Fall 2007 | Winter 2008 | Spring 2008 | Summer 2008 | Volume XXXVI, Number 3

JNMM Journal of Nuclear Materials Management

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JNMM (ISSN 0893-6188) is published four times a year by the Institute of Nuclear Materials Management Inc., a not-for-profit membership organization with the purpose of advancing and promoting efficient management of nuclear materials.

SUBSCRIPTION RATES: Annual (United States, Canada, and Mexico) $200.00; annual (other countries) $270 (shipped via air mail printed matter); single copy regular issues (United States and other countries) $55; single copy of the proceedings of the Annual Meeting (United States and other countries) $175. Mail subscription requests to *JNMM*, 111 Deer Lake Road, Suite 100, Deerfield, IL 60015 U.S.A. Make checks payable to INMM.

ADVERTISING, distribution, and delivery inquiries should be directed to *JNMM*, 111 Deer Lake Road, Suite 100, Deerfield, IL 60015 U.S.A., or contact Jill Hronek at 847/480-9573; fax, 847/480-9282; or E-mail, inmm@inmm.org. Allow eight weeks for a change of address to be implemented.

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Fifty Years of Nuclear Materials Management

By Nancy Jo Nicholas
INMM President

Our Institute has achieved a very important milestone. The INMM was founded on the May 17, 1958, and Dr. Ralph Lumb was elected the first chairman of the INMM in October 1958. To ensure that this milestone does not go unnoticed, we have formed an *ad hoc* committee under the leadership of Ed Johnson and Debbie Dickman to plan a year-long celebration of the INMM's 50th anniversary. This committee developed a brochure to highlight INMM's activities over the past fifty years and is planning some special events to commemorate INMM's 50th anniversary at the 2008 Annual Meeting, and another celebration for the 50th Annual INMM Meeting in July 2009. The summer issue of the *Journal of Nuclear Materials Management* will highlight our first fifty years as a professional society dedicated to the management of nuclear materials. Whether you're a technologist or policy expert, a facility manager or a safeguards inspector, these are exciting times to be in the nuclear field, and INMM members are on the forefront. At this year's annual meeting I'm looking forward to both celebrating our successes with some of our INMM past presidents and founding fathers and to discussing ideas for INMM's next fifty years!

Confronting the Illicit Trafficking of Nuclear and Radiological Materials

This issue of the *Journal of Nuclear Materials Management,* like the special issue from a year ago, is focused on the important topic of reducing risks from radioactive and nuclear materials. With our wide-ranging technical divisions and diverse membership, INMM is taking a multifaceted approach to addressing the issues associated with of nuclear security and radiological material trafficking. INMM has been a leader in providing a forum for experts from around the globe to share ideas about these topics. Over the past several years we have held and co-sponsored a number of productive workshops focusing in this area. Through a technical program coordinated by Ken Sorensen and the Packaging and Transportation Technical Division, hundreds of participants at the 15th International Symposium on Packaging and Transportation of Radioactive Materials (PATRAM 2007) conference in Miami, Florida, USA, last October explored heightened challenges to nuclear material packaging and transportation. The Nonproliferation and Arms Control Technical Division's standing committee on International Security of Nuclear and Radiological Materials has led the charge. Ruth Duggan is chairing this standing committee, which, in conjunction with the INMM Northeast Chapter, held a workshop February 19-20, 2008, in Arlington, Virginia, USA, on reducing the risk from radioactive and nuclear materials as a follow-on to the successful March 2007 INMM workshop in Santa Fe, New Mexico, USA, she organized on this topic. Several insightful technical papers have been presented at recent INMM annual meetings with valuable suggestions on how to improve the detection of illicit trafficking in nuclear materials, how to meet the challenges of event adjudication, and how to minimize the impact on legitimate commerce and nuclear medicine patients.

Annual Meeting News

Planning is well under way for our 49th INMM Annual Meeting, which will be held July 13-17, 2008, at the Nashville Convention Center and Renaissance Hotel in Nashville, Tennessee, USA. Visit the INMM Web site at www.inmm.org/meetings for information about the program and registration. Abstracts for more than 300 papers and posters have been organized into an outstanding technical program for this year's meeting. We are planning several activities for students, including a Career Fair on Wednesday night, and we'll be holding a number of special events (including a birthday cake) to commemorate and celebrate INMM's 50th anniversary. I encourage you to make plans now to attend this year's annual meeting.

Should you have suggestions, comments, or questions about INMM, I encourage you to contact me at 505/667-1194 or njnicholas@lanl.gov (or contact INMM headquarters at 847/480-9573 or inmm@inmm.org).

Reducing the Risk

By Dennis Mangan
Technical Editor

In my editor's message a year ago (the spring 2007 issue) I noted that the Nonproliferation and Arms Control Technical Division, chaired by Steve Mladineo, through a superb effort by Ruth Duggan, chair of its Standing Committee on International Security of Radioactive and Nuclear Materials, and others put together an excellent series of papers addressing the unique problems faced with the plethora of radioactive materials around the world. In that special issue, Mladineo, in his introductory paper, noted that his standing committee held a workshop in March 2007, *Reducing the Risk from Radioactive and Nuclear Materials.* In this issue, Duggan and her co-authors provide a summary of this workshop, *Priorities for Technology Development and Policy to Reduce the Risk from Radioactive Materials.* Also, this issue includes four papers from that workshop, all interesting and informative reading. Again I would like to thank Duggan and her colleagues for their efforts.

The first one, *The IAEA's Illicit Trafficking Database: A User's Perspective on Strengthened Reporting,* is by William Wanderer from SAIC, Washington, DC, USA. He provides insights into the history and current state of the IAEA's database and how it gets populated. He likewise suggests means to strengthen the database to make it more effective. The second paper, authored by Firmi Banzi of the Tanzania Atomic Energy Commission, is *Safety and Security of Radioactive Materials in the United Republic of Tanzania.* This is an informative article on the work being done in Tanzania addressing the safety and security of radioactive materials and radiation-emitting devices solely used in diagnosis technologies including medical applications. The third article is *High-Risk Radioactive Sources: Cradle-to-Grave Physical Protection* by Nicholas Fernandez from the Center for International Trade and Security at the University of Georgia, Athens, Georgia, USA. This interesting article proposes approaches to addressing the security of radioactive sources based on the fundamental principles of physical protection used to design security systems for nuclear facilities. The author addresses all phases of the radioactive source's life from birth to disposition. The final paper addressing the security of radioactive sources is *Triborder Radioactive Material Trafficking and Threat Environment.* This paper, by Charles Streeper from Los Alamos National Laboratory, Los Alamos, New Mexico, USA, discusses the potential problems associated with illicit trafficking is the region bordered by Paraguay, Brazil, and Argentina in South America. The author discusses past incidents of illegal trafficking and urges increased measures to address the problem.

The final two papers in this issue do not address the security of radioactive sources but rather address statistical sampling of large changing inventories of stored nuclear material, and safeguards for reprocessing plants. *Statistical Algorithm for Sampling from a Growing Population* is authored by: Tom Burr, Los Alamos National Laboratory, Los Alamos, New Mexico, USA; Floyd Spenser, Sandia National Laboratories, Albuquerque, New Mexico, USA; Dennis Weier, Pacific Northwest National Laboratory, Richland Washington, USA; and Ronald Weitz, SAIC, Albuquerque, New Mexico, USA. This paper addresses the problem facing inspectors who perform inspections on a large inventory of nuclear material whose population continues to grow. Since it is not possible to inspect every container in a an inventory of thousands, statistical sampling is required. Thus the question, "Out of the entire population, how many containers must be randomly selected and inspected to be able to say with a certain level of confidence that inventory is as declared?" The final paper address reprocessing plant safeguards in Japan, and is authored by Osamu Yamamura, consultant to the Japan Atomic Energy Agency (JAEA), Ryuichi Yamamoto, JAEA, and Shigeo Nomura, JAEA, Tokai-Mura, Ibarake, Japan. In *Historical Role of the Tokai Reprocessing Plant in the Establishment of Safeguards Technologies,* the authors discuss the long road needed to get adequate International Atomic Energy Agency safeguards at the Tokai Reprocessing Plant, and how the lessons learned are being applied to the new large-scale commercial nuclear reprocessing plant in Rokkasho, Japan.

Our Book Review Editor, Walter Kane, of Brookhaven National Laboratory (retired), has an interesting review piece on two books that are somewhat complementary: *Security Risk Assessment and Management* by Betty Biringer, Rudolph Matalucci, and Sharon O'Conner (Wiley & Sons, 2007); and *Vulnerability Assessment of Physical Protection Systems,* by Mary Lynn Garcia (Butterworth-Heinemann, 2006)

As you are aware, the Institute will begin its fiftieth year celebration at the upcoming 2008 Annual Meeting in Nashville, Tennessee, USA. The celebration will end at our 2009 Annual Meeting in Tucson, Arizona, USA. Ed Johnson and Debbie Dickman have the responsibility for planning this year-long celebration. Both of these upcoming Annual Meetings should be extra special, and I look forward to seeing you there.

JNMM *Technical Editor Dennis*

Priorities for Technology Development and Policy to Reduce the Risk from Radioactive Materials

Ruth Duggan
Sandia National Laboratories

Galya Balatsky and William Severe
Los Alamos National Laboratory

Morris Hassler
BWXT Y-12

Abstract
The Standing Committee on International Security of Radioactive and Nuclear Materials of the INMM Nonproliferation and Arms Control Technical Division conducted a workshop in March 2007, Reducing the Risk from Radioactive and Nuclear Materials. This kickoff workshop examined issues and best practices in three panel discussions: Nuclear Trafficking Detection/Response, Transportation Security/Standards, and Tensions and Synergies Between Safety and Security for Nuclear and Radioactive Materials. Technology gaps, policy gaps, and prioritization for addressing the identified gaps were discussed. Participants included academics, policy makers, radioactive materials users, first responders to catastrophic events, physical security and safeguards specialists, and vendors of radioactive sources. This paper summarizes the results of this workshop.

Introduction
In March 2007, sixty-three individuals representing the national laboratories, industry, academia, and government agencies participated in the Standing Committee on International Security of Radioactive and Nuclear Materials of the INMM Nonproliferation and Arms Control Technical Division Workshop on Reducing the Risk from Radioactive and Nuclear Materials. This workshop examined and proposed technologies and policies that could reduce the risk from radioactive and nuclear materials. The workshop focused on three aspects: nuclear trafficking, transportation security, and safety/security integration. Panelists highlighted existing efforts and identified current challenges. The second session of the workshop focused on identifying opportunities for technology, policy, and their integration to reduce the risks from these materials.

Comprehensive Protection of Radioactive and Nuclear Materials
The security concern associated with radioactive and nuclear materials stems from their use in weapons of mass destruction or disruption in the form of radiological dispersal devices, improvised nuclear devices, and nuclear weapons. These materials not only need to be protected while in use, in transit, and in storage, but steps must also be taken to protect them from illicit trafficking, theft, and sabotage. In these circumstances, forensics is also a key element to ensure attribution and prosecution. Material must be identified and placed into a material accounting system and must be detected at perimeters and borders. Response must be capable of handling these materials in pre-detonation and post-detonation events. The consequences of events using these materials must be minimized. All of these must be combined into an effective system so as to make their attractiveness as a weapon of choice unappealing.

Elements of a comprehensive system include:
- Nonproliferation policies with monitoring and verification systems
- Coordinated global detection system for tracking and interdiction
- A render secure program that includes disposition
- Response and recovery to effectively address consequences
- Mechanisms for attribution that include forensics and analysis
- Public education system to decrease panic and empower people to be a part of the system.

Current Challenges for Addressing Radioactive Material Trafficking
While trafficking has received a significant amount of attention in the past fifteen years, not much progress has been made toward establishing a common view on the trafficking phenomenon and

there remain diverse views on what threats are emanating from trafficking as well as what actions should be taken to combat those threats. The International Atomic Energy Agency (IAEA), along with other organizations, has collected trafficking event information, including dates, locations, and materials involved, that is used for analysis of trafficking trends. The panelists on the trafficking panel expressed different opinions on how to approach trafficking. It was emphasized that "nuclear trafficking is a playground for terrorists," since terrorists can inflict damage to the Unites States, its allies, and interests by obtaining nuclear and radioactive materials. It was highlighted during the discussions that in order to better understand trafficking, we need better knowledge about its components: the threats emanating from trafficking; the processes by which trafficking operates, the environment in which it occurs and who are the perpetrators. It was also established that we need to learn more about motivations and intents of perpetrators.

In discussing measures to address trafficking we encountered some controversies. While we need to protect information so it will not fall into the hands of terrorists, the use and sharing of information is important for our efforts to understand and combat nuclear trafficking. While regulations are important due to security and safety concerns, excessive regulations would impede legitimate commerce and businesses and our efforts to over-regulate the industry could backfire by forcing law-abiding companies out of business, thereby encouraging unscrupulous and opportunistic businesses.

Responding to nuclear trafficking is an evolving process. Current issues include facilitating information sharing and building trust between the different components involved in combating nuclear trafficking. Additionally, it was agreed that there is a need to build a nuclear trafficking community and to reach out to international partners. Another current issue is reducing the quantity of materials available for trafficking, for example, unused, unwanted, or poorly controlled radioactive and nuclear materials and materials located at old dump sites. Despite serious security concerns about nuclear trafficking, it was considered important to remember that the vast majority of movement involving radioactive materials are not illicit and that legitimate activity must be facilitated to support commercial applications of radioactive materials.

Best Practices and Current Challenges for Addressing Radioactive Material Transportation Security

Graded material categorization is a necessary basis for determining transportation security requirements. There are currently several different systems of categorization depending on whether the concern is radiation protection or security during transport. While there are some overlaps in the different categorization systems, each discipline involved in the safety and security of these materials during transportation uses its own standard. The wide variety of radioactive materials application in industry and medical fields results in a fragmented and inconsistent standard of protection that depends upon whether the material is in use, in storage, or in transport. While there have been some attempts to harmonize safety and security, historically these materials have not been given the same level of attention that nuclear material transportation security has seen.

The graded approach applied to nuclear material transportation security should have an equivalent standard for other radioactive materials. However, it should be noted that too much regulation hinders commerce and could outweigh the benefits of the material, especially in the medical field where it is most needed. Some regulations would actually increase the risk from these materials by making them exist longer in a transportation state versus a secured facility.

Best Practices and Current Challenges in the Integration of Safety and Security of Radioactive Materials

For safety and security requirements, categorization of radioactive material is also key. Currently, the categorization basis for safety would differ from that for security, if a security categorization did exist. The internationally recognized safety categorization is based primarily on immediate, deterministic health effects. A security-based categorization could be based on such factors as long-term health effects, economic consequences, and desirability for malicious use. For both bases, applying a layered defense is essential. A strategy of eliminating excess stocks of radioactive material, appropriately protecting existing material, and detecting illicit material must be exercised. Efforts are underway to work with manufacturers to better secure radioactive materials within equipment, to find ways to make materials less effective for use as weapon components, and to find less-threatening, yet effective alternatives for materials currently in use. These solutions to security would also need to be developed to ensure that the safe uses of the radioactive materials continue to provide benefit.

A community of safety and security professionals should be brought together to identify the necessary integrated safety and security approaches as well as the public awareness and education needed to ensure better understanding of the role of radioactive materials, the difference between radioactive materials and nuclear materials, and the effects of a radiological event. Standards should be coordinated and made consistent to allow for safe and secure transport of materials, safe and secure use of radioactive materials, and disposition of materials when no longer needed.

A National Strategy to Combat Terrorism

Fundamentally, a national strategy to combat terrorism would include the following:

- The ability to estimate or even determine terrorist intentions, capabilities, and plans to develop or acquire weapons of mass destruction (WMD)
- Mechanisms to deny terrorists access to materials, technology, and expertise
- Strategies to deter WMD deployment
- The capability to detect and disrupt attempted movement of WMDs
- A robust system to both prevent and respond to WMD attacks
- Forensics to define the nature and source of a terrorist-employed WMD

However, it should be noted that while terrorists, and particularly, transnational terrorists, seek to create catastrophic events and will use the path of least risk to achieve them, terrorists will weigh effectiveness of a weapon, its accessibility, and the needed expertise to determine risk. The planning and execution of a WMD attack can be too difficult and too revealing, but that does not mean it can be dismissed. Recent chemical attacks demonstrate long-standing interest and planning.

The United States must increase the strength of existing bilateral and international partnerships and continue to develop new partnerships toward a global regime. It must seek to be a part of the detection system that recognizes and reports anomalies and must move beyond planning and actively pursue implementation. It must assist partners when possible and hold them accountable to the partnership. International standards and best practices for material security must be globally adopted and intelligence about terrorists must be shared with law enforcement.

Recommendations

The second day of the workshop focused on identifying and prioritizing actions needed to enhance the security of radioactive and nuclear materials. In short, the group determined that the best value comes from integrating a security culture and safety culture around the use and disposition of these materials. Even reaching agreement and consistency on unified domestic security policy standards for management of these materials would be helpful. This includes better defining the risk that these materials pose (health and denial of use through contamination) and applying a graded approach to enhanced security. Building a community to specifically deal with nuclear trafficking integrating both the policy and technology perspectives can work to achieve faster results both in information sharing and technology development. Fundamentally, the United States must work to reduce the amount of material available to adversaries through programs such as the National Nuclear Security Agency's Global Threat Reduction Initiative. As the demand for nuclear energy increases, we must support standards that require material to be in transit for as little time as possible, and technologies and policies to better secure material, especially radioactive materials, while in transit.

The group also recommended that the Institute of Nuclear Materials Management continue to engage the community on this topic and seek to integrate other entities involved in reducing the risk from radioactive and nuclear materials. A second annual meeting was held in February 2008 and addressed the topics of Threats Emanating from Illicit Trafficking; First Priority Actions to Combat Trafficking; Air Transport of Radioactive Materials; Tracking Technologies; Categorization of Materials; and Modeling and Simulation Tools.

