability of obtaining the material is high. There are thousands of similar sources in use in industry today. The personnel that use them on a daily basis are not educated professionals, particularly reliable, and some may have police records. These people are not highly paid and may be targets for bribes. Some may have histories of narcotics or alcohol use, and thus could be targets for bribes or extortion. The probability of obtaining such material is very great. Since there is no specific time constraint and it takes only one person to steal these sources, the probability of success can approach 1.0.

Po = 0.9

The probability of interdiction is low. This material is easily transported and shielding is relatively easy. There are already many "lost" or stolen pellets in circulation. The probability of interdiction is low unless loss is detected almost immediately and the person who stole it is known.

Pi = 0.1

Consequences:

The consequences can be high depending on how the material is deployed. Use $1Billion for rough estimate.

Risk = Po x (1-Pi) (Consequences)
= 0.9 x (1-.1) ($1Billion) = $810,000,000

This is probably a low estimate. The actual value may be much greater due to disruption of transportation patterns, modifications of security procedures for public transportation, loss of ridership, and psychological effects. Many of these effects are difficult to estimate.

Example 3 - Ingestion of Radioactive Material

Background:

The lone terrorist (LT) is home-grown, radicalized by a rogue Imam or Mullah at a mosque in the United States. He is recruited by the Mullah and desires to cause the greatest possible damage to this country. He is not willing to perform a suicide mission but wants to gain publicity for himself, become an international "celebrity" and live in a protected environment in an Islamic country.

His hero is Anwar al-Awlaki, a notorious homegrown terrorist. It is noted that Awlaki's sermons were attended by accused Fort Hood shooter Nidal Malik Hasan. U.S. intelligence intercepted at least 18 emails between Hasan and al-Awlaki in the months prior to the Fort Hood shooting.

LT is instructed to quit his job as a bank teller and find a job "flipping burgers" at a fast food restaurant in a large city. He continues to work there for several months to establish a good reputation and he is promoted to shift supervisor. Following a sermon at the mosque one Friday, he is approached by the Mullah and given a small glass vial. LT is informed of the details of his mission and told that he will not be coming to the mosque again.

On his next workday, LT fills the saltshakers used to salt fries when they are taken from the deep fryer. He adds the vial of powered material to the salt, mixes it thoroughly, and uses it until it is depleted. He continues to work at the restaurant for another day and then quits, stating that he has found a better position elsewhere. He buys a ticket to London Heathrow and when he arrives he takes another plane to France and then on to Cairo, Egypt. In Cairo, he meets a connection that takes him to Yemen.

The substance LT added to the salt was Polonium-210. It was smuggled into the country by an unknown accomplice. This radionuclide produces only alpha radiation, a type of radiation that is difficult to detect. It could be smuggled through a sophisticated security screen with little chance of discovery. Scans to detect alpha radiation could be easily defeated by packaging the material as a pill in a blister pack, commonly used for over the counter drugs. In fact, it could have been in the clear plastic bag that is used to contain liquids when undergoing airport security.

The assassination of Alexander Litvenenko demonstrates the deadly effects of this material. On 1 November 2006, Litvinenko suddenly fell ill and was hospitalized in what was established as a case of poisoning by radioactive polonium-210. After his death on 23 November 2006, at age forty-three, scientists determined that Mr. Litvenenko had approximately 1.85 MBq (50 mCi) of Polonium (Po-210) in his body. In terms of mass, this would equate to 10 micrograms[35] of material. In terms of toxicity, it represents about 200 times the amount of Po-210 necessary to kill a person.

Shortly after LT left the country, a number of people were hospitalized with strange symptoms. After numerous tests, they were found to be suffering from radiation poisoning. Most eventually died. Law enforcement began to interview each victim to determine what he or she each had in common. After several days of investigation it was determined they had all eaten at the same fast-food restaurant. By this time, LT was safely in Yemen. He appeared on a video, claiming that he was responsible for the attack and warning that more attacks were imminent.

The source of the Polonium was never determined with certainty. It was suspected the material could have been produced in a research reactor in Iran or possibly North Korea. Another possibility was that the material was stolen from a facility that manufactures static eliminators and air ionizers. With a half-life of only 138 days, it is highly unlikely that it was produced in one of the former Soviet Union countries for use by the KGB and later sold to terrorists. Additional discussion of possible sources for obtaining the material is contained in the IAEA Factsheet at the end of this example.

Risk Assessment:

Successful implementation of this scenario is dependent on two major factors.

The first is the availability the radioactive material. Polonium 210 can be a very dangerous material when used as suggested in this example. This material emits only alpha particles and is very difficult to detect since it can be shielded by virtually any type of container. However, it is known to have been used for assassinations and clearly would create terror if used as described above. It is very probable that terrorists, with adequate funding and international connections, could obtain some amount of this material. This type of an attack must be avoided by preventing the material from reaching the United States.

The second factor is finding someone who is not a known terrorist, and presumably, not under surveillance, that will perform the actual placement of the material in a public food supply. Unfortunately, recent events indicate such people are available and willing.

Consequences:

It is believed that an attack of this type would have

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[35] Ten micrograms = 3.527396195x 10-7 ounces. Stated another way, this is about one-third of one-millionth of an ounce.

very high consequences. The anthrax attack in 2002 had a profound effect on mail service for at least a year and cost billions of dollars in lost time, expenditures for new equipment to detect the anthrax spores in mail sorting equipment as well as psychological effects. The Tylenol poisoning[36] episode resulted in new packaging requirements and almost bankrupted the product manufacturer. The Jack-in-the-Box E. coli-poisoning event in 1993[37] resulted in economic distress for that fast-food company. A radiation-poisoning event would probably result in orders of magnitude higher consequences than the examples cited. It has been shown that public tolerance for naturally occurring events is much greater than pre-meditated and, especially, terrorist events.

Risk is estimated to be in the tens to hundreds of billion dollars if such an event were to occur. If the radioactive material reaches the United States undetected, then the probability of success is very high. A Wikipedia article, which admittedly is not considered an unimpeachable source, contains the following remarks concerning the deleterious effects of Po-210.

"A fatal 4.5 Sv (J/kg) dose can be caused by ingesting 8.8 MBq (238 microcuries, μCi), about 50 nanograms (ng), or inhaling 1.8 MBq (48 μCi), about 10 ng. One gram of ^{210}Po could thus, in theory, poison 20 million people of whom 10 million would die."

A typical static eliminator contains about 500 microcuries, so ingesting the amount of Po-210 in one would be nearly twice the fatal dose. Inhalation takes considerably less, but would be less efficient.

IAEA Factsheets & FAQs for Polonium-210[38]

Basic facts

Polonium-210 (Po-210) is a radioactive element that occurs naturally and is present in the environment at extremely low concentrations.

It is a fairly volatile (50% is vaporized in air in 45 hours at 55°C) silvery-grey soft metal.

Po-210 has a half-life of 138 days. This is the time it takes for the activity to decrease by half due to a process of radioactive decay. Po-210 decays to stable lead-206 by emitting alpha particles, accompanied by very low intensity gamma rays. The majority of the time Po-210 decays by emission of alpha particles only, not by emission of an alpha particle and a gamma ray. Only about one in a 100,000 decays results in the emission of a gamma ray. Alpha spectroscopy is the best method of measuring this isotope.

Origin

Being produced during the decay of naturally occurring uranium-238, polonium-210 is widely distributed in small amounts in the earth´s crust. Although it can be produced by the chemical processing of uranium ores or minerals, uranium ores contain less than 0.1 mg Po-210 per ton. Because Po-210 is produced from the decay of radon-222 gas, it can be found in the atmosphere from which it is deposited on the earth´s surface. Although direct root uptake by plants is generally small, Po-210 can be deposited on broad-leaved vegetables. Deposition from the atmosphere on tobacco leaves results in elevated concentrations of Po-210 in tobacco smoke. There are tiny amounts of Po-210 in our bodies.

Po-210 can be manufactured artificially by irradiating stable bismuth-209 with thermal neutrons resulting in the formation of radioactive Bi-210, which decays (half-life 5 days) into Po-210. Polonium may now be made in milligram amounts in this procedure which uses high neutron fluxes found in nuclear reactors. Only about 100 grams are produced each year, making polonium exceedingly rare.

Uses

Po-210 is used in neutron sources (where it is mixed or alloyed with beryllium). It is also used in devices that eliminate static electricity in machinery where it can be caused by processes such as paper rolling, manufacturing sheet plastics, and spinning synthetic fibers. Brushes containing Po-210 are used to remove accumulated dust from photographic films and camera lenses. Static eliminators typically contain

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[34] The Tylenol poisonings, code-named TYMURS by the FBI, took place in the autumn of 1982 in the Chicago area of the United States. These poisonings involved Extra-Strength Tylenol medicine capsules which had been laced with potassium cyanide. The incident led to reforms in the packaging of over-the-counter substances and to federal anti-tampering laws. The case remains unsolved and no suspects have been charged.

[37] The chain lost millions of dollars in sales and revenue as a result of the disaster, and millions were paid out as settlements in wrongful death lawsuits. Moody's Investors Service downgraded Foodmaker's debt to junk status as it had no confidence that sales would return to normal levels. Bankruptcy was imminent.