Acknowledgements

The authors wishes to acknowledge the following panel chairs and speaker contacts for their contributions and support without which this workshop would not have succeeded: Galya Balatsky and William Severe of Los Alamos National Laboratory, Mark Soo Hoo of Sandia National Laboratories, and Morris Hassler of the Y-12 National Security Complex. The authors and workshop team would also like to thank the INMM Southwest Chapter for hosting this workshop and providing logistics support. The authors and workshop team gratefully acknowledges the generous support of the workshop sponsors, including Los Alamos National Laboratory, Oak Ridge National Laboratory, Y-12 National Security Complex, Sandia National Laboratories, Canberra Albuquerque, Gregg Protection Services, Ortec, and Pacific Northwest National Laboratories.

The IAEA's Illicit Trafficking Database: A User's Perspective on Strengthened Reporting

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Note: The views expressed in this paper are solely those of the author and do not purport to represent those of SAIC, the IAEA, or any other organization.

Abstract

The International Atomic Energy Agency's Illicit Trafficking Database (ITDB) is a successful and established program for exchanging and analyzing authoritative data on nuclear and radiological trafficking incidents. However, ITDB member states could realize a greater return on their participation by reporting additional information on trafficking incidents, namely nuclear forensic and national law enforcement data. This additional reporting is a logical complement to the ITDB's proven strengths in multilateral trafficking data collection, storage, and dissemination, and will enhance both ITDB and member state analysis of illicit nuclear trafficking.

Introduction

The International Atomic Energy Agency's (IAEA's) Illicit Trafficking Database (ITDB) is a unique and indispensable asset in the global fight against nuclear and radiological material smuggling. The risks posed by such smuggling are clear. Improperly handled or disposed-of radioactive sources pose threats to human health and the environment. A radiological dispersion device has the potential to cause panic and wreak financial chaos on an affected area, to say nothing of the ultimate terrorist weapon: an improvised nuclear explosive. In addition, nuclear smuggling challenges the basis of the international nonproliferation regime—a non-nuclear weapons state could confound the entire export control and safeguards system by illicitly acquiring a few dozen kilograms of fissile material.

The ITDB is an integral response to this diverse range of threats and differs from other nuclear and radiological material trafficking databases in important ways. Only the ITDB functions as a global coordinator of authoritative, state-confirmed trafficking data. In this capacity, ITDB data not only fuels IAEA trafficking analysis, but also provides an unparalleled resource for national analytical efforts, furnishing trafficking incident information on regions and countries that may otherwise be unavailable. This unique information provides a basis for effective action at the national or international level, with IAEA resources ready to assist member states in addressing the human health, incident response, material protection and accountability, border detection, and safeguards challenges posed by illicit trafficking.

This paper does not recount the mission nor analyze the data of the ITDB—these topics are well covered in ITDB annual reports and elsewhere.[1] Rather, this paper seeks to provide insights into the day-to-day functions of the database, based on the author's personal experience working with the ITDB in 2005-2006. The paper describes the process by which the IAEA obtains and solicits information on trafficking incidents from member states, and also calls for member states to build upon the successful, established structure of the ITDB by sharing nuclear forensic and national law enforcement data on trafficking incidents. Adding this information to the existing ITDB reporting framework would logically complement currently available trafficking data and enable additional analysis and more comprehensive responses to illicit nuclear and radiological trafficking worldwide.

Day-to-Day Operations

To understand how additional reporting might be incorporated, it is important to first understand how the ITDB works. The phrase ITDB invokes two distinct but interrelated entities. Broadly, there is the IAEA's Illicit Trafficking Database program, established in 1995 and located in the IAEA's Office of Nuclear Security. Additionally, within the program there is the actual computer database that archives trafficking information. IAEA staff maintain the trafficking database, liaise with member state points of contact, provide annual and quarterly trafficking analyses, and work with other staff within the Office of Nuclear Security to host regional trafficking seminars. The scope and direction of these ITDB program activities are determined by ITDB member states at the annual stakeholders' meeting.

The ITDB is populated with trafficking incidents and data in two ways. First, points of contact from the ninety-seven ITDB member states submit trafficking incident notification reports to the ITDB program office. These notifications should detail, at a minimum and in a timely manner, the date and location of an incident, as well as the type, amount, and characteristics of the material involved.

Once an incident notification report is received, ITDB staff create a new incident record in the database and designate it as officially confirmed. The staff add metadata to each record so that incidents can be searched and analyzed by country, material type, incident type, etc. Each incident is summarized briefly and this abstract is updated as states provide additional incident information.

The second source of trafficking information is the daily open source information collection performed by ITDB personnel. Each morning, ITDB experts search the Factiva news database, the Open Source Center (formerly the Foreign Broadcast Information Service) and other news sources, collecting any new allegations of illicit trafficking worldwide. In addition to these three searches, ITDB experts monitor several nongovernmental organization and national nuclear regulatory Web sites for updated trafficking information. Each of these reports is entered into the ITDB as an open source incident. ITDB staff then send a copy of the open source report, along with an incident notification request, to the appropriate member state point of contact. If the country mentioned in the report is not a participating ITDB member, ITDB staff send a request for information to the national nuclear regulatory authority. Non-ITDB member states have, on occasion, responded to ITDB requests for information. If a member state responds to confirm or deny the open source report, the incident status in the database is changed accordingly.

Information gleaned from open sources must, of course, carry appropriate caveats, but the importance of open source information to the ITDB should not be underestimated. The majority of incidents in the ITDB originate from open sources, and several of the most significant incidents recorded to date have first been reported in open sources. For example, months before the incident was widely known, the ITDB recorded an obscure open source allusion to the most recent highly enriched uranium (HEU) trafficking case, involving 100 grams of about 90 percent U-235 seized in Georgia in January 2006.[2] Such open source reports give the ITDB an important foot in the door and trigger the incident confirmation request process. Even if states respond tentatively or informally at first, the IAEA can engage them, identifying and then delivering the assistance needed to detect and prevent future smuggling.

Trafficking incidents range from the anodyne, such as medical isotopes for cancer therapy being misrouted in the mail, to the malicious, including attempted or successful poisonings with radioactive material. Some types of incidents are quite common, and occur almost weekly, such as thefts of industrial moisture density gauges or well logging sources from truck beds or industrial sites. These and many other frequent incidents form a background noise over which analysts strive to detect the far more dangerous incidents. Of the more than 2,000 incidents logged in the ITDB to date, roughly half state-confirmed and half open-source, there have been only eighteen confirmed instances of trafficking in highly enriched uranium or plutonium.[3]

Within the IAEA, access to ITDB information is restricted on a need-to-know basis, and a double layer of security prevents unauthorized or outside access. In order to view the database, potential users must first be granted an appropriate level of administrative access, and then have the database software physically installed on their individual computers.

The ITDB's staff produces quarterly and annual analytical products for ITDB member states. These analyses discuss significant events occurring in the reporting period, the types of materials and locations involved, and noteworthy open source reports that require further information. In addition, the ITDB staff collaborates with analysts in the IAEA's Division of Safeguards Information Management to discuss nuclear material events with potential safeguards implications. Acute or chronic nuclear material trafficking incidents could affect the IAEA's ability to assess the non-diversion of nuclear material in a given country.

Strengthening the ITDB by Expanding Data Reporting

If regularly reported by member states, two additional types of trafficking incident information could allow for significantly greater insight into nuclear and radiological trafficking when combined with the ITDB's already rich data set. Analysts need the maximum amount of data available to best understand and defeat illicit trafficking—ideally, this would be a cradle-to-grave history of each incident. Analysts seek to know not only what material was stolen, but also where from, by whom, in what manner, and for what purpose, as well as how the material was transported, by what route, to what destination, and for what ultimate use.

However, rather than this desired full-length incident narrative, member states usually report trafficking data that offers mere snapshots of incidents, e.g., what material was seized and where. This limited information impairs an analyst's ability to assess motives, trends, routes, methods, and scams, as well as to make proper diagnoses and policy recommendations. The hundreds of incidents catalogued each year in the ITDB yield much data, but analysts require more insight into the trafficking phenomenon. An essential, unanswered question is why, if trafficking attempts have been nearly uniform failures to date, delivering neither profits to sellers nor products to buyers, does the practice appear to persist unabated?

Yet, the details of individual incidents that, when combined, could illuminate broader trends and result in better counter-trafficking strategies do not go uncollected, merely unreported. States are obligated by United Nations Security Council Resolution 1540 to "develop and maintain appropriate effective border controls and law enforcement efforts to detect, deter, prevent, and combat, including through international cooperation when necessary, the illicit trafficking and brokering in [weapons of mass destruction]."[4] To this end, national courts prosecute nuclear and radiological material trafficking cases, and the subsequent court findings provide the best available insight into the perpetrator's motive, methods, and perceptions of risk versus reward. This is precisely the type of detailed information that can enable analysts to address the root causes of the nuclear and radiological trafficking phenomenon.

Since 2005, the ITDB has cooperated with Interpol's Project Geiger, working to share this technical and law enforcement data on selected incidents.[5] This cooperation sets an excellent precedent for using law enforcement data in conjunction with the ITDB and has the potential to enhance incident analysis. However, this should not be the sole channel for national law enforcement data reporting.

Instead of relying only on limited or ad hoc reporting through Interpol, member states should report court findings as follow-on reports to ITDB incidents as a matter of course. Not only would this qualitatively increase the information available on each incident, but this would also allow member states to demonstrate their vigorous prosecution of nuclear smuggling events within their borders as required by international law, further deterring would-be smugglers.

States may understandably be reticent to share such court information for fear of jeopardizing successful prosecutions or of revealing intelligence sources and methods. Yet, whatever summary or redacted information states can legally share, either directly with the IAEA or via Interpol, would be valuable to the ITDB and other member state analyses. States could omit all of the suspect's personally identifying information, as well as the sources of sensitive reporting, without diminishing overall analytical usefulness.

Coupled with court findings, nuclear forensic data hold tremendous potential to enhance trafficking analysis. Nuclear forensic analyses seek to trace nuclear or radioactive materials back to their country or even facility of origin by comparing the isotopic signature of a sample with a set of known references. This technology is a powerful tool to combat nuclear smuggling by tracing material to the source, identifying safeguards or security shortcomings, and perhaps even deterring the use of an improvised nuclear device. To this end, the Nuclear Smuggling International Technical Working Group (ITWG) has worked with the IAEA's Office of Nuclear Security to develop a model action plan to help states handle seized radioactive material and receive assistance in nuclear forensics investigations.[6]

Yet, nuclear forensic attribution efforts are hamstrung in two ways by inadequate information sharing. The ITDB is an ideal venue to help solve this problem. First, the isotopic compositions of source or commercial materials are not widely available, and the compositions of fissile materials in weapons programs are often held as state secrets. Thus, laboratories around the world performing analyses of seized material will likely not have access to a sufficiently large material reference set to ascribe origin, particularly if the seized material is from a weapons program. Secondly, states tend to share analytical results of seized data on a bilateral or ad hoc basis. Yet, even if states cannot agree to pool isotopic data on their own materials and create a truly global nuclear materials library, the ITDB could still serve as a global librarian, disseminating analytical results from seized material.

Upon receiving analytical results from the ITDB, member states could consult their own reference materials and other technical means to determine the material's origin. Similarly, the IAEA could refer to its own sample database at its Safeguards Analytical Laboratory. The ITDB is a logical place to collect and archive nuclear forensic data on seized samples alongside all other incident data from state reports, open sources, and IAEA missions. Some member states currently provide summary analytical data on a voluntary basis, but this should become a routine part of trafficking incident follow up. Ensuring that all interested parties have access to the same data on seized materials eliminates duplicative efforts and increases the likelihood of determining material origin.

Conclusion

In the twelve years since it was created, the IAEA's ITDB has proven to be a prudent investment for participating countries. Information provided by each member state is returned nearly a hundredfold, along with IAEA analyses and assistance in improving material security and combating nuclear trafficking. A larger data reporting investment by member states would yield proportionally larger national security gains.

Countries should take advantage of the unique strengths of the ITDB: an international guarantor and coordinator of nuclear trafficking information to a growing set of diverse countries. By expanding routine incident reporting and follow-up to include the results of forensic analyses and the outcome of national efforts to prosecute smugglers, all participating states would benefit. Providing this additional data would not only describe individual incidents more fully, but would also generate more penetrating analyses of the entire illicit trafficking phenomenon. The ITDB is a one of a kind resource for translating shared information into improved global security, and member states should seek to maximize its effectiveness.

William R. Wanderer, Jr., is a nonproliferation analyst for Science Applications International Corporation (SAIC). He contracts to the National Nuclear Security Administration and has worked as a consultant at the International Atomic Energy Agency. He holds an M.A. in international relations from the University of Chicago and a B.A. in political science from Monmouth College.

End Notes

1. *See ITDB Fact Sheet for 2006,* http://www.iaea.org/NewsCenter/Features/RadSources/PDF/fact_figures2006.pdf, published September 11, 2007, accessed October 10, 2007. Also Turkin, Viacheslav and William Hammond. *The Illicit Trafficking Database Programme – Trends and Patterns in Confirmed Incidents Involving Nuclear Material.* IAEA Safeguards Symposium, Vienna, October 2006.
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Safety and Security of Radioactive Materials in the United Republic of Tanzania

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Abstract

Sealed radioactive sources have been used in the United Republic of Tanzania (URT) for many years in a wide range of legitimate applications. On the other hand, the URT is aware that nuclear and radioactive materials, if they are not adequately controlled, could create a radiological hazard to the personnel using the material, and can pose a potential risk to public health, the environment, and national security. In view of this, the URT places dual attention on nuclear technology transfer for peaceful applications as well as the global initiative for safety, security, and accountability of the radioactive materials. The URT has therefore enacted legislation to control the peaceful use of ionizing radiation in the country and keeps inventories of all licenses for radiation-emitting devices and radioactive materials in both in-use and spent or disused sources.

To ensure compliance with the international guidelines for the protection of workers, the public, and the environment, the URT has launched a sustainable program for searching and securing sources not in use, and keeping the sources secure in the Central Radioactive Waste Management Facility. In addition the URT coordinates nuclear security training programs to frontline officers including both regional and national courses in order to bring nuclear security awareness and combat illicit trafficking incidents. Furthermore, border detection capability has been improved with radiation detection instruments, which are used to measure dose rates on suspected packages.

The URT is also committed to ensuring that physical protection of facilities is enhanced against sabotage during use and storage by strengthening the security upgrades at the facilities.

This paper outlines the programs and processes that the URT has launched to promote the peaceful application of nuclear technology and security of radioactive materials. It also discusses emerging technological opportunities as well as challenges that the URT faces to apply nuclear technology to attain economic development.

Introduction

The United Republic of Tanzania (URT) solely uses radioactive materials and radiation-emitting devices in diagnosis technologies, including medical applications. This use of radioactive materials and radiation-emitting devices has continued to grow since the inception of nuclear technology in the URT in 1938. Currently, the major focus is on increasing the use of nuclear technologies for sustainable social and economic development, including, but not limited to the following: medical care, food production, quality control of industrial products, research and teaching, construction, water management, and preservation of the environment. While placing much attention on nuclear technology transfer for peaceful applications, the URT continues to explore ways and means that enable the full use of nuclear technology to meet the critical socioeconomic needs, such as power production and expansion of its use in the health sector.

Projections for the future expansion of use of nuclear and radioactive materials, however, are expected to go hand-in-hand with the global initiative for safety and security of nuclear and radioactive materials, which are key elements in the URT. The URT has achieved significant milestones in radiation protection and safety since 1983, when the URT established the National Radiation Commission. This commission, while primarily focused on control and safety of radioactive materials and workers in 2003 began actively being involved in the security of radioactive materials. In the wake of recent deadly terrorist attacks in a number of countries, the URT, along with the international community, recognizes that stronger measures are needed to upgrade the physical protection of facilities with high-risk radiation sources. These facilities need to be protected against attempts to acquire radioactive materials for the intention of building radiological dispersal devices (also known as dirty bombs). Such possibilities appear more probable today because sophisticated extremist groups have shown keen interest in acquiring nuclear weapons.[1,2] This paper outlines the programs and processes that the URT has launched to promote the peaceful application of nuclear technology and security of radioactive materials. It also discusses emerging technological opportunities as well as challenges that the URT faces to apply nuclear technology to attain economic development. Emphasis is put on what the international partners are doing to support the URT to advance nuclear technology and security.

Regulatory Infrastructure for the Protection and Control of Nuclear and Radioactive Material

To ensure compliance with the international guidelines for the protection of workers, the public, and the environment and to ensure the peaceful application of nuclear technology, the URT enacted legislation called the "Protection from Radiation Act 1983."[3] This act established a competent government authority, the National Radiation Commission (NRC), to advise the government on matters related to atomic energy as well as to control the peaceful use of ionizing radiation in the country. The NRC accomplished the following: registering all users and sources of radiation, periodically inspecting radiation safety, licensing all practices using radiation sources and devices, controlling the use of atomic energy and nuclear technology for peace, advising the government on policy related to the technology, promoting nuclear technology applications, coordinating International Atomic Energy Agency (IAEA) projects and consultations through competent bodies, and also advising the responsible minister on international nuclear agreements (protocols, conventions, and treaties). The URT is preparing a draft proposal for revising its legislation to reflect current revisions in the code of conduct on the safety and security of radioactive materials.

Further, to ensure compliance with the revised international dose limits and recommendations from the IAEA's *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources* and the International Commission on Radiological Protection, the URT revised its Protection from Radiation Act, 1983, to produce the Atomic Energy Act, 2003[4,5]; in so doing, the NRC was renamed to the Tanzania Atomic Energy Commission (TAEC).[6] As stipulated in Part II, Article 6 of the 2003 Act, the TAEC took over all the mandates of the government competent regulatory authority. In addition, the URT has promulgated three specific regulations to give details and more clarification on the legislation. The regulations are specifically for the following: control of radioactivity contamination in foodstuff regulations (1998), radioactive waste management regulations (1999), and ionizing radiation regulations (2004). According to Part II, Section 5 of the 2003 Act, the TAEC operates under the Ministry of Higher Education, Science, and Technology and its Board of Commissioners, and obtains funding directly from the government. The TAEC secretariat executes its daily duties through three directorates: Nuclear Technology Directorate, Radiation Control Directorate, and Finance and Administration Directorate. Each directorate constitutes two divisions, with two sections within each division.[7]

Radiation Protection and Compliance with Legal Licenses

As the uses of radioactive sources expand in the URT, protecting these sources becomes more challenging. Despite the difficulty of this task, the URT is actively involved in building awareness in the country about the need to control and physically protect radioactive sources at their locations. As Part V, Article 32 of the Act 2003 states, the prime responsibility for the safe management and security of radioactive sources is on the licensees.[8] Through inspecting facilities and licensing of practices, the TAEC ensures control of the use of ionizing radiation sources and installations.

Part III of the 2003 Act states prohibitions relating to the control of ionizing radiation sources and installations, which govern the following licenses:

- Possession and use of medical diagnostic X-ray equipment
- Possession and use of radiotherapy sources
- Possession and use of unsealed radioactive materials
- Use of non-medical radiation devices or radioactive materials
- Possession or use of ionizing radiation-emitting equipment or devices for non-destructive testing
- Modifying ionizing radiation devices, material, or premises
- Import/export of radiation devices
- Import/export of radioactive materials
- Transport of radioactive materials
- Administering ionizing radiation to persons/patients
- Import and export of foodstuffs and fertilizers

The first step in obtaining a license is to complete an application that has questions related to specific practices. The application form is then submitted to the TAEC for evaluation. The Technical Committee uses the information provided in the application form along with information from inspection reports to evaluate the applications. A license is therefore granted, renewed, or denied based on these criteria.

The TAEC keeps inventories of all licenses for radiation-emitting devices and radioactive materials in both in-use and spent or disused sources. More than 1,000 radiation workers in 400 licensed facilities are routinely monitored, and their dose records are kept updated. A dose record indicates that occupational workers received average doses ranging from 0.2 to 5 milliSieverts. This achievement was made possible using the "As Low As Reasonably Achievable" principle.

Part XI, Section 72 of the act details offenses relating to unlawful possession and use of nuclear or radioactive material. It covers a broad scope and provides for a penalty of 5,000,000 Tanzanian shillings (~$5,000 USD), imprisonment for not less than five years, or both.[9]

In addition, pursuant to United Nations Security Council Resolution 1373 (2001), the URT has enacted a separate legislation that deals specifically with counterterrorism.

Management of Radioactive Sources

As in many developing countries, the management of low-, intermediate-, and high-level radioactive waste remains a key challenge in the URT.[10] Currently, the URT utilizes an above-ground interim storage facility while it explores the feasibility of long-term storage for the coming years. At this time, the URT is interested in finding better methods for safely disposing spent, high-activity radioactive sources (SHARS). There is great hope that, in working with the IAEA and experts from Nuclear Energy Corporation of South Africa, the URT will manage the spent sources using a mobile hot cell to condition these sources for disposal. Conditioning operations are currently planned in the URT before the end of 2007. The URT is also on a list of countries earmarked by the IAEA for assessing the potential of bore-hole storage for disposal of disused sealed sources; this storage method would be an alternative for countries that generate small volumes of radioactive waste and have no other disposal options.

Uranium Exploration

An area of increased recent interest in the URT involves uranium exploration for future potential mining and production. Interest among many investors has been driven partly by uranium price increases and the projection of continued growth in demand. TAEC is taking the responsibility of monitoring the safety of workers from the beginning of the exploration process. TAEC also maintains a close supervision on the transport of uranium ore samples from sites to remote analytical laboratories. Currently, there is a good existing collaboration between the mining companies and the TAEC on performing these activities.

Africa Regional Nuclear Security Cooperation

The URT is a member of the African Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology (AFRA) (IAEA, Regional Africa [RAF]). In collaboration with other African countries, the URT participates in all projects related to increasing national awareness and national capacity within African countries for prevention, detection, and response to malicious acts involving nuclear and other radioactive materials or facilities and the illicit trafficking in nuclear and other radioactive material.

Under the same collaboration, the URT also participates in the following IAEA-related nuclear security projects:

- Nuclear Security Implementation Support (AFRA I-3) RAF/0/021
- Nuclear Security Implementation Support (AFRA I-5) RAF/9/036
- Strengthening National Infrastructure for Control of Public Exposure with Emphasis on Safety in Management of Radioactive Waste RAF/9/037

The main objective of AFRA cooperation is sharing the benefits of nuclear technology for development while preventing the misuse of this technology for destructive ends. In addition, this cooperation established a network of communication channels to ensure smooth dissemination of related information within the continent to respond to the mitigation of consequences of possible nuclear terrorist actions. However, areas for improvement remain in the legal, administrative, and technical arrangements for controlling and protecting nuclear materials and radioactive sources in some countries.

Nuclear Security Activities in the URT

It is well known that nuclear and radioactive materials could create a radiological hazard to the personnel using the material, and a potential radioactive material release to the public and environment. The radiological hazards are strongly dependent on the characteristics of the radioactive materials. In the context of the current widely dreaded possibility of nuclear terrorism, physical security of radioactive materials has emerged with a significant importance. The URT commitment is to ensure that physical protection of facilities is enhanced against sabotage during use and storage. To implement the security of radioactive materials, the URT has launched a program to collect all spent or disused sources and orphans from users' premises to the central storage facility, and has strengthened the security at the facility. The border detection capability has been improved with radiation detection instruments, which are used to measure dose rates on suspected packages. At the same time, frontline officers (FLO), such as customs officials, have been trained to identify packages containing radioactive materials and to use the instruments. TAEC annually organizes specific, tailored training courses for roughly 200 individuals; these individuals range from users of radiation sources, police, and customs, to airport guards, clearing and forwarding companies, and intelligence and regulatory authorities.

The URT periodically invites teams of experts from safety, security, and safeguards to advise or provide peer reviews in areas such as regulatory control, physical protection, and materials control and accountability.

Since 2003, the URT coordinated the following missions:

- IAEA's International Nuclear Security Advisory Service (INSServ) reviewed both overall and specific needs of the URT to strengthen the capacity to prevent, detect, and respond to nuclear terrorism. The INSServ mission helped the URT identify the broadest nuclear security needs, including measures against illicit trafficking and controlling and securing radioactive sources. The recommendations generated by the INSServ team provided a platform for the more specific nuclear security assistance provided subsequently through IAEA programs, or through bilateral assistance by the U.S. Department of Energy (DOE).
- DOE experts reviewed the effectiveness of physical protection systems and material control systems in the URT in line with the Global Threat Reduction Initiative (GTRI)

program. They also provided advice on the implementation of the security upgrades of facilities with high-risk radiation sources.
- The IAEA's Radiation Safety and Security of Radioactive Sources Appraisal (RaSSIA) assessed the effectiveness of national regulatory infrastructures for radiation safety and security of radioactive sources against established international standards. The RaSSIA mission made a comprehensive assessment of the regulatory infrastructure along with an action plan designed to bring the regulatory infrastructure up to international standards. The RaSSIA report also provided advice to help the URT develop national strategies to find and secure orphan radiation sources.
- The IAEA's Management of SHARS provided technical experts for the collection of spent sources into a mobile hot cell, and conditioned these sources for disposal.[11]

To foster effective and efficient implementation of the duties related to security, the URT has developed working relationships with international organizations and other key agencies, including the following:
- The joint DOE/International Criminal Police Organization (INTERPOL) Cooperative Radiological Instrument Transfer program for training of FLOs and provision of radiation detection equipment to police in the URT and Uganda
- The Cooperative Monitoring Center International Research Scholar programs at Sandia National Laboratories for training scientists on physical protection of facilities with nuclear and radioactive materials
- Training courses on the search and secure of orphan sources and provision of detection equipment for East and Central Africa (the URT and Kenya have already benefited from this program).

Illicit Trafficking of Radioactive Materials

The IAEA illicit trafficking database (ITDB) has vast numbers of reported cases of illegal possession of radioactive materials all over the world. In the URT, the first case of illicit trafficking was reported in 1996. Due to the efforts of FLOs and regulatory authorities, additional illicit trafficking shipments have been intercepted, making record of twelve incidents involving illicit trafficking of radioactive materials and two incidents of stolen radioactive materials to date. According to the TAEC database, the radionuclides involved in the illicit trafficking incidents include Cesium-137, Radium-226, and Uranium-238. The activities of the intercepted sources range from a few Becquerels to 4.5 Tera Becquerels; along with these activities are the incidents of the stolen sources that involved Cesium-137. Eventually, all the sources captured in the illicit traffic incidents—along with other sources that are spent, orphaned, and disused—are kept secure by the regulatory authority. Since the URT is actively involved in the IAEA ITDB, all incidents of illicit trafficking in the URT have been reported to the IAEA ITDB.

Searching for and Securing Radioactive Materials

History indicates that sealed radioactive sources have been used in the URT for many years in a wide range of legitimate applications. At the end of the sources' useful life, the radioactivity falls and they become spent or disused. However, the residual level of radioactivity in some sources can still be high, representing a significant radiological hazard. If not properly managed and disposed of, such disused radioactive sources pose a potential health hazard to the public for periods of time, depending on the half-life and activity level of the radionuclides, which may extend to several decades. These sources can also present immediate security concerns; if they are not strictly controlled, the sources might be stolen and their radioactive materials used in radiological dispersal devices (dirty bombs) for acts of terrorism. The Goiana accident in Brazil in 1986 was a typical example of uncontrolled sources that caused a painful memory in the lives of many people who were most affected by the accident.[12] Against this backdrop, searching for and securing radioactive materials became vitally important in the URT. After the training courses held at Arusha and the reception of radiation detection equipment donated by the DOE, the URT launched a sustainable program for searching and securing sources not in use, and keeping the sources secure in the Central Radioactive Waste Management Facility (CRWMF). More than fifteen sources of Category 1–3 have been collected and transferred to the CRWMF; these sources will be managed by the SHARS team later on in the team's mission.

Emergency Preparedness and Response

Experience in response and preparedness for nuclear and/or radiological emergencies is still developing in the URT. This is one of the areas in which the URT aspires to develop additional capabilities and personnel expertise.

Training and Technical Assistance

The URT has been actively involved in a vast number of the IAEA programs, including meetings, conferences, and training programs. One of the main objectives for participating in these programs is to increase awareness and capability, train personnel to control and protect nuclear and other radioactive materials from illegal activities, and respond to such events and provide safety measures, as necessary. Conducting training on equipment and upgrading equipment and facilities were an essential part of capacity-building for the enhancement of national safety and security infrastructures.

The URT coordinated nine nuclear security training programs for the period from 2005 to 2007. These included both regional and national courses that covered nuclear security awareness, combating illicit trafficking, training in the use of radiation detection equipment, physical protection, and searching for and securing orphan sources. Other relevant courses covered control of radioactive material and inventory management systems for radioactive sources.

The URT has received and deployed equipment for detection and monitoring illegal movement of radioactive materials across borders.

The Long-Term View

A major challenge for the URT is to continue to foster the global security of nuclear and radioactive materials within the country and in cooperation with its neighbors; however, finding sufficient funds to address these key issues is a concern, given the priority needs in a national action plan. These key issues include coordination of evaluation missions, logistical support for recommendations in bilateral and multilateral programs, and timely facilitation of implementation of the recommendations. The URT has a concerted plan focused on three areas of nuclear security (prevention, detection, and response) that build and expand upon a number of existing TAEC activities. These activities include the following:

- Protect nuclear and other radioactive material and intensify regulatory control and accountability of high-risk radiation sources (Category 1–3) from malicious acts
- Strengthen the national capabilities to uncover illegal acts and possession of nuclear and radioactive material, and to effectively respond to malicious acts or threats, such as a possible dispersal of radioactivity
- Review legislation to reflect current revisions in the code of conduct on the safety and security of radioactive materials
- Foster and maintain a quality assurance culture, leading to accurate dosimetry, dose delivery, and patient protection
- Coordinate the GTRI activities for the East and Central Africa regional partnership project
- Continue with activities to locate, recover, and secure orphan sources
- Continue to employ the opportunity under the Convention on Assistance in the Case of Nuclear Accident or Radiological Emergency to handle illicit trafficking sources and incidents
- Strategically plan for the continual updates to equipment and expertise

Conclusion

Nuclear security is an essential element of global peace. As such, it is a responsibility of every nation in the world to take keen interest to enhance the global security. The global nuclear threat can only be eliminated through a mutual cooperative effort by the international community to accede to agreements and conventions and support the GTRI program. On the other hand, nuclear technology continues to be an important tool for the development of society and the economy, taking into consideration the safety, security, and accountability of the radioactive materials.

Acknowledgements

The author is grateful to the U.S. Department of Energy, in particular Phil Robinson, John Pelletier, and Michael Itamura for continuing cooperation with and generous support of nuclear security programs in the East and Central Africa region and continuing to upgrade the infrastructure in Tanzania.

I wish to especially thank Mark Soo Hoo for sponsoring my visit at the CMC International Visiting Research program at Sandia National Laboratories and also the CMC team: Michael Strosinski, Robert Martinez, Gilbert Morales, Linda Holle, and Ruth Bitsui for the wonderful logistical support and generous cooperation I enjoyed during my stay in New Mexico.

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High-Risk Radioactive Sources: Cradle-to-Grave Physical Protection

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Abstract

Recent acts of terrorism worldwide have highlighted the need to secure dangerous materials to prevent their acquisition for malicious purposes. Some of these materials are high-risk radioactive sources that are used for cancer treatment, oil extraction, food irradiation, and many other purposes. While these sources are safe if used properly, the potential for their theft and eventual use in radiological terrorist attacks is real. This paper discusses special physical protection systems that are currently used to safeguard nuclear facilities and ways to apply and adapt some of their components to radioactive sources at various stages of their life-cycle.

Introduction

"What is needed is cradle-to-grave control of powerful radioactive sources to protect them against terrorism or theft."—Mohamed ElBaradei, IAEA Director General

On September 11, 2001, America witnessed the execution of the most elaborate terrorist plot to date. That day left America reeling, with both senior officials and average citizens wondering, "What could be next?" With the stunning realization that the creativity and determination of hatred knows few bounds, added emphasis has been placed on protecting dangerous materials that pose a high security risk to the public that were once thought to be merely a safety concern. Among this group of potentially dangerous items are high-risk radioactive sources. These sources pose a unique security threat, should they be allowed to fall into the hands of an individual or group with malevolent intentions.

These sources are dangerous because of their potential for use in what has become known as a "dirty bomb," a crude weapon designed to spread radioactive material over an area. These weapons are not dangerous so much for their potential for mass destruction, but rather, for their potential for mass *disruption*. While they may cause, at most, dozens or hundreds of deaths in the near term, and their destructive potential pales in comparison to nuclear weapons, they are nonetheless very threatening.[1] In addition to the immediate deaths, there would be an immense economic impact from decontamination, especially when one considers that some radioisotopes, such as Cesium-137, chemically bond with building materials, thereby increasing the difficulty of post-incident decontamination.[2] With decontamination and property losses considered, such an attack could cost many billions of dollars.[3] If the immediate deaths and tremendous economic impact were not a great enough cause for concern, the long-term psychological and social effects of a crude radiation attack should be. Radiation is colorless, odorless, and tasteless, and has the potential to foment panic, anxiety, stress, loss, guilt, and a host of other intangible human traumas in the event of a dirty bomb attack.[4]

The threat is further realized in uncovered terrorist plots and reports. Numerous sources including the 2007 U.S. National Intelligence Estimate highlight the desire of extremist groups such as al-Qaida to procure non-conventional weapons, including dirty bombs.[5] The well-publicized cases of Jose Padilla and Dhiren Barot, both alleged dirty bomb conspirators linked to al-Qaida, further underscore the issue.

Despite the importance of this subject, high-risk radioactive sources have not been given the level of attention that is needed. So far, security concerns have focused almost completely on nuclear materials, while the focus on radioactive materials was almost exclusively safety-centric.[6] Though the prevailing attitudes are changing regarding the security implications of hazardous radioactive materials, much more work in this area remains to be done.

The publicly available literature reflects this reality, with precious little of it devoted to cradle-to-grave radioactive source security. Numerous scholarly articles on radioactive sources exist; however, most of these articles are focused primarily on safety issues. The small body of security-related literature that exists focuses on the problems of orphaned radioactive sources, waste management, illicit trafficking, and regulatory issues.[7] Of those, only a small number recognize the importance of full life-cycle protection, with much of the focus devoted to securing sources during the utilization phase while omitting their creation, disposition, and transportation.

What is needed is an examination of the application and adaptation of physical protection systems to high-risk radioactive sources throughout the life-cycle to protect such sources from illicit acquisition. This paper is intended to fill that gap. It will analyze the adaptation and application of the functional components of physical protection. These components, deterrence, detection, delay, response, and mitigation, will be examined in the context of the four life-cycle stages of creation, utilization, disposition, and transportation to provide a picture of a high-risk source life-cycle that is physically protected to the greatest extent that is prudent, practical, and feasible. First, however, one needs an understanding of the basics.