[38] Copyright ©, International Atomic Energy Agency, P.O. Box 100, Wagramer Strasse 5, A-1400 Vienna, Austria

from one to tens of GBq (1 GBq equals approximately 27 curies) of radioactivity.

Po-210 emits so many alpha particles each second that the energy released from one gram is 140 watts, and a capsule containing about half a gram will spontaneously reach a temperature of 500°C. As a result, it has been used as a lightweight heat source to power thermoelectric cells in satellites. A Po-210 heat source was also used in each of the Lunokhod rovers deployed on the surface of the Moon, to keep their internal components warm during the lunar nights. However, because of its short half-life Po-210 cannot provide power for long-term space missions and has been phased out of use in this application. Polonium is not subject to IAEA safeguards.

Toxicity

Po-210 is highly radioactive and chemically toxic element. Direct damage occurs from energy absorption into tissues from alpha particles. As an alpha-emitter Po-210 represents a radiation hazard only if taken into the body. It´s important to note that alpha particles do not travel very far - no more than a few centimeters in air. They are stopped by a sheet of paper or by the dead layer of outer skin on our bodies. Therefore, external exposure from Po-210 is not a concern and Po-210 does not represent a risk to human health as long as Po-210 remains outside the body. Most traces of it on a person can be eliminated through careful hand-washing and showering.

Po-210 can enter the body through eating and drinking of contaminated food, breathing contaminated air or through a wound. The biological half-life (the time for the level of Po-210 in the body to fall by half) is approximately 50 days. If taken into the body, Po-210 is subsequently excreted, mostly through feces but some is excreted through urine and other pathways. People who come into contact with a person contaminated by Po-210 will not be at risk unless they ingest or inhale bodily fluids of the contaminated person.

About Illicit Trafficking Incidents Involving Po-210

Of the approximately 520 incidents reported by States to the IAEA´s Illicit Trafficking Data Base since 2004, 14 incidents have involved industrial Po-210 sources. Three of these incidents occurred in 2006. The incidents involved the theft, loss, or disposal of static eliminators and air ionizers containing sealed Po-210 sources. Po-210 used in these sealed sources is bound with other materials and extraction of the Po-210 would require some chemical treatment in a laboratory.

Example 4 - Dirty Bomb Attacks on a Major American Port

The last example is taken from the following paper:

A Risk and Economic Analysis of Dirty Bomb Attacks on the Ports of Los Angeles and Long Beach[39]
By H. Rosoff and D. vonWinterfeldt[40]

Abstract:[41]

This article analyzes possible terrorist attacks on the ports of Los Angeles and Long Beach using a radiological dispersal device (RDD, also known as a “dirty bomb”) to shut down port operations and cause substantial economic and psychological impacts. The analysis is an exploratory investigation of a combination of several risk analysis tools, including scenario generation and pruning, project risk analysis, direct consequence modeling, and indirect economic impact assessment. We examined 36 attack scenarios and reduced them to two plausible or likely scenarios using qualitative judgments. For these two scenarios, we conducted a project risk analysis to understand the tasks terrorists need to perform to carry out the attacks and to determine the likelihood of the project’s success. The consequences of a successful attack are described in terms of a radiological plume model and resulting human health and economic impacts. Initial findings suggest that the chances of a successful dirty bomb attack are about 10–40% and that high radiological doses are confined to a relatively small area, limiting health effects to tens or at most hundreds of latent cancers, even with a major release. However, the economic consequences from a shutdown of the harbors due to the contamination could result in significant losses in the tens of billions of dollars, including the decontamination costs and the indirect economic impacts due to the port shutdown. The

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[39] Ibid., Rosoff and von Winterfeldt.”

[40] Address correspondence to H. Rosoff, Center for Risk and Economic Analysis of Terrorism Events, University of Southern California, Los Angeles, CA, USA; rosoff@usc.edu.

[41] Quoted verbatim from article as published.

implications for countering a dirty bomb attack, including the protection of the radiological sources and intercepting an ongoing dirty bomb attack are discussed.

Discussion of assessment:
The above referenced article describes a detailed study performed by the authors and several collaborators. The article focused primarily on the assumption that a moderate quantity of radioactive material (100,000 curies) was stolen from a U.S. blood or industrial irradiator. Once stolen, it was transported to a warehouse near the port for dirty bomb construction. A separate terrorist cell was assumed to construct the dirty bomb and a third cell was assigned to transport the bomb to the selected site of the explosion. It was further assumed that the device was detonated at a sufficient distance from the explosion that the terrorists were not physically affected.

Twelve scenarios were considered, four transportation scenarios, and three detonation scenarios. The two most likely scenarios were selected for detailed evaluation. The analyses performed to assess the consequences of the attack were very thorough and the interested reader should obtain a copy of this article, or better still, a copy of the restricted version to fully appreciate the granularity of this work. However, for the purposes of this report, only a summary of results will be presented.

Conclusions:[43]
A terrorist attack using a dirty bomb in the United State is possible, perhaps even moderately likely, but would not kill many people. Instead, such an attack primarily would result in economic and psychological consequences. Moreover, it would not be easy to carry out a dirty bomb attack. Considering the difficulties associated with obtaining and transporting radioactive material, building the dirty bomb, and detonating the device successfully, our preliminary analyses suggest that the chances of a successful attempt are no better than 15–40% for the medium radioactivity scenario, and less likely for the high radioactivity scenario. Of course, multiple independent attempts would increase these chances. While our probability estimates are mostly illustrative, the chances of terrorists succeeding with an attack that involves relatively low-level radioactive material from a U.S. facility are larger than their chances of succeeding with the import of a large quantity of foreign sources. This is because transporting foreign source material through a number of international ports increases susceptibility to detection. If a dirty bomb attack is successful, the consequences depend primarily on the amount of radioactive material in the detonated source term, the amount released into the air, weather conditions, and the population density in the impacted region.

The medium radioactivity scenario analyzed in detail suggests there would be some, but fairly limited, health effects and possibly significant economic impacts. The most costly economic impact would result from a lengthy shutdown of the ports and decontamination efforts. The length of the harbor shutdown would in part depend on the decision to declare access to the ports as safe. In a national emergency, standards of safety different from those promulgated by the EPA may be appropriate. For example, worker safety standards may be more appropriate than public safety standards. The same also holds true for clean-up standards. Because we don’t know how policymakers and harbor workers will react in such an emergency, we have parameterized the length of the harbor shutdown, from 15 days to one year, corresponding to roughly $130 million to $100 billion in costs. The economic consequences of evacuations, property value impacts, and business losses due to stigmatization in the plume area are in the billions, but not in the tens or hundreds of billions. People and the economy are likely to respond in a resilient way. Many people would relocate for some time out of the areas with relatively high levels of radioactivity (100 mrem or more), but they would not stop working. Also, businesses may relocate and later return to their original location. Similarly, effects on property values may be severe in the short term but, like in many other disasters, return back to normal in a year or so. Regarding countermeasures, our analysis clearly supports ongoing programs to install radiation detection technology around the harbor. In addition, the analysis raises concerns regarding the security risks associated with cargo material as it is offloaded from ships but not yet transported through the portals, incoming containers from the U.S. mainland (by truck, small

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[43] Quoted verbatim from article as published.

boat, or air), and harbor perimeter control. Finally, the analysis suggests preventing terrorism by interdicting vulnerable activities during the planning and preparing stages of an attack scenario. Such action might include being more proactive in controlling and protecting the original sources of radioactive material.

Discussion of conclusions:
The authors agree with the conclusion that such an attack is moderately likely and that such an attack would not kill many people. The purpose of such an attack is to disrupt, not destroy. It is difficult to estimate the psychological effects. The estimate of an overall probability of success of between 15 to 40 percent is actually quite high considering the complexity of the attack and the size of the facility. Their suggestion that multiple attacks would increase the probability can be argued. Once an attack is attempted at one location, the probability of success will be reduced significantly. One lesson learned by the terrorists is that the United States has an excellent record of "closing the barn door after the horse has been stolen." Of course, this greatly increases the cost of the consequences of an attack, so one of the purposes of terrorist is realized, i.e., causing a large financial impact. This observation should be considered when estimating the cost of consequences.

The cost estimates for consequences varied over a wide range, i.e.,

$130 Million < Consequences < $100 Billion

The low end of the range would appear to be unrealistic considering previous terrorist attacks. Using the values from the article and the modified RAMCAP risk equation, a risk assessment can be made. For the low end of the range, assume an overall probability of success of 15% and consequences of $130Million. For the high end, assume 40% overall probability and consequences of $100 Billion. Thus:

Low End Risk = (.15) ($130 Million) = $19.5 Million

High End Risk = (.40) ($100 Billion) = $40 Billion

Appendix F - Interviews with MIAN Licensees

I. Meetings Held in Austin and San Antonio During the Week of February 8-11, 2011

J. William Jones and John R. Haygood visited a number of sites that have MIAN materials to discuss the project and to obtain comments from potential users. The following information was obtained.

Meeting agenda:
The meeting agenda was the same for all. William Jones and John Haygood provided an overview of the MIAN project. Each presentation was somewhat different and was tailored to the particular type of operation we were visiting. After presenting the overview we listened carefully to the comments of the interviewees and made notes regarding their overall response to the material and noted suggestions. At the end of the meeting we went through the six questions at the end of the presentation outline. A copy of the presentation outline is attached. The responses to the questions are provided for each interviewee corresponding to the question number. Names were withheld if requested by the interviewee. The names were withheld at the request of the legal counsel. It is noted that everyone was very responsive, cooperative and most had reviewed the materials that were provided ahead of time.