Understanding the Issues

High-Risk Radioactive Sources: A Brief Introduction

Radioactive sources, due to the varied applications of radiation, are used in a wide variety of fields, from medicine to well-logging, and from food processing to precision measurement. These sources are housed within the specialized equipment that utilizes their radioactive properties for their intended purpose. From a security perspective, radioactive sources are classified as high-risk due to a number of important factors. Certainly, the disruptive potential of the given radioisotope contained within a given source is the factor of greatest concern. This potential depends on a source's mass, type of radioactivity, degree of radioactivity, half-life, and ease of dispersal.[8] Two other related factors of concern are the attractiveness of a source to an individual or group with malevolent intent, and the ease with which such an individual or group could acquire a given source.

That said, not all of the myriad radioactive sources in existence pose a potential security threat. For instance, common household smoke detectors are ubiquitous, and a great many of them contain radioactive materials. However, the radioisotope commonly used to detect smoke, Americium-241, is utilized in such minute quantities that smoke detectors do not pose a credible security threat because millions of detectors would have to be collected to gather enough material to cause significant harm.[9] Likewise, common store-bought bananas are radioactive, but to a very small degree and are clearly of no security concern. Conversely, a large, highly radioactive Cobalt-60 source used in an industrial or agricultural irradiator could pose a security threat. Because Cobalt-60 is highly dangerous, it requires very heavy shielding proportional to the size of the source. Due to the massive amounts of shielding used in large irradiators, the Cobalt-60 sources are unlikely to be able to be removed and dispersed. However, if that particular irradiator was subject to lax security measures and was near a populated area, it might be a very attractive target to those with malevolent intent, who could then expose the source, subjecting the immediate area to massive amounts of radiation. Similarly, disused Cesium-137 sources from medical equipment, stored at hospitals and inadequately secured could pose a serious threat. In short, both physical and situational factors are the determinants for high-risk classification.[10]

Radioisotopes and Sources of Concern

In general, sources of concern are those that contain sufficient quantities of certain radioactive materials that would make them both dangerous to the public if used in a nefarious manner, and attractive to individuals or groups wishing to cause harm and disruption. Such sources, if used in an act of terrorism, would likely cause societal disruption through the economic, social, and psychological effects on the population.

High-energy gamma-radiation emitters such as Cobalt-60, Cesium-137, and Iridium-192 are dangerous because their powerful emissions are deeply penetrating and can only be blocked by thick lead or concrete.[11] The effects of a loose high-energy Cesium-137 source were felt in the radiological accident that occurred in Goiânia, Brazil, in 1987. More than 200 people were contaminated, many fell ill, and four died. The accident also required a large and expensive decontamination effort.[12] High-energy alpha-emitters, such as Americium-241 have less deeply penetrating radiation, which can be blocked by the outer layer of skin on humans. However, if high-energy alpha emitters are ingested, internal exposure can be deadly. This was the case in the highly publicized 2006 poisoning death of Alexander Litvinenko, who unknowingly ingested Polonium-210, a potent alpha-emitter. High-energy gamma-emitters such as Strontium-90 fall in between alpha- and beta-emitters in terms of penetrative ability and pose both an external and internal health risk to humans.

These high-energy sources and others like them are contained within numerous devices and are utilized in various industries. For instance, irradiators with large, high-energy gamma sources are used in the agricultural industry to kill harmful bacteria in food products before they reach the end-user. Similar applications exist for using gamma sources to irradiate blood products and kill pathogens prior to transfusion. Other medical applications for high-risk isotopes exist in radiotherapy for cancer treatment. These devices are broken up into two categories: teletherapy and brachytherapy. Teletherapy involves an externally located source, whereas brachytherapy involves placing the source on or within cancerous tumors. One such device, the Gamma Knife, uses a phased array of nearly two hundred high-energy gamma sources to precision target intense radiation at brain tumors, thereby killing the cancerous tissue.[13] High-dose rate brachytherapy units administer prescribed doses of high-energy radiation via direct source contact with the target tissue. High-risk, high-energy sources are also utilized throughout industry for testing and measurement of metals and for well-logging in the search for petroleum deposits. High-risk radioisotopes even have applications for power generation. Known as radioisotope thermoelectric generators (RTGs), these devices utilize the heat produced by radioactive decay to provide standalone power at remote locations.[14]

These various sources and others that contain high-energy alpha-, beta-, gamma-, and neutron-emitting radioisotopes in sufficiently large quantities are potential security risks simply because of their particular radioactive characteristics. As such, it is prudent to provide adequate physical protection for the sources throughout their life-cycle so as to protect them from illicit procurement, thereby protecting the public from a potential dirty bomb attack.

Table 1. High-risk radioactive source applications

Application	Radioisotope	Typical Activity (in Ci)	Typical Activity (in TBq)	IAEA Categorization
RTGs	Strontium-90 Plutonium-238	20,000 280	740 10	1 1
Industrial Irradiators	Cobalt-60 Cesium-137	4,000,000 3,000,000	150,000 110,000	1 1
Medical Irradiators	Cesium-137 Cobalt-60	7,000 2,400	260 89	1 1
Gamma Knife Teletherapy	Cobalt-60	7,000	260	1
Industrial Radiography	Cobalt-60 Iridium-192	60 80	2.2 3.0	2 2
High-Dose Rate Brachytherapy	Cobalt-60 Iridium-192 Cesium-137	10 6 3	.37 .22 .11	2 2 2
Well-logging	Americium-241/Beryllium Cesium-137 Californium-252	20 2.0 .3	.74 .074 .011	3 3 3

Source: International Atomic Energy Agency, "Categorization of Radioactive Sources," IAEA-TECDOC-1344 July 2003.

The Radioactive Source Life-Cycle

An understanding of the life-cycle of high-risk radioisotopes is necessary to appreciate the unique security challenges that exist in each phase. Each phase, from creation, to utilization, to disposition, with transportation in between, raises different security questions. For instance, how could a physical protection system apply to high-risk sources in transit? Is it possible to apply the principles of physical protection to mobile source-containing equipment that operates in remote areas? These are some of the questions that this paper will attempt to answer. First, however, it is necessary to understand the typical life-cycle of high-risk radioactive sources.

Unlike naturally-occurring elements, most high-risk radioisotopes are created in nuclear research reactors. They typically undergo further refinement nearby to isolate the materials of interest and to process the radioisotopes into a usable form. Those isotopes are thereafter either sold raw to a source manufacturer, or made into sources by the radioisotope producer. The packaged sources are later sold to equipment manufacturers who incorporate the sources into their products for use in various fields.

The equipment containing the sources, such as Gamma Knife teletherapy devices, irradiators, or well-logging tools, is utilized by end-users such as hospitals, poultry processors, and oil-drilling corporations, respectively, often until the sources decay below their usable level of radioactive emissions. The sources are then disposed of. Ideally, this occurs through legitimate and regulated routes, with the disused sources disposed of at licensed facilities. However, users sometimes dispose of these sources outside of the regulated disposition framework. In these unfortunate cases, the sources are *orphaned*, or abandoned.

In between and sometimes during these phases, sources are in transit. Sources must be delivered to equipment manufacturers; equipment needs to be transported to end-users; some pieces of equipment are intended to be mobile during use; finally, sources need to be transported to disposal sites. Figure 1 is a graphical representation of the radioactive source life-cycle.

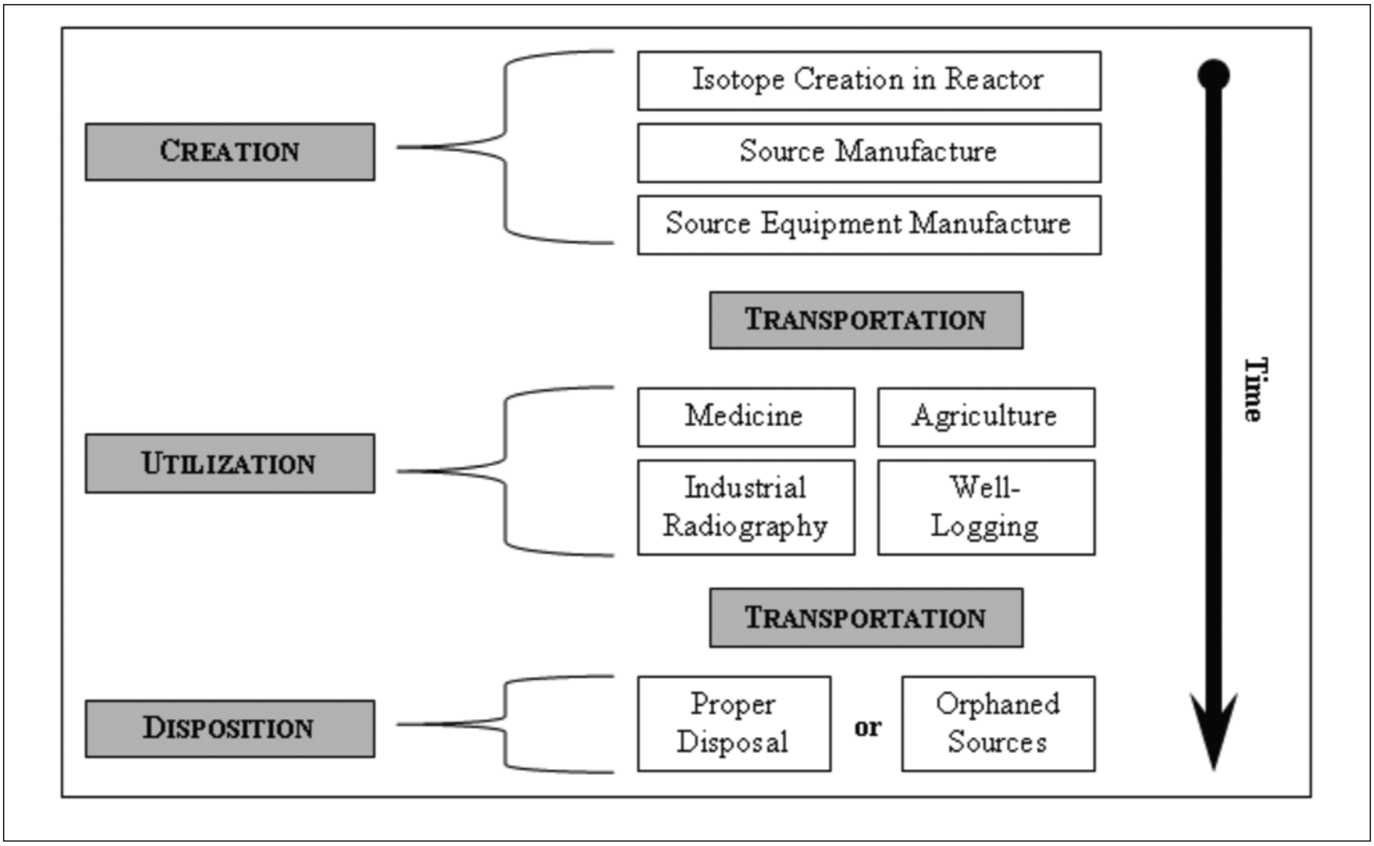
Each of these phases provides unique challenges to the development of adequate physical protection systems (PPS). These phases, along with the components of PPS discussed below, are the basic concepts that necessarily serve as the backbone of a complete understanding of cradle-to-grave physical protection.

Components of a Physical Protection System

Physical protections systems, such as those commonly implemented at nuclear facilities must be designed to stop a given threat. There are five layered security components, three essential and two supplemental, in any adequate physical protection system. The three core components are each crucial to the PPS, with the system compromised should one of the troika be missing or inadequate. These three are detection, delay, and response.

Detection is a crucial and necessary component of any physical protection system, given the purpose of PPS–to prevent access by clandestine actors to sensitive items. To stop an unauthorized incursion, it is first necessary to know that such an attempt is taking place. Detection occurs through a combination of technical elements such as alarms and human elements such as security

Figure 1. The radioactive source life-cycle



personnel. Delay is also an essential component of any physical protection system. After an intrusion is detected, active and passive obstacles stand between the intruders with the goal being to "buy time" for the response team to interrupt and apprehend the intruders. Response teams can range from specially trained on-site tactical squads to local police or military units.

Each of these three components is essential to protecting the source material that could be used in a crude radiological weapon. Without response, the intruders might not be stopped from completing their objective; without delay, the responders might not have enough time to assemble and intervene; without detection, responders would never be summoned. While these three components are absolutely necessary, two more—deterrence and mitigation—are also important and can bolster any PPS.

The purpose of deterrence is to dissuade any potential adversary from attempting to gain unauthorized access to a given sensitive area. Delay mechanisms often serve dual roles as deterrence mechanisms, as a series of walls and electrified fences topped with razor wire could very well make a potential intruder question the feasibility of achieving his goal. Other deterrence mechanisms could include intimidating armed guards at entrance points and other visible or otherwise known formidable obstacles.

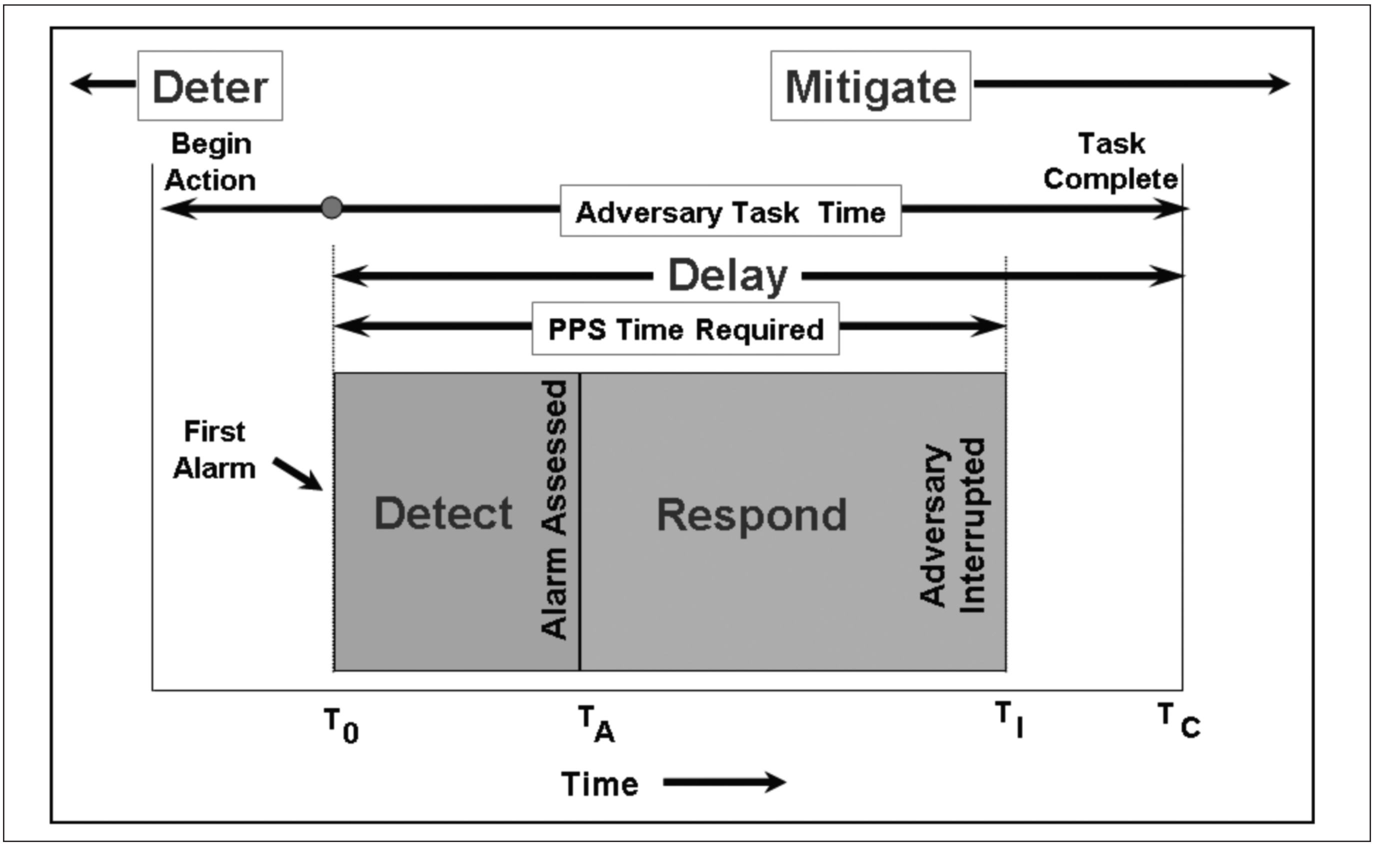
Mitigation is a mechanism to minimize potential consequences in the event that the response force fails to interrupt an adversary. If the response force fails to interdict the intruders then steps should be taken to mitigate the consequences if possible. These steps would occur after the incursion as a "second line of defense."

Despite the incredible importance of the technical components of physical protection systems, they alone cannot secure these sources. Just as detection, delay, and response are essential co-requisites in any adequate PPS, a healthy culture of security also plays a critical role. A robust security culture is, in essence, an organizational culture in which a healthy respect for the threat permeates all levels of the organization, from the "most senior leaders down to the lowliest technician."[15] This respect for the extant threat translates into a security-focused, proactive, and innovative organization that works in conjunction with the PPS components to counteract threats continuously, rather than waiting for a bureaucratic mechanism to institute best practices.[16] Without a healthy security culture embodied by source handlers in all phases of the life-cycle, even the most robust physical protection system can be rendered ineffectual through carelessness, ignorance, or laxity.

Cradle-to-Grave Physical Protection

The effective combination of the five PPS components with a developed healthy security culture makes for adequate and effec-

Figure 2. The physical protection systems component timeline



Source: The above figure was developed from the Sandia National Laboratories pocket reference guide, "Physical Protection of Radioactive Sources/Radionuclide Reference for First Responders," Version 1.0, 2006.

tive physical protection systems. The challenge is to adapt and apply these components to high-risk radioactive sources in a variety of environments and situations, throughout source life-cycle to protect these sources from use in an act of terror. In some instances, compromises and trade-offs must be made to adapt the PPS to the situation at hand. These components must be applied in a prudent, practical, and feasible manner, designed around the assessed risk. It should also be noted that these systems should be implemented in a manner that provides that greatest amount of protection, up to the level that is determined to be needed, without becoming cost prohibitive. The following paragraphs will delve into these challenges and offer possible solutions to arrive at a picture of complete physical protection of high-risk radioactive sources throughout the life-cycle.

Creation

The creation of high-risk radioactive source equipment can be broken down into roughly three sub-stages. First, the isotopes must be created, most often in small research or larger production nuclear reactors. Second, specified amounts of a given isotope must be placed within a layered housing to prevent leakage of the isotope into the environment. Third, the sources must be incorporated into the various pieces of equipment that will then be sold to end-users.

The physical protection components have fairly straightforward applications in this stage. Due to the "brick and mortar" nature of the research reactors and associated source production facilities, PPS components can take the typical form, similar to those seen on nuclear power reactors. Furthermore, sources are supplied by just a few major producers, thereby making PPS implementation less difficult.[17]

The International Atomic Energy Agency TECDOC-1355, "Security of Radioactive Sources," serves as a rough guide to the implementation of adequate PPS, with a few modifications. The measures outlined in the interim guidance are relevant and useful; however, the recommendations must be modified to insure that the three essential components of a PPS are included in every application. As previously mentioned, mechanisms of detection, delay, and response must be implemented together; without one, the system is rendered impotent against criminal action.[18] Any scaling up or down of the robustness of the high-risk source PPS must then be achieved through higher or lower degrees of component implementation, rather than through the addition or elimination of these essential elements.

For the most at-risk sites (i.e., those with large quantities of high-risk sources or radioisotopes, that exist in comparatively dangerous areas, or would otherwise be very attractive targets for malevolent action), the Group A recommendations contained in TECDOC-1355 should suffice with the addition of mitigation mechanisms if at all possible.[19]

For adequate deterrence, visible or otherwise known robust security is necessary. With the purpose of deterrence being to dissuade criminals from attempting to gain entrance, the criminals must be aware of the robust security measures that are in place. There should also be some degree of invisible security, should the visible and perceived invisible protective measures fail to deter an intruder. For fixed installations such as those involved in the source creation phase, guards should be charged with limiting access to the building to authorized personnel only. Such guards would make entrance through main personnel points unattractive. Other potential entrance points, (i.e., ventilation ducts, loading docks, etc.) should also be thoroughly secured.

To adequately detect intrusion, different components must work in unison to detect and assess an attack. Various alarms and sensors should be placed at the entrance points to sensitive areas. Because of the potential for nuisance alarms, or false positives, a system of human alarm assessment must be in place to provide adequate detection capabilities. Along these lines, personnel must operate within a security culture that has a healthy respect for threats, keeping alarm systems active, and investigating alarms with due diligence. On-site personnel could also function in this capacity, and additional personnel should scan video feeds cameras covering the sensitive areas. An adequate communication system must exist between the technical and human elements, transmitting data to accurately assess the alarm.

Delay mechanisms such as armed guards and fences often serve dual roles as deterrence mechanisms. They can be broken down into two groups: passive and active. Passive delay mechanisms are static physical structures designed to increase the time it takes for an intruder to reach a given sensitive area. For fixed installations, layers of locked doors are a common means of delay. Another method of passive delay is to insure that there is no direct path to the target area. A longer path may not be very convenient for everyday personnel, but it can add crucial seconds to the response window. Active delay mechanisms are intended to slow adversaries down when they are triggered and would only likely be necessary in extremely high-risk scenarios. Smoke emitters that fill a room, thereby blocking the vision of an intruder are one possible form of active delay. Even more aggressive active delay mechanisms include “sticky foam” and razor wire drop coils. Sticky foam is a tenacious foam that, when sprayed, inhibits human movement, effectively stopping an intruder. Razor wire coils can be attached to the ceilings of sensitive areas, triggered to drop to the floor in the event of unauthorized intrusion. As one can imagine, these coils are especially effective when used in conjunction with smoke emitters, however such extreme measures are not likely to be necessary in most cases.[20]

The response mechanism is almost entirely a human one, focused on the response personnel themselves. In-depth training in weapons, tactics, and counterterrorism is necessary for the response personnel to have a high degree of likelihood of stopping well-trained and determined adversaries. Additionally, these tactics must be rehearsed regularly in order to maintain sharpness and readiness. Another element of a response mechanism is equipment. The response force should be prepared from an equipment standpoint, not just with firearms and body armor, but also with personal radiation monitors, and perhaps sensitive handheld detectors to aid in stopping an intruder who has already succeeded in taking radioactive material. Sites that require the highest level of security could utilize on-site private response teams. Otherwise, relationships should be formed with local law enforcement tactical teams. Regular, on-site tactical training of the law enforcement teams would be fruitful and would aid a great deal in mission success should their training scenario become a reality. Another possibility is to share the cost burden of training local police units in issues regarding radioactive materials and their security implications.

These facilities with high-risk radioactive sources should also incorporate mitigation mechanisms so that, in the event of a response team failure at the site, the consequences are lessened to the greatest extent possible. Such mechanisms could consist of specialized search teams equipped with radiation detection equipment to attempt to find the adversary before he leaves the immediate vicinity. Other mitigating actions include alerting local law enforcement of the loss and to continue the search, heightening border security, and implementing checkpoints on transit routes.

These measures must be implemented to the degree that is both necessary and feasible. Perimeter fencing may not be necessary or feasible in certain settings such as hospitals, but may be at source creation sites. Physical protection systems must be designed with the threat and the potential consequences as the basis, with an eye toward practicality.

Utilization

There are approximately 22,000 licensed entities in the United States utilizing some 2,000,000 radioactive sources.[21] While only a fraction of these sources can be considered high risk, the need for adequate physical protection is great. The application of PPS to sources during the utilization phase can be more complicated, given the varying contexts in which sources can be found to be in-use. Large industrial irradiators do not face the same threats that confront well-logging equipment. Likewise, Gamma Knife devices are subject to different challenges than are mobile industrial radiography equipment. The elements of the PPS will, in some cases, need to be modified due to implementation issues. The aim of this section is to provide an idea of how an adequate PPS will look in various scenarios, keeping in mind that degrees of protection will vary based on the threats faced and the consequences of successful intrusion.

The largest sources, such as large Cobalt-60 industrial irradiators, have design characteristics that make them inherently secure from theft. These sources require tremendous amounts of heavy shielding, thus making safe access to the source time-consuming. The sources themselves are often stored and operated under large pools of water or in relatively secure irradiation cabinets.[22] The removal of such a source in a manner that would not immediately incapacitate the intruders is highly labor- and equipment-intensive, so much so that these sources can be considered to have highly effective inherent deterrent and delay mechanisms. Due to the unlikelihood of success in stealing such massive sources, the remaining scenario is on-site dispersal.

To protect against such a scenario, robust detection measures should be used. Motion-sensor activated cameras with direct video feeds monitored by local authorities could be utilized. Any motion would then trigger an alarm, giving law enforcement immediate assessment capability and the ability to quickly respond. A perimeter fence and a series of locked security doors should stand between an intruder and the large source equipment. Timely action in this scenario is paramount. In other schemes, criminals might need to gain access, but also exit, to do damage. In these plots, however, a prepared terrorist need only gain access to do damage, and exit may or may not be necessary. Quick detection and response could mean the difference between an apprehended intruder and a very large, exposed, high-energy gamma source.

Hospital settings typically have built-in delay mechanisms consisting of long, winding corridors and controlled-access doorways that would ideally help to delay an adversary after being detected from reaching a high-risk source. Delay mechanisms must not be too robust, as they could possibly interfere with patient treatment; however, inherent delay mechanisms can exist within the sources themselves if these sources are constructed to be secure. Overt deterrence mechanisms in hospitals are relatively weak. Armed guards and razor wire would deter malevolent actors, but would clearly be unsettling for patients and hospital personnel. The emphasis in this situation, like that in the case of irradiators, must be placed on detection, response, and increased inherent delay.

Sources such as mobile high dose rate (HDR) brachytherapy units, industrial radiography equipment, well-logging equipment, and RTGs pose a great challenge for PPS implementation. These sources are mobile and/or utilized in remote locations, potentially making them more attractive to criminals than other sources. Furthermore, because of the intended use of these sources, most are portable, significantly reducing the challenges that a criminal would face in attempting to steal such a device that could later be used in a dirty bomb.

The deterrent effect, if any exists, is a function of how remote and inhospitable the location is. To a determined terrorist, such locales are unlikely to have such an effect. Delay mechanisms are also problematic, as many of these devices are designed to be accessed often during field use. Any delay mechanisms that are too effective are likely to be circumvented by the operators in the name of convenience and efficiency. Furthermore, remote locations are not promising ones for a timely response.

Despite the challenges posed, it is possible to adapt the core principles of detection, delay, and response to protect these types of sources. In terms of detection, there are both human and technical solutions. Through constant real-time human accountability of the sources by the users in conjunction with an established communications link to the relevant authorities, an attempted theft of such devices would be detected by humans on the ground, and an outside response could be initiated. Also, issues regarding inconvenient delay mechanisms could be remedied to some degree by fostering a healthy security culture among source operators. With a healthy respect for the threat that exists, security would take priority over convenience. As a redundant detection measure, high-risk attractive sources could be fitted with global positioning system tracking to monitor their location.

Potentially the best possible means of delay is robust equipment design. Equipment should be designed so as to prevent unauthorized access to the source, thus giving the source within added security. Such equipment, in combination with embedded tracking devices and remote alarms, could allow enough response time to prevent a criminal from removing the source for possible use in a crude radiological weapon. Furthermore, if trained and sufficiently equipped, the on-site operators could serve as an immediate response force, should they survive any initial assault.

Mitigation techniques for the utilization phase are similar to those in the creation phase, with search crews dispatched in an attempt to find the source. In cases where a border crossing with the stolen source is probable, sealing those borders and implementing thorough radiation searches of vehicles and people leaving the country would also help to mitigate the consequences of the theft.

While securing in-use high-risk sources in certain scenarios can be exceedingly difficult, it is a feasible goal. Through an adaptation of the essential physical protection components to fit a given scenario, the source can be as effectively protected as is prudent and possible given realistic restraints such as cost. Furthermore, the PPS must be designed based on the threat and consequences of theft. As such, some sources will not require highly rigorous physical protection systems to reasonably secure them.

Transportation

Between every phase of a source's life-cycle, that source must be transported. Source manufacturers must ship their products to end-users, and end-users will at some point have to send old sources to be disposed. The nature of transportation poses some challenges to the implementation of physical protection systems. In contrast to fixed sites, a potential adversary can be selective about his action point, picking a point along a set transportation route that would be most advantageous from his perspective. This puts the transport PPS at an inherent disadvantage over a fixed-site PPS.

However, the essential components can be adapted and grouped to provide adequate physical protection of high-risk sources. As with all physical protection systems, the strength of the mechanisms varies with the threat. High-risk transports will serve as the model here, with varying lesser degrees of protection possible corresponding with lesser threats.

To adapt the fixed-site PPS to transportation, the transport vehicle and human escorts and/or vehicle drivers must serve in the delay, detection, and response capacities. Accompanying personnel share the detection duties with technical measures on the vehicle, and would best accomplish this role if they operated within a culture of security. The human factor should work in conjunction with technical alarms positioned around the transport vehicle to monitor all potential points of entry. Triggered alarms should sound in the driver's cabin, a central monitoring station, as well as in any escort vehicles that may accompany the shipment.

Layered, passive delay mechanisms should be implemented within the transport vehicle itself. For instance, the exterior of the delivery vehicle should be locked, with the sources within contained in safe and secure housings that, due to regulations, require tools and a fair amount of time to open.[23] Also, the transport casks housing the high-risk sources must be tied down to prevent shifting during transit, thus providing another layer of delay. The possibility remains that an adversary would attempt to circumvent the delay mechanisms by overwhelming the driver and hijacking the vehicle. The likelihood of this occurring without a response being initiated is slim, and the restrictive nature of the highway system combined with a GPS locator on the vehicle would greatly increase the likelihood of interdicting the transport vehicle. Active delays such as sticky or rigid foam could be utilized inside of the transportation vault, if determined to be needed, but the escort personnel will in effect serve as the primary active delay mechanism.

The response mechanism is a layered one as well. Once alarms are triggered and positively assessed, a response would be needed. The primary response force would likely be local law enforcement, or with the highest-risk sources, the escort personnel. Communication between the delivery vehicle, the response force, and the monitoring station must be incorporated so as to insure cooperation and a higher degree of success in stopping any potential criminal action.

Mitigation techniques can be applied during a particular transport mission, or as a part of general practice. For particular transports, should personnel become aware that the transport vehicle is being watched, scheduled stops could be changed or the route could be altered in an attempt to thwart adversarial action. In general, route and time variations will make high-risk source transports unpredictable, and therefore, more difficult to intercept.

The grouping and sharing of detection, delay, and response among the personnel near the high-risk source, the remote monitoring personnel, and the non-human mechanisms allows for the implementation of an adequate and effective physical protection for the high-risk sources in transit.

Disposition

Disposition can occur in three modes at the end of a source's useful life. Simply because a source is no longer useful for its intended purpose does not mean that it is no longer a security risk. For the largest sources of Cobalt-60, such as a maximally loaded Gray-Star, Inc. Genesis Irradiator with a one-million-curie source, it would take more than 150 years to decay to one millicurie.[24] Even for small sources of certain isotopes, such as Americium-241, with a half life of 433 years, it can take many centuries to decay to a level that would no longer pose a security concern. As such, many of these sources remain security concerns long after their useful lifetime and must be protected from illicit acquisition so as to prevent their use in an act of radiological terrorism.

The ideal and most secure ending to the high-risk source life-cycle is one of safe and secure disposition at a waste disposal site. These sites are good candidates for physical protection systems because they are fixed, and the sources are not frequently moved. Also, there is the built-in delay mechanism in the heavily shielded casks that are buried underground and monitored. As such, systems similar to the ones described for fixed-site protection can be used.

Secure indefinite storage is another avenue of source disposal but it can be costly. The proper protection of these disused high-risk sources requires that adequate detection, delay, and response mechanisms be in place. If an end-user wished to implement such a system, the standard fixed-site PPS should be applied. However, if the end-user chooses to orphan a source, it is quite a difficult problem for PPS implementation. For this reason, it is highly important for the responsible governmental agencies to work to prevent sources from being orphaned in the first place, through greater information sharing, more robust accounting, and higher penalties.

Orphaned sources pose a problem because they are typically unknown to authorities. There are not likely any alarms to be tripped to detect a possible theft of an orphaned source. Similarly, delay mechanisms are flimsy. If a malevolent actor is aware of an orphaned source's location, he would only need a means of transport to procure it. Guards and electrified fences are forms of protections that are by definition absent from orphaned sources. With an extremely weak detection mechanism, any response force is rendered nearly useless, as they will be uninformed of any event that would require their action.

With the near complete absence of the core components of a PPS, orphaned sources cannot be fully physically protected. On a positive note, an inherent deterrence mechanism operates in these cases because a search for an orphaned source without knowing its location would appear to be a futile exercise. However, if a criminal gains knowledge of an unknown orphaned source's whereabouts, there is not much that can be done to interrupt the acquisition of the source for potential use in a dirty bomb. Multiplying the difficulties of applying the components of physical protection systems are the sheer numbers of reported missing sources. The U.S. Nuclear Regulatory Commission receives some 200 reports of orphaned or otherwise missing sources each year. Furthermore, agency officials believe that these reports represent a small fraction of the actual number of missing sources.[25] Though high-risk sources likely comprise only a small percentage of all orphaned sources, there is still cause for concern. The problems of PPS application, exacerbated by the numbers of orphaned sources, have limited the potential avenues for action in these cases to mitigation and efforts to reintroduce these sources into the physical protection architecture.

One such reintroduction measure is the U.S. Department of Energy's Off-site Source Recovery Project (OSRP). It is the OSRP stated mission to "remove excess, unwanted, abandoned, or orphan radioactive sealed sources that pose a potential risk to health, safety, and national security."[26] Mitigation mechanisms would function under the assumption that orphaned sources had been acquired by malevolent actors and could include rapid response units to counter a threat once it is discovered, radiation scanners on major thoroughfares and in high-value areas, heightened security at borders and high-value areas, or public outreach programs to spread awareness about the appearance of and potential threats caused by high-risk sources.[27] The development of a healthy security culture among high-risk source users could potentially prevent further source abandonment. Also, an educated public could be a valuable tool in helping not only to secure more orphaned sources.

Conclusions and Recommendations

High-risk radioactive sources pose a significant danger to societal and human well-being. To prevent their acquisition by malevolent actors for possible use in crude radiological weapons, it is crucial that adequate physical protection measures be consistently implemented throughout the source life-cycle. The PPS core components of detection, delay, and response, supplemented by deterrence and mitigation techniques that are used for nuclear facilities and materials can be adapted and effectively applied to sources during their creation, utilization, transportation, and disposition. To do so, it is sometimes necessary to emphasize one component to bolster others that are inherently weak given a certain situation. Without such life-cycle protection, it will never be possible to consider high-risk sources secure, and the threat of radiological terrorism will continue to be great.

In order to provide complete life-cycle physical protection, source handlers at every stage of the life-cycle must analyze the threat and potential consequences that exist and use that analysis as the design basis for their physical protection systems. In doing so, source handlers can implement prudent, practical, and feasible systems that match their security needs, varying in degree rather than in number of components.

Where holes in the physical protection fabric exist, such as in the cases of orphaned sources, the responsible agencies must continue to work to develop and implement programs and regulations that work to improve security where physical protection systems cannot. In doing so, they can help to reintroduce sources into the physical protection framework, and in other cases, prevent them from ever leaving.