The questions posed to the licensees were:

1. How would the program affect your operations if it were a voluntary one? If it were a mandatory (required by regulators) one?
2. What are your greatest concerns when considering security issues for protecting radioactive materials?
3. Do you think the RAMCAP program might help you address those concerns?
4. Do you think the screening tool might be useful by helping licensees improve their security?
5. Overall, do you feel this RAMCAP program, or one like it, might benefit your operations by helping you to improve your security?
6. Can we use your name for reference as having been contacted for input? We will not reveal any information regarding your site or security.

Meeting 1 - February 9, 2011:

RTS Testing Services
10854 Gulfdale Street, San Antonio, Texas 78216
Met with Nora Alaniz, President

Materials on site:
Radioactive materials used and stored on site consist of a couple of radiography cameras containing Ir-192. They have several trucks that take sources out to job sites where they perform radiography of welds and metal objects and they also perform other non-destructive testing. The cameras are used to perform radiography on aircraft at a nearby airport, and at fab shops and pipelines throughout Texas. They can also do the work out of state.

Notes:
RTS provides industrial radiography services. We were given a tour of the facility including the storage location for the cameras and the small shooting bay where they perform in-house projects.

Ms. Alaniz was initially apprehensive about the increased security we were presenting, however she was aware of the dangers of losing control of the materials. She did not desire to have to perform additional work for security. Ms. Alaniz was very interested to learn how the material could be used to terrorize the public. We described several scenarios and she agreed that they were plausible and the potential was there for large consequences.

Ms. Alaniz related a recent incident where she refused to send out a crew to a site because the roads were icy. She was afraid that the driver could be forced to leave the truck in case of an accident. She took a chance on losing a client to insure that the material was guarded at all times. In another anecdote she told us that she came in early frequently to spot check the employees to make sure they were following the required safety and security procedures.

These anecdotes illustrate that an owner may be in the position to make the “hard” decisions whereas an employee in charge of security may not be so empowered. Further, Ms. Alaniz appears to go beyond the minimum requirements. She is convinced that the RAMCAP process can make her facility safer.

Additional items and recommendations by Ms. Alaniz.

Security can become lax over time when there is no apparent threat. That is why she makes "spot checks" on the employees at random intervals.

Responses to questions:
1) Ms. Alaniz stated that she prefers a voluntary program over one required by regulation.
2) One of her concerns is that a person can gain access to the site during working hours, such as through the back door. Employees may not be capable of resisting and securing materials when systems are turned off because of ongoing work operations.
3) Ms. Alaniz feels that the RAMCAP program will help make the facility more secure.
4) Ms. Alaniz responded Yes.
5) Ms. Alaniz responded Yes.
6) Ms. Alaniz said that we are allowed to use her name for the report. We will provide her a copy when final.

Final comments:
We believe that Ms. Alaniz is a great example. She takes security seriously and goes beyond the minimum requirements. She takes a common sense approach to overcome common problems.

Meeting 2 - February 10, 2011:
A major university in Texas with medical applications (name withheld by request).

Met with the Radiation Safety Officer (RSO).

Materials on site:
There are four medical devices on site that are under increased controls. There are number of sources that exceed the IAEA D-values, but are not required to be under increased controls. There are numerous lesser uses of radioactive materials.

This facility has a number of sources in several locations. They are under increased controls and have been "upgraded" under the NSSA program. Our evaluation of the facility was that they were very professional and their program was exemplary. In spite of the fact that they met or exceeded all regulatory requirements, they felt that the RAMCAP process could aid them in developing a more secure facility. They were interested in the scenarios we presented and they had not considered some of them. They had not realized the overall risk and consequences that could result from a terrorist event.

Responses to question:
1) A voluntary program is preferred
2) They already have well tested system. A DOE grant has provided additional security to external threat. They are more worried about insider threat. Physical security is good; they believe their campus police and guards would respond with deadly force if necessary.
3) RAMCAP will be helpful for materials that fall below IC levels. Understanding risk will make employees more security conscious. Management will be more likely to fund security requests if they understand the risk, and thus the need.
4) The RSO responded "Yes". It would help verify IC programs and make non-IC more secure.
5) Yes, the additional screening tool will help.
6) No. Legal counsel prohibits use of name of facility and personnel.

For the proposed RAMCAP screening document, the RSO recommended the consideration of adding:
1. radiation detection alarms (for example, on exit routes);
2. random checks of employees when they are not normally checked; and
3. control card entry systems.

Final comments:
These facilities are well protected under current system. However, they are still vulnerable to terrorists using deadly weapons and who are willing to die to achieve goals. Insider threat cannot be ruled out. This is a high profile facility and could be a target for obtaining radioactive materials. They are very cooperative and will assist us to further develop the enhanced security tools. The RSO and staff were eager and dynamic in providing for both a high level of security and a high level of safety. Overall, this appears to be a proactive program and is an excellent example of how the security system should work under current regulations.

Meeting 3 - February 10, 2011:

Austin Cancer Centers
11111 Research Blvd.
Austin, Texas 78702

Met with Dr. Kevin O. Khadivi, Radiation Safety Officer

Materials at site:
Brachytherapy sources (individual sealed sources applied to expose tissues to external radiation, although the exposure may be internal) are stored onsite. They may be taken to a hospital surgical room for application. The sources, collectively, are less than IC quantities, but may exceed D-value quantities. Two sites have large sources that, if stored together, would exceed the IC quantity.

Dr. Khadivi had read the relevant materials and was prepared to discuss the project and his security program. He is responsible for security at two locations, each of which is below the threshold for IC but together would require IC procedures. He is very supportive of the program and stated that it would add value to his security. He contributes several excellent suggestions that will be discussed later.

Responses to questions:

1) Dr. Khadivi prefers a voluntary program rather than a mandated regulatory program. He reasons that because he knows their system better than anyone else, he will be most effective at providing security. Our proposed security enhancement process will provide him with information and a methodology for ranking his facility security according to risk.
2) Dr. Khadivi's greatest concern is that the use of radioactive materials will cause disruption of society and greatly increase the cost of protecting against events in the future, should there be an event.
3) Yes- RAMCAP can help him enhance his security program. It adds another layer of assessment and will result in a better overall system.
4) The screening tool will be useful in evaluating his security.
5) Yes.
6) Yes, we can use him as a reference.

Dr. Khadivi suggested that there are ways to inform the public about terrorist events without causing fear. He suggested a web site where people can go to learn more about the actual danger of radioactive materials, and thus prevent a panic. The web site would be non-government and use credible sources of information. Thus, people would be more likely to believe that the information was correct and reliable.

He also suggested that organizations such as the Health Physics Society could provide designated spokesman in the case of an event that would present a calm, reasoned response and describe the actual dangers, short and long term. They would be knowledgeable about remediation techniques and the time necessary to restore access, etc. This information would be made available to the media.

These resources would also be made available and coordinated with the State Emergency Response Centers. Note that the states are responsible for responding to an event and the chain of command should be followed.

These suggestions could, if properly implemented, reduce the consequences of an event.

We intend to stay in contact with Dr. Khadivi and utilize his help whenever possible.

Meeting 4 – Februay 10, 2011
Fugro Onshore Geotechnics
Fugro Consultants, Inc.
8613 Cross Park Drive
Austin, Texas 78754

Met with David R. Mason, Manager, Materials and Engineering.

Materials on site:
The company maintains about 20 moisture-density (MD) gauges at its main site and has two (2) other sites that possess about 10-20 additional MD gauges. The gauges are taken to field locations for testing the density and/or moisture content of soil and other materials used in road construction. Asphalt can also be tested. Most work is performed on highway and large parking lot bases.

Mr. Mason is the security officer for Fugro and has several locations within the state. The total of all materials under his purview are well below the IC limit. He seemed to be concerned that a new program was being developed to assess security and feared that he would need to expend additional funds to meet yet another requirement subject to inspection. We discussed how this program was designed to be a voluntary project and would not require the services of an outside consultant. Further, the purpose is to aid him in making his facilities more secure without adding a burdensome and costly process. We also explained how risk to the country can be reduced by making it more difficult to obtain these materials. Once he was convinced of the

nature of the project he was very supportive and made several good suggestion s for improving our security enhancement tool.

Responses to the six questions:

1) Mr. Mason is inclined to use it if it is voluntary.
2) Mr. Mason 's greatest concern is theft of a gauge.
3) He wanted to know how to rank his facilities. We discussed how we need to have a "passing" score for different types of facilities and differing amounts of material. Clearly, the more material at a site and the ore dangerous the material, the higher the score should be to provide adequate security. We will have to develop such a scoring system in Phase II. We might refer to the score as being "reasonable and customary" for the amount of stored materials.
4) Yes. He recognizes that this could provide ideas and concepts for improving security.
5) Yes
6) Yes

II. Conference Call with Licensee

In addition to the site visits and in-person interviews reported above, a conference call was held with the University of Texas Medical Branch (UTMB). The following is a report of this call.