A healthy, security culture must exist among personnel throughout the phases of a high-risk source's life-cycle. In this way, the PPS systems would function properly from cradle to grave, thereby protecting these sources from those who would use them in an act of terror. More work must be done in the area of security culture and its application to the high-risk radioactive source life-cycle to foster a greater awareness of its importance.

By implementing complete cradle-to-grave physical protection, high-risk radioactive sources will be better protected from falling into the hands of those who wish to foment terror and disrupt society. In light of the consequences, such complete life-cycle physical protection should be seen as an imperative, rather than an ideal.

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27. Such a program should aim to spread simple, existing, open-source information to the public. Being that a determined terrorist can be assumed to have searched public information on the subject, concerns of negative externalities should be assuaged.
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Triborder Radioactive Material Trafficking and Threat Environment

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Background

The Triborder Area (TBA) in South America encompasses three states and is formed by three cities, Ciudad del Este, Paraguay; Foz do Iguaçu, Brazil; and Puerto Iguazú, Argentina. This region covers only 1,200 square kilometers and has a population of around 630,000 people. The TBA is notorious for being a region of illicit trafficking, cross-border and organized crime, money laundering, and arms dealing, and has also been implicated as an area vulnerable to terrorist activity.

Map of Triborder Area with major arteries from key cities[1]

There has also been a lingering concern about extraterritorial support and possible fundraising for Hizballah and HAMAS through the Muslim communities in the region.[2] Connections between the TBA and Middle East terrorist organizations have been corroborated by evidence such as an Argentine prosecutor's determination that the 1992 and 1994 bombings of Jewish targets in Argentina were conducted by Hizballah militants who infiltrated the region through the TBA.[3] The TBA has also been designated by the U.S. Department of Treasury as posing a significant threat through a well-connected network that provides financial and logistical support to Hizballah.[4] Al-Qaida has also been described as having ambitions and possibly has already infiltrated the region with terrorist cells.[5] Paraguay's former district attorney on drug trafficking and terrorism has corroborated these claims by proclaiming the TBA a zone of refuge for terrorists. What facilitates this threat is mostly Paraguay's, but to a certain extent all three states', lack of counterterrorism and money-laundering legislation, porous borders, ineffective customs and immigration controls, and corruption within all border related agencies up to and including the judicial system.[6]

Radioactive Material Trafficking/ Terrorism Cases

For the most part, the high incidence of illicit trafficking and crime in the TBA has not led to increased terrorism or the smuggling of radioactive material. However, the absence of reported incidents does not preclude the existence of the threat. As previously mentioned, the TBA's lack of effective border controls, corruption among politicians and other agencies, a weak legislative and regulatory framework in Paraguay and other issues may conceal cases of significant concern.

In one case in July 2004, eighteen sacks containing 600 kilograms (kg) of 75 percent Thorium (Th) and 7.8 percent Uranium (U)[7] valued at $500,000[8] were discovered during transport in a van in Amapà, Brazil, by federal police. This incident was discovered by chance and only because an investigation was initiated into the illegal exploitation of land.[9] After further research it was found that three specialized and internationally networked groups in uranium trafficking were in charge of the mine and had purchased 1,000 hectares containing no less than 50,000 metric tons of ore for $1.2 million with plans to expand the exploration for uranium. Wiretaps on these three groups disclosed trafficking deals containing upwards of ten metric tons and eight more metric tons reportedly stored somewhere in São Paulo, far more than the 600 kg that had been revealed solely by chance. Additionally, this network of criminals had noteworthy political and governmental connections. Front companies sold and exported the material to French Guiana at which point it was forwarded to other countries.[10] Although, this ore was not processed into yellow cake nor separated and enriched, it presents an example of the existence of a pathway for sophisticated and internationally connected smuggling networks and the potential for the diversion and proliferation of radioactive or nuclear material.

Earlier in 1993, in an obscure event, similar to the 2004 case of trafficking Th/U, a man possessing a small amount of thorium was detained by police.[11] It appears that this earlier minor incident was not taken as a signal by authorities to further investigate the possibility of other Th/U mining or trafficking.

The terrorist bombings in Buenos Aires of the Israeli embassy in 1992 and the Argentine-Israeli Mutual Association (AMIA) Jewish Center in 1994 resulted in 115 deaths with high numbers of casualties.

After a twelve-year hiatus in determining the culprits for the attacks, Argentine special prosecutors indicted eight Iranians and one member of Hizballah in the AMIA attack.[12] Similar motives and culprits are believed to be behind the Israeli embassy attack and both attacks have been linked by Argentine authorities as originating from the TBA.[13] In 2002, a drug trafficker who had lost a family member in the AMIA attack financed a sting operation through Argentina's Secretariat of State Intelligence (SIDE) that led to the divulgence of information on past and future planned terrorist attacks by Hizballah and makes mention of the plan of using ammonal (an ammonium nitrate, TNT, and aluminum powder high explosive) and an unknown "radioactive material" transported and exploded in a bus in front of the Israeli embassy.[14] Although the radioisotope to be used and more details of this event have not been revealed by this research, the surfacing of this incident is an example of how the TBA has provided sanctuary to a sophisticated international terrorist group with financing and connections and at least the capability and intended goal of discharging a radioactive dispersal device.

From a regional perspective, thefts of orphaned[15] radioactive sources may also be vulnerable to acquisition by a terrorist group and routed through the TBA. For example, in 2005 a significant amount of radioactive cesium was stolen from an oil company in La Gloria, Colombia (north of Bogotá). The material is still considered missing and Al-Qaida has been suspected of conducting the operation.[16] In 2006, Venezuelan authorities reported five incidents[17] of theft involving Iridium-192 and "highly dangerous" Cs-137 capsules. The Ir-192 capsules were discovered in a rescue of a storekeeper kidnapped by three policemen.[18] Therefore, the minimal amount of radioactive material misuse in the TBA does not exclude the continent as a whole and the TBA might even be an operative area for groups attempting to steal radioactive material outside of the TBA.

Multilateral Anti-Terrorism Cooperation with TBA States

Several forums of anti-terrorism cooperation exist that could be used to approach radioactive material security issues with the three states comprising the TBA:

- 1998—Tripartite Commission of the Triple Frontier (a U.S. delegation was added as a participant in 2003, and the commission was dubbed 3+1)
- 1998-99—Organization of American States through the Mar de Plata and United Nations General Assembly established the Inter-American Committee Against Terrorism (CICTE)
- 2006—Brazil: Regional Intelligence Center in Foz do Iguaçu
- MERCOSUR (Southern Common Market): Security Commission
- Organization of American States—Committee on Hemispheric Security
- Cooperation on United Nations Security Council Resolution 1540
- Memorandums of Understanding between the United States and South American states for the Megaports Initiative

Conclusion

According to the International Atomic Energy Agency, the majority of illicit trafficking cases involving radioactive material come in the form of sealed radioactive sources.[19] Although both Brazil and Argentina each have a proven track record of effective export controls on nuclear materials, the possibility of unaccounted for material and the risks associated with the environment in which the materials are located should never be discounted.

Based upon the discussion above on the lawless environment, criminal infrastructure, and the fact that all cases of radioactive materials smuggling were discovered circumstantially in the TBA, priority should be given to containing the current threat, and assessing the security of radioactive materials within all of South America. Argentina and Brazil are both major producers of radioisotopes.

Notes

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Statistical Algorithm for Sampling from a Growing Population

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Abstract
The problem of sampling from a growing population of stored fissile material containers, to confirm that the container contents are as declared, is investigated. An algorithm is developed that establishes the sampling requirement, in the presence of measurement uncertainty, to achieve a desired confidence that the proportion of defective items in the final inventory does not exceed a given level.

Introduction
In the sampling scenario of interest, inspectors make periodic visits to a facility storing fissile material to randomly select containers and make external radiation measurements to confirm that their contents are as declared. If one or more of the measured attributes of a container fail with respect to predetermined thresholds, that container is declared to be defective. Ideally, such sampling would be conducted on a static population and the measurements would be errorless. The methodology for drawing statistical inferences from the data collected in the ideal case is well developed and readily available. In practice, the population may not be static throughout the duration of the sampling campaign and the measurements will be susceptible to error. The population may change during some portion of the sampling campaign, for example, due to the continued loading of containers into the facility. In addition, the instrumentation may occasionally classify a non-defective container as defective (false fail) or a defective container as non-defective (false pass) because of statistical fluctuations inherent in the radiation counting process and/or random variations in container properties that impact radiation transport (e.g., dimensions, densities).

An algorithm has been developed to analyze this non-ideal sampling scenario. It is based on the standard approach, using the hypergeometric distribution for sampling without replacement during any one visit and the binomial distribution for sampling with replacement from visit to visit. (That is, the same container will not be sampled twice during the same visit, but may be sampled in two different visits if randomly drawn a second time.) This approach has been extended to allow for a growing population and for measurement uncertainty, as described in the following sections. Although others [Sanborn (1987), Jaech (1991), Lu (1997), Lu and Kennett (2005)] have included the effect of measurement uncertainty, to our knowledge the approach described here is unique and has not been previously published.

Sampling Scenario
In the scenario under consideration, a sampling campaign is conducted to confirm, with prescribed confidence, that the defective rate in the final population of fissile material containers is not greater than some agreed value. To accomplish this, inspectors visit the storage facility periodically to select and measure containers from the population resident in the facility at the time of each visit. The population may grow during the intervals between visits but will be static for the duration of each visit. The radiation-based measurements performed to confirm material contents are subject to uncertainties induced by statistical fluctuations. When the inspectors arrive for their i^{th} visit, there will be N_i containers and D_i defective containers in the inventory, where $N_i \geq N_{i-1}$ and $D_i \geq D_{i-1}$.

Statistical Evaluation
If the inspectors sample n_i containers during that visit, by enumerating all possible samples and all possible defect-free samples, the probability that they will draw d defects is

$$P_i(d) = H(d, n_i, D_i, N_i),$$

where H(,n,D,N) is the hypergeometric distribution:

$$H(d,n,D,N) = \frac{\binom{N-D}{n-d}\binom{D}{d}}{\binom{N}{n}},$$

$$\text{where } \binom{N}{n} = \frac{N!}{n!(N-n)!}, \quad N! = N(N\text{–}1)(N\text{–}2)\ \dots\ (2)(1).$$

A distinction must be made between *drawing* and *discovering* a defective item, because, in the presence of measurement uncertainty, there are non-zero probabilities of false pass and false fail decisions. Let f_p be the false pass probability and f_f the false fail probability. The probability that the instrumentation will "discover" zero defects among n_i containers with d defects is given by

$$Q_i(d) = f_p^{\,d}\,(1-f_f)^{n_i-d}.$$

The first factor in this expression is the probability that the d defective items will falsely pass and the second factor is the probability that the n_i-d good containers will not falsely fail. Thus, the overall probability that all n_i containers will pass on the i^{th} visit is obtained by summing the product of $P_i(d)$ and $Q_i(d)$ over all possible values of d:

$$R_i = \sum_{d=0}^{n_i} P_i(d)\,Q_i(d).$$

The probability of finding no defects through the inspectors' first j-1 visits is

$$S_{j-1} = R_1 \ x\ R_2\ x \dots x\ R_{j-1} = \prod_{i=1}^{j-1} R_i .$$

The probability of finding the first defect during the j^{th} visit equals S_{j-1} times the probability of discovering a defect on the j^{th} visit (where $S_0 = 1$):

$$T_j = S_{j-1}\,(1-R_j).$$

Therefore, the probability of finding a defect during the first j visits is

$$U_j = \sum_{i=1}^{j} T_i = 1 - S_j .$$

In this derivation, it is tacitly assumed that the n_i containers selected for measurement during a sampling visit are chosen randomly from the entire population present in the facility at that time. This is a good approach for discovering defective items that are loaded early. However, a more flexible approach is to partition the sample into two components: containers drawn from the *old* subpopulation (that is, from the population of containers that were present at the time of the last sampling visit), and containers drawn from the *new* subpopulation (composed of all containers loaded since the last sampling visit). Thus, inspectors will select n_{oi} *old* containers and n_{ni} *new* containers during the i^{th} visit, with the constraint that $n_{oi} + n_{ni} = n_i$. This modification complicates the previous analysis only slightly. The probability of the inspectors drawing d defects during their i^{th} visit is now broken into two probabilities, one for each of the two (old and new) subpopulations:

$$P_{oi}(d) = H(d,\ n_{oi},\ D_{i-1},\ N_{i-1}) \quad \text{and} \quad P_{ni}(d) = H(d,\ n_{ni},\ \Delta D_i,\ \Delta N_i),$$

where $\Delta N_i = N_i - N_{i-1}$ and $\Delta D_i = D_i - D_{i-1}$. Similarly, the probability that the instrumentation will pass all containers selected during that visit is expressed separately for the two subpopulations:

$$Q_{oi}(d) = f_p^{\,d}\,(1-f_f)^{n_{oi}-d} \quad \text{and} \quad Q_{ni}(d) = f_p^{\,d}\,(1-f_f)^{n_{ni}-d}.$$

The probability R_i that all n_i containers will pass during the i^{th} visit is now the product of two summations:

$$R_i = R_{oi}\ x\ R_{ni} = \sum_{d=0}^{n_{oi}} P_{oi}(d)\,Q_{oi}(d)\ \ x\ \sum_{d=0}^{n_{ni}} P_{ni}(d)\,Q_{ni}(d).$$

The remainder of the analysis is unchanged. Extensions for sampling plans that allow for the discovery of a small number of defects are given in the Appendix.

Previous studies [Sanborn (1987), Jaech (1991), Lu (1997)] that considered measurement uncertainty each assumed that the measurement error had a normal distribution with mean zero and standard deviation σ_{Meas}, and ignored any systematic error components. This allowed the use of equations that included σ_{Meas} but assumed that each measurement result was independent. So, for example, a false fail or false pass result on item i would not impact the probability of a false fail or false pass result on item j. Here we also ignore systematic error and assume that all measurements are independent, but we avoid direct use of σ_{Meas}. However, σ_{Meas} is indirectly used because it impacts f_p and f_f without involving a distributional assumption such as whether the measurement errors are normally distributed. A recent paper [Lu and Kennett (2005)] illustrates one way to accommodate the effect of both random and systematic errors in zero-defect sampling from a fixed population with up to three measurement methods. The approach ignores the false-fail issue (implicitly sets $f_f = 0$) and assumes that an assay method will detect zero defects among n_i containers having d defects with probability f_p^d if the measurements are independent and with probability f_p^n if the measurements each have the same systematic error. The quantities f_p^n and f_p should differ by a term that depends on the magnitude of the assumed systematic error, although this issue is not discussed in Lu and Kennett. Fortunately, this illustrates that the effect of both random and systematic errors can be accommodated using minor modifications to the equations we present.

Applications

The objective of sampling is to attain a confidence C that there are fewer than some number D_t defective containers in a fully loaded population of N_t containers, or equivalently that the fraction of defective containers in the population is less than D_t/N_t. The algorithm presented above can be used as an analysis tool in the assessment of potential sampling strategies when planning a sampling campaign to achieve this objective. To apply this algorithm, one first estimates the cumulative population size N_i based on assumptions regarding the backlog of containers in the inventory at the time sampling begins (N_1), the container loading rate (ΔN_i), and the number of containers in the fully loaded inventory (N_t). The probabilities of incurring decision errors, f_f and f_p, are estimated based on expectations regarding instrument capabilities, measurement procedures, and variability of container properties. The number n_i of containers sampled per visit will generally be fixed by an agreement between the inspecting and inspected parties. These n_i containers may be broken out as n_{oi} containers drawn from the old subpopulation and n_{ni} from the new subpopulation, at the discretion of the inspecting party. The probabilities associated with detection of defects are dependent upon the sampling numbers per visit, n_i, as well as on the defect loading profile per visit, D_i. The defect loading profile is constrained only by the requirement that the total number of defects at the end of loading is D_t. In principle, one should determine the number of sampling visits necessary to achieve a desired confidence C for all possible sequences of D_i (i.e., ways defects can be introduced into the inventory) and take the maximum of these as the required number of visits (see, for example, the discussion of "nuisance parameters" in Wendell [1996]). However, it has been found to be generally sufficient to examine only a few bounding cases of D_i (e.g., uniform, early, and late loading of defects) to make this determination.

Specific applications to zero-defect, two-stage, and three-stage sampling protocols are now described. Some of the terms and variables used here are defined in the Appendix.

Zero-Defect Sampling

In zero-defect sampling, the only *passing* sample is one in which no defects are found. Let I be the number of sampling visits required to achieve confidence C that fewer than D_t containers (or less than a fraction D_t/N_t of containers) in the fully loaded inventory are defective. The value of I for zero-defect sampling can be derived by first determining values of M in the inequality equation

$$U_{M-1} < C < U_M$$

for each of various bounding defect loading scenarios represented by D_i (e.g., all defects loaded early, all loaded late, or randomly distributed), and then equating I to the maximum of M, subject to the condition that I be large enough that the sampling visits extend through the end of the loading period so that the late-loaded containers can be adequately sampled. The defect scenario $\{D_i\}_{wc}$ that produces the largest value of M is identified as the most stressing or "worst case" scenario.

If the zero defect sampling strategy is adopted and no defects are found through I visits, then confidence C is achieved that the fraction of defects in the inventory is no greater than D_t/N_t. If one defect is found during the I visits, the reduced confidence in this condition is given by U_I and U_I; if two defects are found during this period, confidence is further reduced to U_I. Explicit formulas for these quantities are given in the Appendix.

Two-Stage Sampling

Two-stage sampling allows for a successful outcome even if one defect is discovered during the campaign. Implicitly, this means that there is an indifference region for the true population percent defective. By this we mean that we hold the sampling plan accountable (with confidence C) to fail populations having $D_t/N_t > 1\%$ (for example) and to pass populations having fewer than $\varepsilon\%$ defective, where ε is a small value such as 0.05. However, we are indifferent regarding the sampling plan's conclusion if the true percent defective is between 0.05 percent and 1 percent in this example.

Paths to a successful outcome for two-stage sampling and their related probabilities are indicated in the following table, where S'_i denotes the probability of detecting exactly one defect through the i^{th} visit. The first stage must extend at least through the end of the loading period. The dash in the table signifies that success is declared without going to that stage. This is equivalent to saying that any outcome is allowed for the "—" stage (that is, a probability of 1 is associated with it).

First stage (i visits)	Second stage (j-i visits)	Probability
0 defects	——	S_i
1 defect	0 defects	$S'_i(R_{i+1}R_{i+2}...R_j)$

The probability of success (sum of probabilities in the table above) is given by:

$$X'_{ij} = S_i + S'_i R_{i+1} R_{i+2} \ldots R_j = S_i + S'_i \left(\frac{S_j}{S_i}\right)$$

The confidence of detection is:

$$C'_{ij} = 1 - S_i - S'_i \left(\frac{S_j}{S_i}\right)$$

Values of $i = I$ and $j = J$ that provide confidence C that the defect rate is no greater than D_t / N_t are determined by applying the algorithm to the defect loading scenario $\{D_i\}_{wc}$ and requiring that. The parameter set (I,J) is not unique.

Three-Stage Sampling

Three-stage sampling allows for a successful outcome if up to two defects are discovered during the campaign. Paths to a successful outcome for three-stage sampling and their related probabilities are shown in the following table, where S''_i denotes the probability of detecting exactly two defects through the i^{th} visit. Again, the first stage must extend at least through the end of the loading period. The dashes in the table signify that success is declared without going to that stage.

Numerical Example

The algorithm described in this paper has been implemented by the authors in Microsoft Excel. As a sample application, consider the following scenario:

- Initial inventory N_I = 3000 containers
- Loading rate ΔN_i = 1000 containers for all i (loaded between visits)
- Fully loaded population N_t = 10,000 containers
- Sample size per visit n_i = *20* containers for all i (subscript suppressed in following text)
- Probability of false fail f_f = 0.0001
- Probability of false pass f_p = 0.05
- Objective: Achieve confidence C = 0.95 that $D_t / N_t \geq 0.01$ (or $D_t \geq 100$)

The total number of sampling visits required to accomplish the objective is of primary interest when developing a sampling plan. The number of visits is strongly influenced by how the inspecting party chooses to partition n into n_{ni} and n_{oi}. (For simplicity in this example, n_{ni} and n_{oi} are taken as constants for all i, and this subscript is suppressed in the following text.) The impact of this decision in the present scenario is illustrated in Figure 1 for a zero-defect sampling approach. In the figure the required number of sampling visits is plotted as a function on n_n (with $n_o = n -$

First stage (i visits)	Second stage (j-i visits)	Third stage (k-j visits)	Probability
0 defects	———	———	S_i
1 defect	0 defects	———	$S'_i(R_{i+1}R_{i+2} \ldots R_j)$
1 defect	1 defect	0 defects	$S'_i((R'_{i+1}R_{i+2} \ldots R_j + R_{i+1}R'_{i+2} \ldots R_j + \ldots + R_{i+1}R_{i+2} \ldots R'_j) \bullet R_{j+1}R_{j+2} \ldots R_k)$
2 defects	0 defects	0 defects	$S''_i(R_{i+1}R_{i+2} \ldots R_k)$

The probability of success (sum of probabilities in above table, after some mathematical manipulation) for specific *i, j,* and *k,* where $j>i$ and $k>j$, is given by:

$$X''_{ijk} = S_i + S'_i \left(\frac{S_j}{S_i}\right) + \frac{S'_i}{S_i}\left(S'_j - S'_i \cdot \frac{S_j}{S_i}\right)\left(\frac{S_k}{S_j}\right) + S''_i \frac{S_k}{S_i}$$

The confidence of detection is:

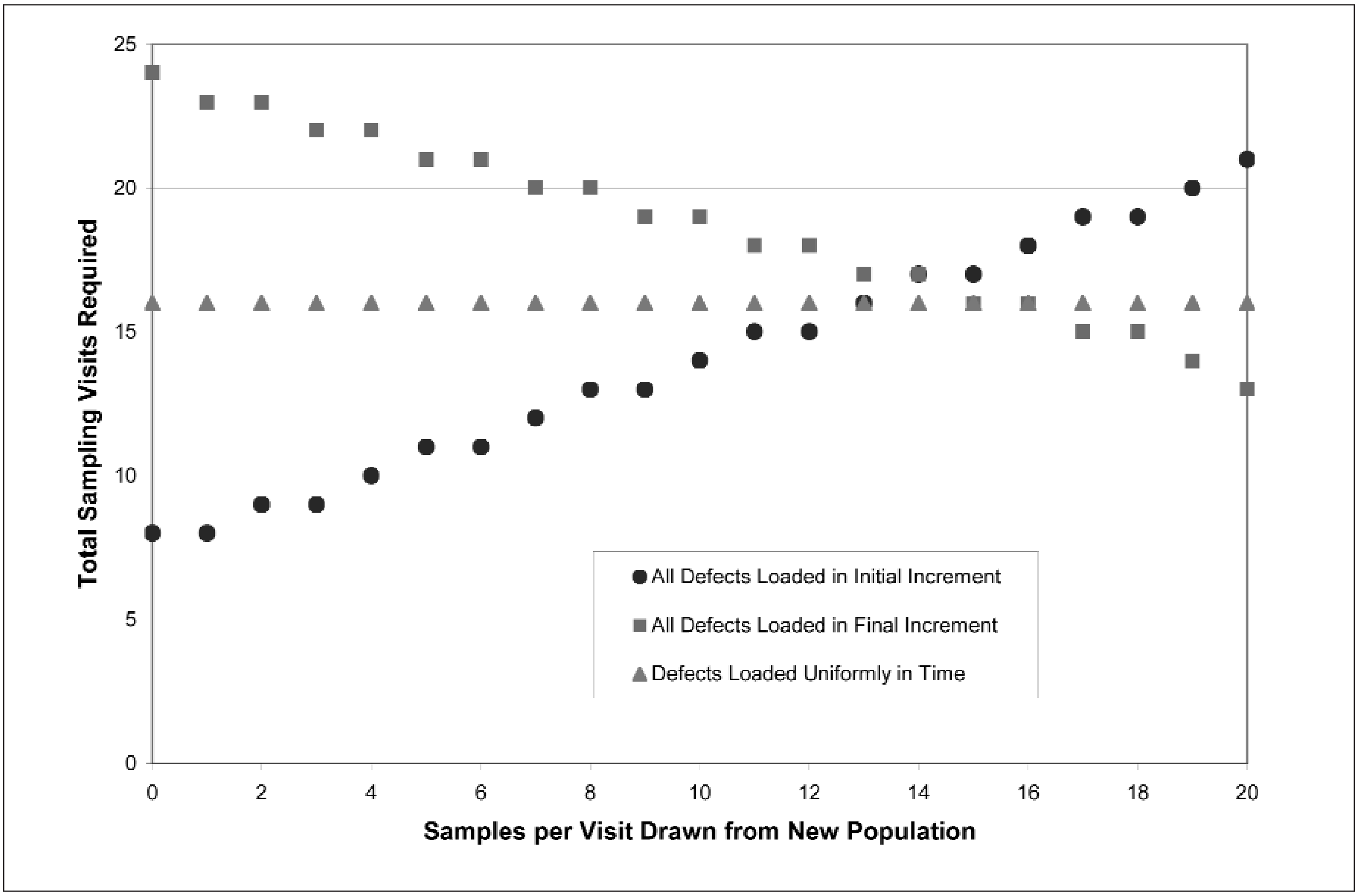
$$C''_{ijk} = 1 - \left\{ S_i + S'_i \left(\frac{S_j}{S_i}\right) + \frac{S'_i}{S_i}\left(S'_j - S'_i \cdot \frac{S_j}{S_i}\right)\left(\frac{S_k}{S_j}\right) + S''_i \frac{S_k}{S_i} \right\}$$

Values of $i = I$, $j = J$, and $k = K$ that provide confidence C that the defect rate is no greater than D_t / N_t are determined by applying the algorithm to the defect loading scenario $\{D_i\}_{wc}$ and requiring that $C''_{ij} = C$. The parameter set (I,J,K) is also not unique.

n_n) for three bounding cases of defect loading: 1) all defects included in the first increment of facility loading, 2) all defects included in the last increment of facility loading, and 3) the defects loaded uniformly over time. As expected, preferential sampling from the old subpopulation (small values of n_n) is more effective for detecting defects introduced into the inventory early in the loading process, while sampling biased toward the new subpopulation is better at detecting late-loaded defects. Because the inspecting party cannot predict when defects will be loaded, it is judicious to select a value of n_n that performs well for all defect-loading sequences. In this example, a value of n_n in the range thirteen-fifteen allows the objective to be accomplished with seventeen sampling visits of zero-defect sampling.

The inspecting party may also explore the option of multi-stage sampling with this algorithm. For two-stage sampling, the objective can be accomplished with I sampling visits if no defects are found and J visits if one is found. Possible values of (I,J) for this scenario, with n_n = 13, include (21,27), (20,28) and (19,29).

Figure 1. Results from sample application



Similarly, with three-stage sampling the objective is achieved in I visits if no defects are found, J visits with one defect, and K visits with two defects. Possible values of (I,J,K) for this example include (26,31,36), (23,28,38), and (20,30,40).

Summary

The algorithm developed in this paper is based on standard statistical techniques that have been extended to address the complications of 1) a growing population and 2) measurement uncertainty. Applications of the algorithm to the planning of zero-defect, two-stage, and three-stage sampling strategies are discussed. Although presented in the context of sampling fissile material containers, this methodology could be used for other applications as well.

Appendix: Extended Statistical Evaluation

In this Appendix, the algorithm developed above is extended to account for the discovery of a small number of defects.

Probability that one container will fail in a sample containing d defects drawn from the old subpopulation during the i^{th} visit:

$$Q'_{oi}(d) = d\,(1-f_p)\,f_p^{\,d-1}\,(1-f_f)^{n_{oi}-d} + (n_{oi}-d)\,f_f f_p^{\,d}\,(1-f_f)^{n_{oi}-d-1}$$

Probability that one defect will be found among the containers drawn from the old subpopulation during the i^{th} visit:

$$R'_{oi} = \sum_{d=0}^{n_{oi}} P_{oi}(d)\,Q'_{oi}(d)$$

Analogous equations for the new subpopulation are obtained by substituting n_{ni} for n_{oi}.

Probability that one defect will be found during the i^{th} visit:

$$R'_i = R'_{oi}\,R_{ni} + R_{oi}\,R'_{ni}$$

Probability that exactly one defect will be found through the i^{th} visit:

$$S'_i = R'_1 R_2 \ldots R_i + R_1 R'_2 \ldots R_i + \ldots = S_i \sum_{j=1}^{i} \frac{R'_j}{R_j}$$

Probability that a second defect will be found during the i^{th} visit:

$$T'_i = S'_{i-1}(1-R_i) + S_{i-1}(1-R_i-R'_i)$$

Probability that a second defect will be found through the i^{th} visit:

$$U'_i = \sum_{j=1}^{i} T'_j = 1 - S_i - S'_i$$

Probability that two containers will fail in a sample containing d defects drawn from the old subpopulation during the i^{th} visit:

$$Q''_{oi}(d) = C_1 (1-f_p)^2 f_p^{d-2} (1-f_f)^{n_{oi}-d} + C_2 (1-f_p) f_p^{d-1}$$

$$f_f (1-f_f)^{n_{oi}-d-1} + C_3 f_p^d f_f^2 (1-f_f)^{n_{oi}-d-2},$$

where

$$C_1 = \frac{d!}{2!(d-2)!} = ½\, d\,(d-1)$$

$$C_2 = d\,(n_{oi}-d)$$

$$C_3 = \frac{(n_{oi}-d)!}{2!(n_{oi}-d-2)!} = ½\,(n_{oi}-d)(n_{oi}-d-1)$$

Probability that two defects will be found among containers drawn from the old subpopulation during the i^{th} visit:

$$R''_{oi} = \sum_{d=0}^{n_{oi}} P_{oi}(d)\, Q''_{oi}(d)$$

Analogous equations for the new subpopulation are obtained by substituting n_{ni} for n_{oi}.

Probability that two defects will be found during the i^{th} visit:

$$R''_i = R''_{oi}\, R_{ni} + R_{oi}\, R''_{ni} + R'_{oi}\, R'_{ni}$$

Probability that exactly two defects will be found through the i^{th} visit:

$$\begin{aligned} S''_i &= R''_1R_2R_3R_4...R_i + R_1R''_2R_3R_4...R_i + ... \\ &+ R'_1R'_2R_3R_4...R_i + R'_1R_2R'_3R_4...R_i + ... \\ &+ R_1R'_2R'_3R_4...R_i + R_1R'_2R_3R'_4...R_i + ... \end{aligned}$$

$$= S_i \sum_{j=1}^{i} \left[\frac{R''_j}{R_j} + \frac{R'_j}{R_j} \sum_{k=j+1}^{i} \frac{R'_k}{R_k} \right]$$

Probability that a third defect will be found during the i^{th} visit:

$$T''_i = S''_{i-1}(1-R_i) + S'_{i-1}(1-R_i-R'_i) + S_{i-1}(1-R_i-R'_i-R''_i)$$

Probability that a third defect will be found through the i^{th} visit:

$$U''_i = \sum_{j=1}^{i} T''_j = 1 - S_i - S'_i - S''_i$$

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Acknowledgement

This work was performed for the Defense Threat Reduction Agency under IACRO 01-8006I (CTR).

Historical Role of the Tokai Reprocessing Plant in the Establishment of Safeguards Technologies

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Abstract

This paper describes the role of the Tokai Reprocessing Plant (TRP) in the development of safeguards technologies (SG) by Japan and the International Atomic Energy Agency (IAEA) and the application of the technologies to the first large-scale commercial nuclear fuel reprocessing plant in Rokkasho, Japan.

Negotiations between Japan and the United States led to TRP accepting: a complete application of the IAEA's SG technologies; development of the U-Pu mixed conversion process; and experimental work of IAEA for development of SG activities. Results under the Tokai Advanced Safeguards Technology Exercise (TASTEX), which was a research and development program agreed upon during the Japan-U.S. negotiations on reprocessing, were reflected in the International Fuel Cycle Evaluation, which was established by the change in U.S. nuclear energy policy. Most of the current SG technologies being applied by IAEA now were developed at this time. Both effectiveness and reliability of such technologies have been validated extensively through the 30 years of operation of TRP.

Introduction

In April of 1977, just before the Tokai Reprocessing Plant (TRP) started its hot operation, the United States suddenly changed its nuclear power policy based on nuclear nonproliferation due to an atomic bomb test by the government of India.[1] The new policy banned comprehensive nuclear fuel cycle activities, especially nuclear fuel reprocessing.

The government of Japan, which wanted independent non-fossil fuel energy resources, began negotiations with the United States on fuel reprocessing as a top priority. The government received strong support from Japanese society, including the mass media, by appealing on the basis of established policy for advancing peaceful uses of atomic energy as expressed in Article 8-Item C of the Japan-U.S. bilateral agreement on atomic energy. Negotiations led to TRP accepting: 1) the complete application of the International Atomic Energy Agency's (IAEA) safeguards technologies (SG); 2) the development and implementation of the U-Pu mixed conversion process as a proliferation resistant technology; and 3) the experimental work of IAEA for development of SG activities. Then, the Japanese government authorized TRP to start its hot operation on September 22, 1977, on the basis of being a non-nuclear weapon state.

Tokai Advanced Safeguards Technology Exercise (TASTEX),[1] which was a research and development program agreed upon during the Japan-U.S. negotiations on reprocessing, was initiated by Japan, France, the United States, and the IAEA. Some programs under TASTEX were transferred to the Japan Support Program for IAEA's Safeguards (JASPAS) and to a cooperative research program between Japan and the United States. Results under TASTEX were reflected in activities of the International Fuel Cycle Evaluation, which was established by the change of U.S. nuclear energy policy. Most of the current SG technologies being applied by the IAEA now were developed at this time.

This paper describes the role of TRP in the development of SG technologies by Japan and IAEA and application of the technologies to the large-scale commercial Rokkasho Reprocessing Plant (RRP) in northern Japan. Some experiences in TRP where the total amount of reprocessed uranium from spent fuel (SF) was about 1,123 tons by the end of October 2006 are mentioned and challenging items for improvement of inspection effectiveness and efficiency are also considered.

Background and Nuclear Material Accountancy

Background

Article 5 of the SG agreement between Japan and the IAEA defined the SG as being implemented in a manner designed:

- To avoid hampering the economic and technological development of Japan or international cooperation in the field of peaceful nuclear activities, including international exchange of nuclear material;
- To avoid undue interference in Japan's peaceful nuclear activities, and in particular in the operation of facilities; and
- To be consistent with prudent management practices required for the economic and safe conduct of nuclear activities.

Japan and the IAEA had bilaterally investigated the SG procedures based on the above. However, the SG agreement between Japan and the IAEA had not yet come into force when the hot operation started in 1977. The Design Information Questionnaire (DIQ) was provided to the IAEA after the SG agreement took effect. There were some difficulties in these trial applications of SG to TRP because 1) the completed facility had no space to allow modifications and 2) commercial confidentiality was required from Saint Gobain Ingéniere Nucléaire (SGN) and the government of France, which had provided the reprocessing technology to TRP. Despite these difficulties, Japan and the IAEA reached an agreement, and Design Information Verification (DIV) was carried out by the IAEA. In addition, the Facility Attachment (FA) to the SG agreement was released based on the results of DIV.