Tuesday, February 1 – 3:00PM EST / 2:00PM CST / 12 Noon PST

Participants:

- James Creel -ASME-ITI
- James W. (Bill) Jones- Contractor
- John Haygood-Contractor
- Mike Mastrangelo-UTMB-Galveston
- Luz N. Cheng -UTMB

Minutes of Call: The pilot was performed by conference call. The call was initiated by James Creel at the above stated time. The agenda shown below was followed. Ms. Luz Cheng informed us in the beginning that she could not talk about details of her security program but could give us comments of a general nature. Jones presented the overview of the MIAN program (see below).

Luz told us that they had gone through the NNSA advanced security assessment process. The process included upgrading the security for their Cesium device to make it more difficult to remove the radioactive material by a terrorist. She also indicated that the security assessment that was performed for their site during this upgrade uncovered practices that could be improved. She also told us that the improved security modifications at UTMB were funded by the Federal IDD program as described in the September 14, 2009 congressional testimony. This program, which is part of a GTRI project, is designed to reduce the threat of an RDD. There are only 1,100 such sites in the US that will receive federal funding to increase security for Cesium devices under this program. Further, the program will not be completed until 2016 at which time all 1,100 sites will be secured.

Luz indicated that the proposed Security Assessment tool we have developed would have been useful at UTMB. (Having gone through the rigorous security screening she felt like the facility was currently well prepared.) She indicated that she thought the tool would serve a useful purpose for all sites that have not had the benefit of the GTRI security enhancement process.

Follow up:
John H. and Bill J. will follow up and try to meet with Luz to review the security-ranking tool in detail. We would like to have her input regarding how the tool can be used to improve site security and any changes or modifications to the tool she might suggest.
Notes by B. Jones, February 1, 2011

Transcript:
Mastrangelo: Generalities, can't give specifics.
Luz: Parallel global threat reduction initiative by DOE. Security assessment and recommend security upgrades. Pay for upgrades for three years. Send facility owners

to training in partnership with SANDIA. Train how to respond and secure. In ASME case, we have tool, and determine gaps.

Bill: GTRA tools, they play on going to 800 sites. But there are some 55K sources facility. Can't cover that much ground through the GTRA program. We're looking for voluntary program for those they don't visit.

Luz: Screening of personnel? Background checks? Some of these are regulations through AS or NRC. Need to filter out the people are working around sources. Security begins with personnel and infrastructure.

Bill: Checklist weighted factors to identify weak areas.

Luz: Public institutions, we don't have funding for high tech security updates. If somebody makes a recommendation, industry has more money than schools. If you go to small business or school, do they fund it themselves?

Bill: We don't make recommendations. Just let them know how they can improve security. Awareness. They can determine proper allocation of limited resources after the assessment is made.

Mastrangelo: Automated?

James: Spreadsheet.

Bill: Nobody wants to put in database where it can be compromised.

Luz: Who is supplying info? Police? UTMB, we did minimum security, then Nat Nucl Security Admin, GTRI, came, and we had to do more. Campus police came through. If they get to source, radiation alarm will sound.

John: No increased controls at UT facilities. Most problems I found were in industrial radiography or other industrial complexes.

Luz: Test the codes and security upgrades. NRC mandated. GTRI won't be finished until 2016.

Mastrangelo: UT has isolated facilities. Hard to mount a response. Luz has indicated our program is of serious use.

Bill: We just wanted to confirm that is was useful and how to deploy. We'll put together next steps at the end of our study. Could be used. Could reduce risk. We're only looking at obtaining material from source.

Luz: NRC and AS has communicated the risk. If anybody has it they know. They'll need help in understanding lack of security but they're already aware.

Meeting agenda: Provided to all participants ahead of time.

1) Introductions-James Creel and Mike Mastrangelo- 5 minutes
2) Brief overview of MIAN project-Bill Jones- 10 minutes
3) Brief Overview of UTMB Security - TBD- as required
4) Discussion-

Brief overview of MIAN project-Bill Jones

1) Topic: Medical, Industrial, and Nuclear Radioactive Materials-Risk to the Public
    - Funded by Alfred P. Sloan Foundation (Fall 2009) at request of FBI and Interpol-Concerned existing programs were not addressing problem properly
    - ASME chosen to perform study because of RAMCAP Plus and previous experience in critical infrastructure protection projects.
    - Final report due March 1, 2011

2) Steps in Project:
    - Review of existing programs for securing materials
        - NRC including increased Controls Program
        - Agreement States
        - National Laboratories
        - IAEA
        - Publications and literature
    - FBI briefing
    - Site pilots and feedback from reviewers

3) Conclusions reached to date:
    - Terrorism is much greater risk than natural hazards
    - Most if not all work to date concentrates on RDD's (Radioactive Dispersal Devices)

- Other means/methods of deploying radioactive materials can result in high consequences
- Many (most?) sites do not have sufficient security to prevent dedicated terrorist attack
- Many sites do not have trained security personnel capable of assessing security levels

4) Outcomes of Study:

- Risk Methodology for determining overall risk
- Material summary and possible uses by terrorists
- Security screening tools for determining security level
- Examples illustrating methodology for scenario-based risk assessments

5) Future work:

- Outreach and implementation of voluntary programs

Appendix G: Security Level Assessment

This appendix contains the following information which has been developed for use by licensees who participate in a voluntary program to enhance security. This enhanced security program as presented below is preliminary and will require additional effort to complete, pilot at a number of facilities, and make available to licensees.

- Enhanced Security Program – a description of a program of security assessment.
- Assessment of Security Status – steps to be taken to assess a security program and enter the information on the screening document.
- Screening Document – a checklist screening document that allows one to assess a program and develop a level of security value.
- Security Level Screening Test-Examples
- Screening Results of 11 Example Programs

ENHANCED SECURITY PROGRAM for MIAN FACILITIES

The proactive program is a screening process that enables possessors of radioactive material to voluntarily assess their own level of security and make modifications to enhance security to higher levels, if necessary.

The steps of the enhanced security program (ESP) consist of:

1. Using a screening tool to assess the current security level.
2. Using an assessment tool to determine the risk that any of the radioactive material might be used as a weapon.
3. Using an assessment tool to determine the consequences and cost should the radioactive material be successfully deployed as a weapon.
4. Compare to acceptance requirement based on category. (Yes-stop, No-go to step 5)
5. Employing additional security measures in the facility's security plan to reduce the potential risk for the material being used as a weapon.
6. Repeating 1-4 until the risks and consequences are reduced to an acceptable level.

EESP includes the use of Increased Controls (IC) for Category 1 and 2 radioactive materials required by government regulations. It also includes Category 3 and 4 radioactive materials, but does not include Category 5.

IC require radioactive material licensees, as a minimum, to:

1. Control access to radioactive material quantities of concern.
2. Monitor and detect unauthorized access.
3. Control licensed material during transport.
4. Physically control portable/mobile devices.
5. Maintain documentation of controls.
6. Protect sensitive information from unauthorized disclosure.

ESP addresses "levels of security", where one level of security is a device and/or method designed to prevent access.[43] For example, a source stored in a locked container would be one level of security. Some examples of individual methods providing one level of security are:

- Locked device or container
- Device/container chained or positively secured to structure, or is physically part of structure
- Locked door to area
- Locked building.
- Locked fence around site.
- Video/audio surveillance.
- Guard.
- Alarmed/monitored security system.
- Presence of authorized personnel.

Thus, placing a locked container in a locked room, in a locked building, inside of a locked fenced area, with a security guard on duty 24 hours per day, would provide a total of 5 levels of security. Personnel in attendance would be one level, as would an operable intruder alert system. On the other hand, a system of background checks would not be counted, but should be considered under the overall security plan of the facility. Not all locked features would be counted as one security level. If a room was used to store radioactive material and the room had two (2) locked doors, only one security level exists. Either door could be penetrated so there is only one level of security. It is also anticipated that the locks being used are effective. Control of keys and codes must be considered.

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[43] Haygood, John R.: "RADIATION SAFETY HANDBOOK - Regulatory Processes Explained," 2nd Edition, 2001, P. 4-2.

It is anticipated that radioactive material could be removed from the possession of a licensee by one of the following:

- Diversion of shipment to/from site
- Inside employee removes
- Theft
- Armed attack team

Ideally, a certain level of security could be set to prevent any of the above methods from being successful. Unfortunately, almost all facilities are different and a given level which is successful for one facility may be inadequate for the next. Thus, each facility should be evaluated on its own merits with the security levels being used as guides.

There are many methods of deploying any stolen radioactive material, but the most likely methods would be drawn from:

- Explosive dispersal of sealed sources
- Placement of individual or clustered sources in transportation system or public areas, such as schools, universities, and government offices
- Radioactive material removed from cladding and placed in dispersible condition - dispersed by explosion
- Radioactive material removed from cladding and placed in dispersible (water soluble) condition- dispersed into water or food supply (schools, universities, commercial businesses, public venues, and government offices could be targeted)
- Perpetrators hide material in unknown location and use fear to terrorize the public

The consequences and costs of the deployment of radioactive material through one of these mechanisms should be evaluated so that the efforts of preventing removal and deployment will be expended in the areas with greatest consequence.

For storage, use, and/or transport circumstances, the selected security methods from the following lists should be employed in a manner that renders unauthorized removal to be highly unlikely.

Active Methods:

- Security plan/program.
- Security training for personnel.
- System of authorizing access (background checks).
- Monitoring/alarm system.
- Video/audio surveillance.
- Guard.
- Method to deploy armed local law enforcement (LLEA).
- Presence of authorized personnel.
- Periodic inspection/inventory.

Passive Methods:

- Locked device.
- Locked container.
- Container chained or positively secured to structure.
- Locked metal (steel) cage.
- Locked door to room of use or storage.
- Locked building.
- Locked fence around site.
- Device/container physically part of structure.
- Device position in structure (such as elevated on platform).

Each licensee (a possessor of radioactive material must have a license issued by the US NRC or an Agreement State) should employ a number of these security methods to minimize the possibility of unauthorized removal. A licensee under IC, for example, would probably employ the following, as a minimum:

- Security plan/program.
- Security training for personnel.
- System of authorizing access.
- Monitoring/alarm system.
- Method to deploy armed local law enforcement (LLEA).
- Periodic inspection/inventory.
- Locked device/container.
- Container chained or positively secured to structure.
- Locked door to room of use or storage.
- Locked building.
- Locked fence around site.

Assuming that the value of each security level is one (1), this would yield a security level of about eleven (11). A licensee NOT under IC but possessing a gauging device with a very large source would probably employ the following, as a minimum:

- Security plan/program or a system of authorizing access.
- Periodic inspection/inventory.
- Locked device/container.

- Container chained or positively secured to structure.
- Locked door to room of use or storage.
- Locked fence around site.

This would only be a security level of about six (6) or seven (7). In most cases, experience indicates a security level of 3 or 4 is typical for non-IC licensees.

This program presents a weighted scheme of security levels. Some security measures are more valuable/ effective than others in prevention, or at least slowing down, unauthorized access. In most circumstances, an armed security guard would be far more effective than a padlock – even a heavy duty one. Thus, weighting of the security devices/ methods will be employed to better estimate the overall security level. The weighting of the various methods will be presented in the screening tool.

A screening tool has been developed to assess the security level for each source, to assess the risk that it might be used as a weapon, and to assess the consequences and cost should the source be successfully deployed as a weapon. The licensee should apply the screening tool to each source possessed that exceeds one (1) IAEA D-level. If the screening process indicates that the security level is too low and/or that the risk of it being used as a weapon and/or that the cost/consequences would be unacceptably high, then additional security steps may need to be employed. The risk assessment methodology for MIAN sites is contained in Section 4 of this document. Site security has a large impact on the overall risk to the public regarding the use of radioactive material for terrorist purposes. One of the key parameters that will reduce overall risk is to reduce the probability of obtaining the material for malicious purposes. While it is impossible to completely eliminate the possibility of theft, armed attack, and other extreme means of obtaining material at all sites, good security practices can greatly reduce this probability.

Notes:

- Health effects and acute injuries can be included separately as non-monetary items or included in monetary costs by assigning a reasonable numerical value for life and/or acute injury.
- Remediation cost should include clean-up cost and replacement / repair of structures and damaged items to bring the facility back to original condition.
- Cost of denial of service should be included as a first-order effect.
- Cascading effects to second order level should be included in cost of consequences. Examples of cascading effects include: (i) food/water contamination, where 1st order = deaths and acute injuries and 2nd order = losses to the serving establishment and suppliers of products affected by the event; (ii) explosion used to disseminate radioactive material, where 1st order = deaths and acute injuries, plus damage to structures and remediation costs and 2nd order = losses due to denial of service, loss of income, and effects on suppliers and customers; and (iii) placement on public transportation, where 1st order = deaths and acute injuries, damage to equipment, and denial of service, and 2nd order = loss of income for passengers and employers, including time lost at jobs and costs of alternate transportation for the duration of service denial. Note that 3rd level cascading could include loss of future business, effects on product brand names, losses at second-tier suppliers (e.g., restaurants in the general area, dry cleaners, public services in general, customer satisfaction, etc.). These costs are not included since they are more difficult to estimate and depend on the resiliency of the affected area to recover from the event.

Guidance for Using the Screening Tool

The screening document (next page) is used to determine the level of security of a given operation where radioactive material is stored or used. It is applied to any device or container that encloses one or more IAEA D-values (see Table A-1 of Appendix A). One screening form is used for each collection of the same isotope located together. For example, if 5 containers of Co-60 and 3 containers of Cs-137 are secured in the same room, one screening document would be completed for Co-60 and one would be completed for Cs-137.

The indicated information should be supplied in the first table of the screening document. If the total quantity of the isotope exceeds one D-value, then the ratio will exceed one and screening should continue. One D-value or more of a given isotope screens in the isotope.

If the ratio is 10 or more and the isotope is on the NRC IC list, IC should already be in effect.

Complete the second table of the screening document by reviewing the security methods that your facility has incorporated. For each item used by your program, enter the security level value of the item in the next-to-last column. The more valuable the security item, the greater the weighting. For example, locking a container has a security level value of “1”, whereas, providing an armed guard has a security level value of “4” because an armed guard can provide for much greater security, in general.

Total the last column. The higher the total, the higher the security level of a program. Further work is necessary to develop security acceptance levels for various materials and recommend steps that should taken to improve security based on your program’s current overall security level.

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source. The greater the value number in the next to last column, the greater the value of the security method. The higher the total in the last column, the greater the overall security level.

Test of: 1. Input material name and quantity

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	
2. Device(s)	Gauge, container, etc.	
3. Form	Encapsulation, solid, liquid, etc.	
4. Ser No	Unique identifier for the source and/or device.	
5. Quantity (Tot)	In Curies	
6. Quantity (Tot)	In Terabecquerels	0.000
7. D-value	In Terabecquerels	0
8. Ratio	Divide Item 5 by Item 6. If ratio > 1, continue.	**0.0**

1 Terabecquerel = 27.027027027 curie 1 curie = 0.037 Terabecquerel

Are Increased Controls required? Employed?

If Item 8 ≥ 1, continue screening. Is s☐ No j c☐ Yes d? ☑ No ☐ Yes s ☐ No

Security Level	Value	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	0
Security training for personnel.	**3**	0
System of authorizing access (background checks).	**2**	0
Monitoring/alarm system.	**3**	0
Video/audio surveillance.	**3**	0
Guard.	**3**	0
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	0
Presence of authorized personnel.	**2**	0
Periodic inspection/inventory.	**1**	0
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	0
Locked container.	**1**	0
Container chained or positively secured to structure.	**1**	0
Locked metal (steel) cage.	**1**	0

Locked door to room of use or storage.	**1**	0
Locked building.	**1**	0
Fence around site **with** entrance control.	**3**	0
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**0**

SECURITY Level Screening Test-Examples

Mock screening for the following typical "setups" where radioactive material is used/stored:

Example of Typical Radioactive Material Setup	Facility Type	IC	Number of D-values*	Security Level
1. 500 mCi Cs-137 gauge in petrochemical plant	I	N	**0.2**	8
2. 100 Ci Ir-192 radiography camera	I	Y	**50.9**	23
3. 5 Ci Am(Be)-241 well-logging tool	I	N	**3.1**	7
4. 20 Ci Am(Be)-241 well-logging tool	I	Y	**12.3**	22
5. 10 Portable MD Gauges: 400 mCi of Am(Be)-241 and 100 MCi of Cs-137	I	N	**0.3**	6
6. 7236 Ci Co-60 Gamma Knife	M	Y	**8924.4**	37
7. 600 Ci Co-60 Blood Irradiator	M	Y	**740.0**	35
8. 300 millicuries as 20 pencils of Cs-137 for brachytherapy	M	N	**0.1**	17
9. 600 Ci Co-60 veterinary teletherapy in university	A	Y	**740.0**	33
10. 25 mCi of P-32 (liquid) for lab research	A	N	**0.0001**	7
11. 5 Ci Am(Be)-241 source for neutron generator	A	N	**3.1**	7

* IC's required if "Number of D-values" is greater than 10.

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 1. Ind: 500 mCi Cs-137 gauge in petrochemical plant

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
9. Source(s)	Radioactive material.	500 mCi Cs-137
10. Device(s)	Gauge, container, etc.	Gauge
11. Form	Encapsulation, solid, liquid, etc.	Sealed Source
12. Ser No	Unique identifier for the source and/or device.	N/A
13. Quantity (Tot)	In Curies	0.5
14. Quantity (Tot)	In Terabecquerels	0.019
15. D-value	In Terabecquerels	0.1
16. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**0.2**

Are Increased Controls required? ☐ No ☑ Yes Employed? ☐ Yes ☑ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☐ No ☑ Yes

Security Level	Value	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	0
Security training for personnel.	**3**	0
System of authorizing access (background checks).	**2**	0
Monitoring/alarm system.	**3**	0
Video/audio surveillance.	**3**	0
Guard.	**3**	3
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	0
Presence of authorized personnel.	**2**	0
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	0

Locked container.	**1**	0
Container chained or positively secured to structure.	**1**	1
Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	0
Locked building.	**1**	0
Fence around site **with** entrance control.	**3**	3
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**8**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 2. Ind: 100 Ci Ir-192 radiography camera

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	Ir-192
2. Device(s)	Gauge, container, etc.	Camera
3. Form	Encapsulation, solid, liquid, etc.	Sealed source
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	110
6. Quantity (Tot)	In Terabecquerels	4.070
7. D-value	In Terabecquerels	.08
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**50.9**

Are Increased Controls required? ☐ No ☑ Yes Employed? ☑ Yes ☐ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☑ No ☐ Yes

Security Level	**Value**	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	3
Security training for personnel.	**3**	3
System of authorizing access (background checks).	**2**	2
Monitoring/alarm system.	**3**	3
Video/audio surveillance.	**3**	0
Guard.	**3**	0
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	5
Presence of authorized personnel.	**2**	0
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	1
Locked container.	**1**	1
Container chained or positively secured to structure.	**1**	0

Locked metal (steel) cage.	**1**	1
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	1
Fence around site **with** entrance control.	**3**	1
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**23**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 3. Ind: 5 Ci Am(Be)-241 well-logging tool

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	Am(Be)-241
2. Device(s)	Gauge, container, etc.	Container
3. Form	Encapsulation, solid, liquid, etc.	Sealed source
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	5
6. Quantity (Tot)	In Terabecquerels	0.185
7. D-value	In Terabecquerels	0.06
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**3.1**

Are Increased Controls required? ☐ No ☑ Yes Employed? ☐ Yes ☑ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☐ No ☑ Yes

Security Level	**Value**	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	0
Security training for personnel.	**3**	0
System of authorizing access (background checks).	**2**	0
Monitoring/alarm system.	**3**	0
Video/audio surveillance.	**3**	0
Guard.	**3**	0
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	0
Presence of authorized personnel.	**2**	0
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	1
Locked container.	**1**	2
Container chained or positively secured to structure.	**1**	1

Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	0
Fence around site **with** entrance control.	**3**	1
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**7**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 4. Ind: 20 Ci Am(Be)-241 well-logging tool

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	Am(Be)-241
2. Device(s)	Gauge, container, etc.	Container
3. Form	Encapsulation, solid, liquid, etc.	Sealed Source
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	20
6. Quantity (Tot)	In Terabecquerels	0.740
7. D-value	In Terabecquerels	0.06
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**12.3**

Are Increased Controls required? ☐ No ☑ Yes Employed? ☑ Yes ☐ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☑ No ☐ Yes

Security Level	**Value**	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	3
Security training for personnel.	**3**	3
System of authorizing access (background checks).	**2**	2
Monitoring/alarm system.	**3**	3
Video/audio surveillance.	**3**	0
Guard.	**3**	0
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	5
Presence of authorized personnel.	**2**	0
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	0
Locked container.	**1**	1
Container chained or positively secured to structure.	**1**	1

Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	1
Fence around site **with** entrance control.	**3**	0
Fence around site **without** entrance control.	**1**	1
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**22**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 5. Ind: 10 Portable MD Gauges: 400 mCi of Am(Be)-241 and 100 MCi of Cs-137

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	Am(Be)-241
2. Device(s)	Gauge, container, etc.	Gauge
3. Form	Encapsulation, solid, liquid, etc.	Sealed sources
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	.4
6. Quantity (Tot)	In Terabecquerels	0.015
7. D-value	In Terabecquerels	0.06
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**0.3**

Are Increased Controls required? ☑ No ☐ Yes Employed? ☐ Yes ☑ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☐ No ☑ Yes

Security Level	Value	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	0
Security training for personnel.	**3**	0
System of authorizing access (background checks).	**2**	0
Monitoring/alarm system.	**3**	0
Video/audio surveillance.	**3**	0
Guard.	**3**	0
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	0
Presence of authorized personnel.	**2**	1
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	1

Locked container.	**1**	1
Container chained or positively secured to structure.	**1**	0
Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	1
Fence around site **with** entrance control.	**3**	0
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**6**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel
Note: Same result for Cs-137 sources.

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 6. Med: 7236 Ci Co-60 Gamma Knife

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	Co-60
2. Device(s)	Gauge, container, etc.	Cabinet
3. Form	Encapsulation, solid, liquid, etc.	Sealed sources
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	7236
6. Quantity (Tot)	In Terabecquerels	267.732
7. D-value	In Terabecquerels	0.03
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**8924.4**

Are Increased Controls required? ☐ No ☑ Yes Employed? ☑ Yes ☐ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☐ No ☑ Yes

Security Level	Value	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	3
Security training for personnel.	**3**	3
System of authorizing access (background checks).	**2**	2
Monitoring/alarm system.	**3**	3
Video/audio surveillance.	**3**	3
Guard.	**3**	0
Armed Guard.	**4**	4
Method to deploy armed local law enforcement (LLEA).	**5**	5
Presence of authorized personnel.	**2**	2
Periodic inspection/inventory.	**1**	1
Other – Describe: Probable death of perps if sources taken.	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	0
Locked container.	**1**	1
Container chained or positively secured to structure.	**1**	1

Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	1
Fence around site **with** entrance control.	**3**	1
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	1
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe: Probable death of perps if sources taken.	**Estimate**	5
Estimated Security Level:		**37**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 7. Med: 600 Ci Co-60 Blood Irradiator

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	Co-60
2. Device(s)	Gauge, container, etc.	Gamma Knife Cabinet
3. Form	Encapsulation, solid, liquid, etc.	Sealed Sources
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	600
6. Quantity (Tot)	In Terabecquerels	22.200
7. D-value	In Terabecquerels	0.03
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**740.0**

Are Increased Controls required? ☐ No ☑ Yes Employed? ☑ Yes ☐ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☑ No ☐ Yes

Security Level	Value	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	3
Security training for personnel.	**3**	3
System of authorizing access (background checks).	**2**	2
Monitoring/alarm system.	**3**	3
Video/audio surveillance.	**3**	3
Guard.	**3**	0
Armed Guard.	**4**	3
Method to deploy armed local law enforcement (LLEA).	**5**	5
Presence of authorized personnel.	**2**	2
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	1
Locked container.	**1**	1

Container chained or positively secured to structure.	**1**	1
Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	1
Fence around site **with** entrance control.	**3**	3
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	2
Other – Describe:	**Estimate**	0
Estimated Security Level:		**35**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 8. Med: 300 millicuries as 20 pencils of Cs-137 for brachytherapy

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	Cs-137
2. Device(s)	Gauge, container, etc.	Container
3. Form	Encapsulation, solid, liquid, etc.	Sealed sources
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	.3
6. Quantity (Tot)	In Terabecquerels	0.011
7. D-value	In Terabecquerels	0.1
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**0.1**

Are Increased Controls required? ☑ No ☐ Yes Employed? ☐ Yes ☑ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☐ No ☑ Yes

Security Level	Value	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	0
Security training for personnel.	**3**	3
System of authorizing access (background checks).	**2**	0
Monitoring/alarm system.	**3**	0
Video/audio surveillance.	**3**	0
Guard.	**3**	0
Armed Guard.	**4**	4
Method to deploy armed local law enforcement (LLEA).	**5**	0
Presence of authorized personnel.	**2**	2
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	0
Locked container.	**1**	1
Container chained or positively secured to structure.	**1**	1

Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	1
Fence around site **with** entrance control.	**3**	3
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**17**

1 Terabecquerel = 27.027027027 curie

1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 9. Acad: 600 Ci Co-60 veterinary teletherapy in university

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	Co-60
2. Device(s)	Gauge, container, etc.	Teletherapy Head
3. Form	Encapsulation, solid, liquid, etc.	Sealed Sources
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	600
6. Quantity (Tot)	In Terabecquerels	22.200
7. D-value	In Terabecquerels	0.03
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**740.0**

Are Increased Controls required? ☐ No ☑ Yes Employed? ☑ Yes ☐ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☑ No ☐ Yes

Security Level	Value	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	3
Security training for personnel.	**3**	3
System of authorizing access (background checks).	**2**	2
Monitoring/alarm system.	**3**	3
Video/audio surveillance.	**3**	3
Guard.	**3**	3
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	5
Presence of authorized personnel.	**2**	0
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	1
Locked container.	**1**	0
Container chained or positively secured to structure.	**1**	1

Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	1
Fence around site **with** entrance control.	**3**	0
Fence around site **without** entrance control.	**1**	1
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe: Must remove source to xport, death	**Estimate**	5
Estimated Security Level:		**33**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 10. Acad: 25 mCi of P-32 (liquid) for lab research

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
1. Source(s)	Radioactive material.	P-32
2. Device(s)	Gauge, container, etc.	Glassware
3. Form	Encapsulation, solid, liquid, etc.	Liquid
4. Ser No	Unique identifier for the source and/or device.	N/A
5. Quantity (Tot)	In Curies	.025
6. Quantity (Tot)	In Terabecquerels	0.001
7. D-value	In Terabecquerels	10.0
8. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**0.0001**

Are Increased Controls required? ☑ No ☐ Yes Employed? ☐ Yes ☑ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☑ No ☐ Yes

Security Level	**Value**	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	0
Security training for personnel.	**3**	0
System of authorizing access (background checks).	**2**	0
Monitoring/alarm system.	**3**	0
Video/audio surveillance.	**3**	0
Guard.	**3**	3
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	0
Presence of authorized personnel.	**2**	0
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	0
Locked container.	**1**	1
Container chained or positively secured to structure.	**1**	0

Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	1
Fence around site **with** entrance control.	**3**	0
Fence around site **without** entrance control.	**1**	0
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**7**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Determination of Security Status

For each source of radioactive material, provide the indicated information and determine the security levels for that source.

Test of: 11. Acad: 5 Ci Am(Be)-241 source for neutron generator

Item	Comment/Information	Description
Note: Screen each source separately -- combine if located together.		
17. Source(s)	Radioactive material.	Am(Be)-241
18. Device(s)	Gauge, container, etc.	Container
19. Form	Encapsulation, solid, liquid, etc.	Sealed Source
20. Ser No	Unique identifier for the source and/or device.	N/A
21. Quantity (Tot)	In Curies	5
22. Quantity (Tot)	In Terabecquerels	0.185
23. D-value	In Terabecquerels	0.06
24. Ratio	Divide Item 6 by Item 7. If ratio > 1, continue.	**3.1**

Are Increased Controls required? ☑ No ☐ Yes Employed? ☐ Yes ☑ No

If Item 8 ≥ 1, continue screening. Is screening continued? ☐ Yes ☑ No

Security Level	**Value**	Selection
Enter the value in the right column for each of the following that applies to this source.		
Active Methods:		
Security plan/program.	**3**	0
Security training for personnel.	**3**	0
System of authorizing access (background checks).	**2**	0
Monitoring/alarm system.	**3**	0
Video/audio surveillance.	**3**	0
Guard.	**3**	3
Armed Guard.	**4**	0
Method to deploy armed local law enforcement (LLEA).	**5**	0
Presence of authorized personnel.	**2**	0
Periodic inspection/inventory.	**1**	1
Other – Describe:	**Estimate**	0
Passive Methods:		0
Locked device.	**1**	0
Locked container.	**1**	1
Container chained or positively secured to structure.	**1**	0

Locked metal (steel) cage.	**1**	0
Locked door to room of use or storage.	**1**	1
Locked building.	**1**	0
Fence around site **with** entrance control.	**3**	0
Fence around site **without** entrance control.	**1**	1
Device/container physically part of structure.	**1**	0
Device position in structure (such as elevated on platform).	**2**	0
Other – Describe:	**Estimate**	0
Estimated Security Level:		**7**

1 Terabecquerel = 27.027027027 curie
1 curie = 0.037 Terabecquerel

Appendix H: Resumes of Investigators

JAMES WILLIAM JONES, Ph.D., P.E

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Huntington Beach, CA 92648
bill@jwjce.com; jwjce.com
(714) 585-4820 (M)

EDUCATION

1973
University of Pittsburgh Ph.D., Mechanical Engineering

1968
University of Texas M.S., Mechanical Engineering

1966
University of Texas B.S., Mechanical Engineering

EXPERIENCE

2003 - Present
Consultant, J. William Jones Consulting Engineers, Inc., Senior Fellow, ASME-ITI, LLC

2004 - 2005
ASME Washington Fellow

2002 - 2003
ASME White House Fellow, Office of Science and Technology Policy Executive Office of the President of the United States

1998 - 2002
MSC Software, Mechanical Solutions Division, Director Expert Solutions Group (MSC/ESG)

1977 - 1998
Silverado Software and Consulting, President

1974 - 1977
Swanson Engineering Associates Corporation, Vice President and Consultant

1971 - 1974
O'Donnell and Associates, Inc. Vice President and Consultant

1968 - 1971
Bettis Atomic Power Laboratory, Senior Engineer

1966 - 1968 Tracor, Inc. of Austin, TX, Engineer

AREAS OF SPECIALIZATION

Corporate Management, Corporate Marketing & Business Development, Risk Analysis and Antiterrorism, Container Security, Protection of Vulnerable Infrastructure Systems, Risk Analysis, Finite Element Analysis Methods, Stress Analysis, Dynamic Analysis, Thermal Analysis, Pressure Vessel Design & Analysis, Design & Analysis of Spent Nuclear Fuel Shipping Containers, Petrochemical and Chemical Vessel Design, Expert Witness Testimony, Failure Analysis, Electronic Packaging.

PROFESSIONAL SOCIETIES AND HONORS

Fellow - American Society of Mechanical Engineers (Elected 1984)

Fellow - Institute for the Advancement of Engineers (Elected 1985); Sigma Xi (Scientific Research Society)

Registered Professional Engineer - Pennsylvania, California and Illinois

T.U. Taylor Award - University of Texas (1967)
Five Patents and Numerous Patent Disclosure Awards (from various employers.)

CURRENT STATUS

Dr. Jones is a consultant to government and industry in the areas of expertise detailed in this resume. He is currently working on a projects funded by the ASME International to optimize infrastructure investment and to reduce risk on campuses of higher education. Until 2008 he was a consultant on contracts with the Department of Homeland Security (DHS) to develop a general risk based guideline which is used to determine how best to allocate resources for prevention and mitigation of terrorism. In this capacity he was retained as a consultant to ASME-ITI. He is a Senior Fellow at the ASME Innovative Technology Institute. The development of the RAMCAP© and RAMCAP Plus® methodologies emanated from conceptual investigations initiated during the year he spent as an ASME Fellow at the Office of Science and Technology (OSTP), Executive Office of the President. More information concerning RAMCAP© and RAMCAP Plus® is available from ASME-ITI. In addition, Dr, Jones maintains offices in Huntington Beach, California, where he provides consulting services to the petrochemical, legal, and commercial products sectors.

While Dr. Jones served as an ASME White House Fellow (2002) in OSTP, he was assigned to work on issues involving protection of critical assets from terrorist attack. In this one year assignment, he assembled a working group consisting of representatives from ten departments of government. A five-year program for R&D requirements for antiterrorism was produced which contains the strategic plans for the agencies represented in the Protection of Vulnerable Systems (PVS) Subgroup. He was also assigned to follow the technology for inspection of intermodal cargo shipping containers. The main thrust of this project was to implement new technology that could significantly reduce the time necessary to inspect each container for weapons of mass destruction. He developed a risk-based strategy to rank terrorist threats to the infrastructure and to assess the efficacy of proposed solutions. He was assigned a temporary Secret clearance to participate in classified meetings while permanent security clearance was being processed. He also was cleared to participate in nuclear power plant assessments.

Before moving to Washington to serve as an ASME WH Fellow, he was Director of the MSC.Software, Expert Solutions Group (MSC/ESG). MSC/ESG maintained a staff of highly trained and experienced engineers who provided consulting services in the area of finite element simulation to their customers worldwide. The MSC/ESG, while under the direction of Dr. Jones, was a service-oriented team focused upon providing solutions to client companies in the areas of analytical and design engineering. In addition to the in-house staff, a group of industry experts from the MSC/ESG Technical Resources Group was employed to provide consulting to industry and government. Additionally, over 150 experienced engineers were available worldwide throughout the MSC organization to provide local responsiveness to clients.

For the previous 22 years, Dr. Jones was President of Silverado Software and Consulting, Inc. (SSC). Before being acquired by MSC.Software in 1998, SSC was a consulting company specializing in the design and analysis of mechanical components and civil structures. SSC provided services to industry, government and the private sector. Dr. Jones founded this company in 1977. At the time of the acquisition by MSC.Software, SSC had over 30 employees in three cities. Prior to founding SSC, he was a principal and founder of a consulting company in Pittsburgh, PA.

AREAS OF EXPERTISE

I. Homeland Security and Risk Analysis Methodology

While serving as a White House Fellow sponsored by the ASME in the Office of Science and Technology Policy (OSTP), Executive Office of the President, he was assigned to developing a Research and Development program for protection of critical infrastructure. He assembled representatives from ten agencies of the Federal Government that had the responsibility for infrastructure components. These included the Nuclear Regulatory Commission, U.S. Postal Service, Department of Agriculture, Department of the Interior, Federal Aviation Agency, U.S. Coast Guard, and other federal agencies. As a result of numerous meetings with senior level representatives from these agencies, it became apparent that there was a pressing need for a risk based methodology for ranking terrorist threat for the allocation of public resources. Dr. Jones approached the ASME risk analysis committee through Reese Meisinger and others who were influential in ASME policy to encourage the ASME to become involved in the risk assessment of critical infrastructure components. This work resulted in a high level White House sponsored workshop (Fall 2002) held under the auspices of OSTP. The primary recommendation of this workshop was to devise a risk based methodology for ranking terrorist threat. In response to this need, a proposal was developed by Dr. Jones and others at ASME and funded by the Department of Homeland Security. This grant resulted in the precursor of the current Risk Analysis and Management for Critical Asset Protection (RAMCAP©) methodology. RAMCAP© has become the standard by which risk assessment of terrorist threats are measured by the DHS. All of the Nuclear Power Plants in the United Stated have been assessed using RAMCAP©. RAMCAP© Sector Specific Guidelines have been developed for Chemical Plants, Petroleum Refineries, Liquefied Natural Gas Facilities, and Spent Nuclear Fuel Shipping and Storage facilities. The RAMCAP© methodology continues to be developed in other sectors as well as regional risk assessments. RAMCAP© has been cited in congressional hearings and testimonies hundreds of times and is often named as one of the most important achievements of DHS to date.

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EDUCATION

Dr. Robert E. Nickell received his B.S. (1963), M.S. (1964), and Ph.D. (1967) degrees in Engineering Science from the University of California, Berkeley.

PROFESSIONAL CAREER

After receiving his doctorate in 1967, Dr. Nickell was employed by Rohm & Haas Company at the Redstone Arsenal in Huntsville, AL, where he worked on solid propellant rocket motors and related explosive munitions for the United States Army. When Rohm & Haas closed their Huntsville operations, he was hired by Bell Telephone Laboratories, Whippany, NJ, where he worked from 1968-1971 on the SPRINT and SPARTAN defensive missile systems, plus classified work on spy satellite systems. When Bell Telephone Laboratories exited the missile defense business in 1971, he was placed on an industrial sabbatical teaching assignment at Brown University, Providence, RI, as an Associate Professor of Engineering (1971-1973). During this period he was given the AIAA/ONR Naval Structural Mechanics Award for his work on dynamic bucking of naval structures from external explosions. After this (1973-1977) Dr. Nickell returned to the Bell System at the Sandia National Laboratories (operated by Western Electric at that time) in Albuquerque, NM, where he worked on nuclear weapons design and analysis and was promoted to Supervisor of Design Technology in the Transportation Technology Department, with responsibility for radioactive material transport packaging design and analysis. This assignment also involved interactions with other units at Sandia National Laboratories carrying out experiments and analyses on preventing terrorist acquisition of nuclear weapons and weapons-grade material. Dr. Nickell left Sandia in July 1977, becoming a private consultant to industry and government, except for direct assignments as a Project/Program Manager for the Electric Power Research Institute (EPRI), Palo Alto, CA, from September 1980 to October 1984, and as the Technical Director for SGI International, La Jolla, CA, from April 1992 to March 1995. Dr. Nickell provides his consulting services through Applied Science & Technology, a California C corporation.

CODES AND STANDARD ACTIVITIES

Dr. Nickell has been involved in various ASME Boiler and Pressure Vessel Code activities for the past thirty-seven years, and is currently the Chair of the Task Group on Impulsively Loaded Vessels of the Working Group on High Pressure Vessels (Section VIII, Division 3). He was the founding Chair of what is now the ASME Code Section III Subgroup NUPACK that has developed rules for the design and fabrication of containment systems for nuclear spent fuel and high-level waste transport packagings. He is also a member of ASME Code Section XI Special Working Group on Nuclear Plant Aging Management, and is the Secretary, RAMCAP Standard Committee, reporting to the ASME Board on New Development. He was the elected Chairman of the three Consultants Service Meetings (CSMs) that developed criteria for the evaluation of brittle fracture for radioactive material transport packagings, under the auspices of the International Atomic Energy Agency (IAEA). 34

OTHER PROFESSIONAL ACTIVITIES

Dr. Nickell is a member of ASCE, ANS, and ASTM, and is a Fellow of the ASME and of the AAAS. Among his many activities within ASME, he was a Member-At-Large of its Board of Governors from 1992-1994, chaired the Board's Committee on Finance & Investment from 1994-1998, served as its 118th President from 1999-2000, served as Secretary-Treasurer from 2001-2004, and currently chairs its Pension Plan Trustees. He is also a member of the Board's Committee on Honors and currently chairs the ASME Headquarters Facilities Task Force.

HONORS AND AWARDS

Dr. Nickell was the 1972 recipient of the Office of Naval Research/American Institute of Aeronautics and Astronautics (ONR/AIAA) Naval Structural Mechanics Award, and was appointed by U.S.

Secretary of Energy Hazel Rollins O'Leary to the National Coal Council for the period 1993-1995, and reappointed for the periods 1995-1997 and 1997-1999. He was selected to present the Robert D. Wylie Memorial Lecture at the Ninth International Conference on Pressure Vessel Technology in April 2000. He has authored or co-authored some 100 papers in refereed journals. He was elected to the National Academy of Engineering in 2007.

EXPERIENCE IN RISK ASSESSMENT

Dr. Nickell has been a consultant to the Electric Power Research Institute (EPRI) since 2001 on vulnerability of nuclear power plant structures, including containment structures and spent fuel pools, to terrorist attack, with major emphasis on aircraft impact, and has served for the past four years on the EPRI Expert Panel on Aircraft Impact Assessment (10 CFR 50.150).

He also consulted with EPRI during the period from 1986-1988 on probabilistic risk assessment of spent radioactive fuel rail and truck casks subject to transport accidents.

He was a member of the original team at ASME ITI working under a grant from the Department of Homeland Security to develop RAMCAP, and was a consultant to ERIN Engineering during the application of RAMCAP to the nuclear power sector.

He was a member of the six-person task force reporting to the Secretary of Energy Advisory Board (SEAB) in 2005-2006 on the reorganization of the DOE/NNSA weapons complex, which included the review of security against terrorist attack at the various sites throughout the complex.

He has been a consultant to Los Alamos National Laboratory since 1998 on the design and operation of containment vessels for dynamic explosive experiments, including the potential need to reduce risk from explosive fragment penetration.

He has been a consultant to Kobe Steel, Ltd., for ten years on the design and operation of detonation chambers for the explosive destruction of chemical weapons, including detonation chambers at Port Kanda in Japan (non-stockpile WWII chemical weapons); in Poelkapelle, Belgium (non-stockpile WWI chemical weapons); Toele, Utah (U.S. Army stockpile chemical weapons); and more recently Nanjing, China (non-stockpile WWII chemical weapons). 35 He is currently a consultant to Amtrak on the vulnerability of railroad tunnels and bridges to terrorist attack.

He consults with ASME ITI on the MIAN/RAMCAP project for the Sloan Foundation.

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EDUCATION

1979 University of Texas, M.S., Environmental Science (Health Physics)

1972 University of Texas, B.A., Physics

LICENSES

Texas Licensed Medical Physicist (Medical Health Physicist Specialty), License No. MP0327

EXPERIENCE

2008 - Present
Consultant: John R. Haygood, Consultant in Radiation Safety

2002 - 2008
Compliance Reviewer, Inspector: Texas Department of State Health Services, Radiation Control

1998 - 2001
Consultant: John R. Haygood, Consultant in Radiation Safety

1981 - 1997
Deputy Director, Radioactive Materials: Bureau of Radiation Control, Division of Compliance and Inspection, Texas Department of Health (Retired 1997)

1979 - 1981
Assistant Chief of Compliance and Supervisor of Isotope Program: Bureau of Radiation Control,

Division of Compliance and Inspection, Texas Department of Health

1972 - 1979
Radioactive Materials License Inspector and X-Ray Inspector: Division of Radiation Control and Occupational Health, Texas Department of Health

1966 - 1969
AEW Radar Repairman: USAF (Staff Sgt - E-5, Top secret and crypto clearances)

AREAS OF SPECIALIZATION

Health Physics
Medical Health Physics
Security
Electronics

PROFESSIONAL SOCIETIES AND HONORS

Member of the Health Physics Society, South Texas Chapter

CURRENT STATUS

Mr. Haygood has over 35 years of experience in radiation control: radioactive materials, x-ray devices, and laser devices. During this time period, Mr. Haygood participated in continuing education courses such as: Health Physics and Radiation Protection, 10 weeks, 1974, US Nuclear Regulatory Commission (NRC); Radiation Protection Engineering, 1988, - Oak Ridge Associated Universities/U.S. Department of Energy and a1 week US NRC course on security for increased controls. He also participated in 25+ federal and state provided technical courses from 1972 to 2008 and 10+ Texas provided management courses. Mr. Haygood has performed numerous compliance inspections of all types of radiation use facilities, and has performed many Increased Controls inspections. He developed a state wide inspection program and managed the enforcement program. As a consultant, Mr. Haygood has several radiation safety training courses approved by the Department of State Health Services, and also presents a two day Radiation Safety Officer training course. He has developed two user training manuals and a Radiation Safety Officer training manual.

Appendix I: Acronym List

AEC - Atomic Energy Commission

ALI - Annual Limit on oral Intake

AMU - Atomic Mass Units

ANS - American National Standard

AS - Agreement State

ASME-ITI - American Society of Mechanical Engineers – Innovative Technologies Institute

CFR - Code of Federal Regulations

CSI - Container Security Initiative

DHS - Department of Homeland Security

DOD - Department of Defense

DOE - Department of Energy

DOT - Department of Transportation

DRD - Disruptive Radiation Device

EC - Electron Capture

EPA - Environmental Protection Agency

ERA - Energy Reorganization Act

ERDA - Energy Research and Development Administration

ESP - Enhanced Security Program

FBI - Federal Bureau of Investigation

FEMA - Federal Emergency Management Agency

HAZUS-MH - Hazards-U.S. Multi-Hazard

HHSD - Department of Health and Human Services

IAEA - International Atomic Energy Agency

IDD - In-Device Delay

IC - Increased Controls

IED - Improvised Explosive Device

IT - Isometric Transition

KeV - Kiloelectron Volts

LEA - Law Enforcement Agencies

LT - Lone Terrorist

MeV - Megaelectron Volts

MIAN - Medical, Industrial and Academic Nuclear

NCRP - National Committee on Radiation Protection

NIPP - National Infrastructure Protection Plan

NNSA - National Nuclear Security Administration

NRC - Nuclear Regulatory Commission

NSTS - National Source Tracking System

OSRP - Off-site Source Recovery Program

RAM - Radioactive Materials

RAMCAP - Risk Analysis and Management for Critical Asset Protection

RDD - Radioactive Dispersal Device

RED - Radiation Exposure Device

SF - Spontaneous Fission

SPECT - Single Photon Emission Computerized Tomography

SSG - Sector-Specific Guidance

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