The effective SG framework was established as follows. When SF is received at the TRP, inspection activities are implemented for each task of: 1) confirming lid opening of a transportation cask; 2) confirming identification number and item counting of SF assemblies; 3) using the Cerenkov viewing device for SF; and 4) completely emptying the cask and closing its lid.

In addition, a physical inventory verification at the time of the Physical Inventory Taking (PIT), which is determined in the nuclear material control regulation, is done in specific areas and where processes are carried out: 1) SF storage pool; 2) shearing and dissolving process; 3) separation and purification process; 4) Pu product storage tanks in the separation and purification process; 5) low level liquid waste treatment process; 6) U storage facility; 7) Tokai Vitrification Facility (TVF); and 8) TRP analytical laboratory.

Inspections done during operation are: 1) confirmations of SF identification number before/during shearing (this is called item control); and 2) confirmations of solution level, sampling, and analytical treatment of the sample during input accounting. Inspections during Pu output accounting include confirmations of solution level, sampling, Pu concentration and analytical treatment (this is called bulk control). The IAEA identifies illegal proliferation as more than one significant quantity (=8 kg for Pu), and is especially strict with regard to Pu. The 8 kg quantity is determined as the approximate amount needed to manufacture a nuclear explosive device. In addition, independent verification of TRP's declaration is carried out by analysis of Pu of the IAEA's samples in its laboratory in Vienna.

Inspections are carried out as a combination of nuclear material accounting for input and output tanks and the containment and surveillance (C/S) systems described later in this paper.

Nuclear Material Accounting

TRP can accurately identify locations of nuclear material in the reprocessing to satisfy safety requirements by installing instruments to measure solution level and density and also by installing sampling equipment in most of the process towers and tanks. In addition, high precision analytical equipment for samples is available when greater sensitivity is needed. These features are common to mid-sized and batch-wised plants like TRP; they simplify measurement and confirmation of nuclear material. Therefore, some the IAEA requirements were incorporated without large modifications such as construction of inside cells.

The material balance area of TRP must accord with the design division. Figure 1 shows material balance of areas 1 and 3, which are basically batch follow-up areas, and material balance area 2, which is basically a continuous treatment area. In addition, input and output accounts are defined to determine balance of each area.

For example, after a SF assembly is sheared, the pellets are dissolved and amounts of U and Pu are measured batch-wise in the input accountability tank. A shipper-receiver difference (SRD) is determined. This is the difference of nuclear material between the shipper's declaration made at the reactor site estimated by the irradiation history of SF and the analytical input account.

The dissolved solution is transferred to the separation and purification process continuously. The amount of Pu in the solution after a Pu concentration process is measured for the batch at the Pu output accountability tank. The U solution is converted to trioxide U powder product in the denitration tower, and the amount of U is measured by analysis of each powder pot.

There are certain key measurement points (KMPs). KMPs that are determined to measure flow amount during operation are called flow KMPs (FKMPs). KMPs that are used during PIT after stopping of operation are called inventory KMPs (IKMPs). Though the amount of nuclear material is measured continuously during TRP routine operation, PIT is carried out to confirm the long-term material balance after operation is stopped for a cleaning process; for PIT, nuclear materials are collected in a few tanks to decrease measurement errors. At first, PIT was carried out biannually; however, the frequency was changed to annually in 1994 based on the results of the Interim Inventory Verification (IIV) started in 1990.

IIV which verifies Pu in the chemical process and in the Pu storage tanks monthly was introduced after negotiation with the IAEA in order to manage the Inventory Difference (ID)* appropriately and to improve detection ability of diversion and timeliness. With the introduction of IIV, the IAEA's inspection efforts at TRP increased. Though TRP is a medium-sized facility with Pu annual throughput of 800 kg, the IAEA has made the most inspection efforts at TRP among facilities worldwide.

Historical Development of SG Technologies

Development of SG technologies was carried out during 1978 to 1981 as TASTEX, which was agreed during Japan and U.S. nego-

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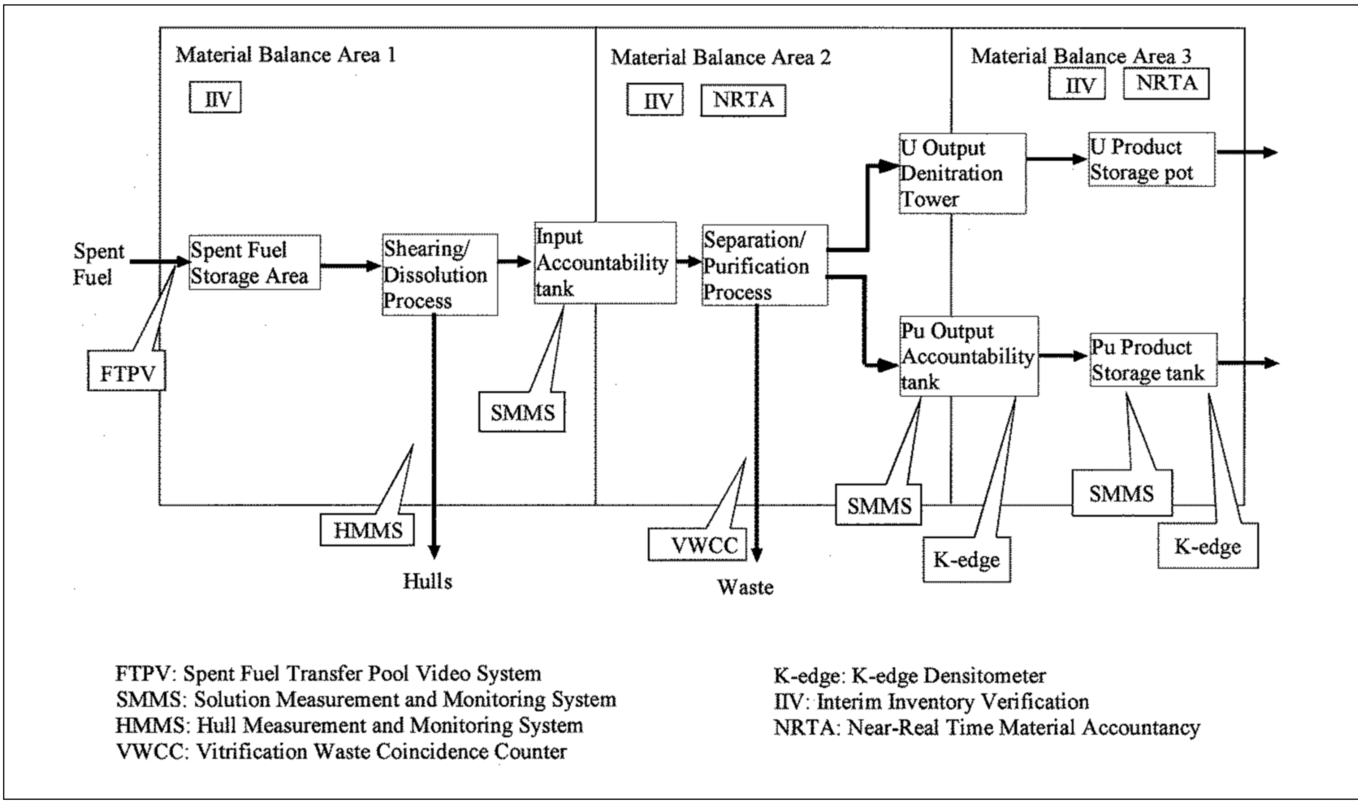
* *ID=BI+R-S-W-EI*

Here, BI is beginning physical inventory, R is receipt, S is shipment, W is retained waste and measured discard, and EI is ending physical inventory.

Figure 1. Material balance areas in Tokai Reprocessing Plant



tiations on reprocessing. There were thirteen research and development themes that covered analytical and surveillance technologies for strategic points of all processes and included the SF receipt area, shearing and dissolution process, the separation and purification process and the Pu storage process. Some themes in the TASTEX were transferred to JASPAS, which started in November 1981.

An agreement between Japan Atomic Energy Agency (JAEA) and the U.S. Department of Energy (DOE) took effect in January 1986 that aimed at more effective and efficient implementation of SG and better cooperation in technology developments with Los Alamos and Sandia National Laboratories.

TRP's role in development of some of the technologies, which are applied to current inspections or are being tested in the field, is described below; challenges for technology transfer are also included.[2]

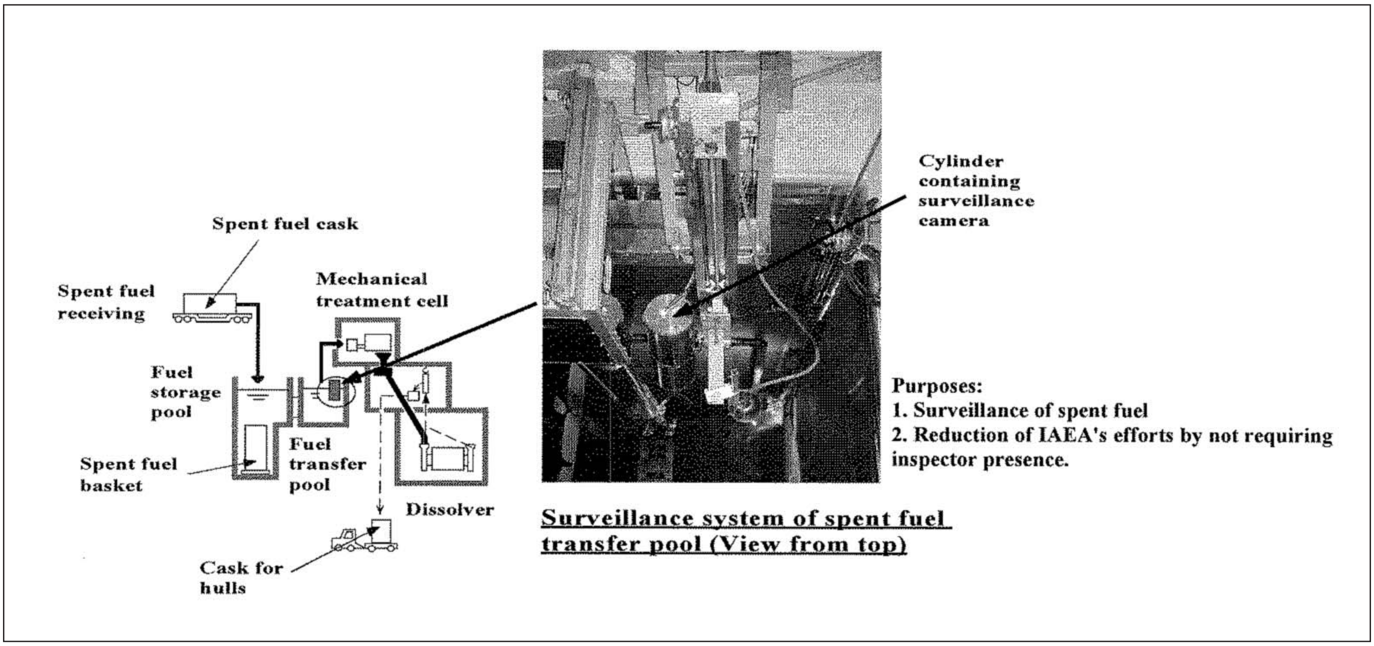
Surveillance System of SF Transfer Pool

As shown in Figure 2, the SF storage basket is transferred from the SF storage pool to the SF transfer pool using an underwater cart and then the SF assembly is lifted from the basket and transferred to the mechanical treatment cell where the assembly is set in the shearing machine. In the SF receiving area, item verification as an assembly unit was made a requirement for the SG. The point where the SF is transferred to the shearing machine was selected as the flow strategic point and a continuous surveillance of SF transfer was required as a detailed item. The development of inspection equipment related to the shearing process surveillance started as TASTEX task A. TASTEX was completed in June 1981 and task A was transferred to JASPAS task JD-2 when JASPAS was established. A surveillance system in the spent fuel transfer pool was developed to confirm the SF assembly and survey movement of an individual assembly during transfer to the shearing process by using a closed circuit video camera (CCTV). The CCTV was installed in housing on the upper side of the SF transfer pool. Good functioning of the surveillance system has been confirmed by the IAEA.

Since SF assembly transfer to the shearing process is a 24-hour operation, it is not effective to require continuous surveillance by an IAEA inspector. The development of an unattended continuous surveillance system for the SF assembly transfer having tamper resistance functions was initiated as JASPAS task JD-8 in March 1983. The completed system consists of 1) the CCTV which monitors the entrance of the channel between the SF transfer pool and the mechanical treatment cell and 2) the console box containing a video-tape recorder (VTR) for the CCTV with a clock and an anomaly detector with three tamper resistance functions. This surveillance system has gone through several improvements since the beginning of the JD-8 task.[3]

Demonstrations to confirm functions of the CCTV, VTR

Figure 2. Spent Fuel Transfer System



and anomaly detector were carried out in September 1986 and February 1988 by the IAEA at TRP. The operating conditions and functions of unattended continuous surveillance were evaluated as providing sufficient SG as inspection equipment.

After the demonstrations were successfully completed, a field test of the system that aimed to confirm no lack of surveillance for a long time and smooth operation of the tamper resistant functions was carried out as a next step from March to May 1988 at TRP. It took about ten years from the beginning of development of this system to its actual plant use. TRP experiences helped in developing the system that met many requirements of the IAEA, including unattended continuous surveillance, tamper resistance, and ease of maintenance. TRP experiences also helped in the IAEA inspector training. Certainly the big advantage of this system has been a reduction in inspection efforts by eliminating the need for an IAEA inspector to be in attendance when the SF assemblies are transferred.

Hull Measurement and Monitoring System (HMMS)

TRP experiences showed that identification of the amount of nuclear materials that remained in a cladding tube after dissolution of a sheared SF assembly, which are called hulls, was needed.

An original design for a nondestructive assay system, which moves up and down spirally around a drum containing hulls, was considered in TASTEX task C. A passive gamma ray detection method was developed by using ^{144}Pr-Ce radioactive equilibrium of SF within a six-year cooling time. However, it was found to be difficult to use, because there were SF assemblies with much longer cooling times in TRP and also the detection limit was much affected by the existence of fission products and nuclear materials that contaminated the dissolver loading cell.

After that, as the cooperative research program AS26 with DOE, a more precise method to measure nuclear materials in the drum for hulls was developed by measuring neutrons emitted from the hulls with a neutron coincidence counter which is usually more accurate than total neutron counters because it is not sensitive to single neutrons from (·,n) reactions or room background.[4] This development ensures that nuclear materials can be measured when the drum for hulls is loaded in a cask. The neutron detector was installed on an adaptor that had been already placed under the cask; this adaptor is normally used for transport cask setting.

The HMMS in Figure 3 was developed as an unattended monitoring system and it is used in combination with a signal transfer system equipped with the IAEA's tamper resistant functionality. It improves inspection effectiveness by obtaining continuous data and reduces inspection efforts by eliminating the need for an IAEA inspector to be in attendance when transferring the hulls.

Solution Measurement and Monitoring System (SMMS)

This system was originally developed and installed as a surveillance system in the Pu operation area and was task I of TASTEX.

The system uses a pneumatic signal from a level recorder and a density recorder installed on each Pu storage tank. The signal is split from a differential pressure transmitter and measured by a crystal vibration pressure sensor through a scanni-valve (precision ±0.01% to full scale). Although the design concept of this system might have been good, it was not practical to handle huge amounts of data like open/close actions of process valves, and SGN, which supplied the reprocessing technology, complained because data related to operation know-how could have been accessed.

The development of an improved system to resolve the above issues was the focus in JASPAS task JA-3 during 1982 to 1989. Although this improved system accessed restricted data such as level, density and temperature of Pu storage tanks, it was not used as an inspection tool because there was no authentication function for the system and no measurement data for inspection use.

Development of a SMMS equipped with an authentication function as an independent system for the IAEA was newly started not only as a task in TRP's SG improvement plan for administrative matters for inspection use but also as JASPAS task JA-6 for technical and budget matters. As shown in Figure 4, the SMMS covers the input accountability tank, the Pu output accountability tank, and the seven Pu storage tanks. Basic design work began in 1995 and installation of the system and its acceptance test by the IAEA were finished in 1999. Actual inspection use was successfully realized through improvements during continuous operation and field tests. The SMMS consists of a computer which can record and indicate data and high precision pressure measurement and control equipment. Level and density of each tank are measured from pressure data of a pair of dip tubes installed in the tank. For example, a pressure signal of a Pu storage tank is transmitted in a fixed interval order via a scanni-valve to a common high precision manometer. The purpose of the scanni-valve is to reduce the number of manometers needed. A programmable logic controller (PLC) calculates the average and standard deviation of level or density from several measurement results. The calculated results of all tanks are transmitted by an optical fiber cable to a data collection computer (DCC) at 30 s intervals. The DCC is in an inspector's room outside the radiation control area; therefore, the inspectors can confirm the data without entering the radiation control area.

The SMMS enables the IAEA's independent measurements which is important for SG, because the SMMS maintains the initial authentication function, which is a tamper resistant function. All equipment of the SMMS is contained in cabinets equipped with an alarm and recorder. Their doors are sealed by Japanese and IAEA inspectors. All alarm and measurement data related to the SMMS are recorded in the DCCs. The hard disk has a duplicate system for any failure. The manometer has a test port which is used to input a standard pressure for calibration and to compare the pressure data with that of an IAEA standard manometer. The comparison measurement by the IAEA enables the authentication of the entire SMMS including transmission lines to the DCCs.[5]

It took about five months to install the SMMS, and Japanese and IAEA inspectors participated in some important installation activities including installations of conduits for connections to the manometer and optical fiber cables.

After the calibration and acceptance test, a continuous operation test was carried out. Trial use was started after some problems encountered during the continuous operation test had been solved. The SMMS development took about 20 years and its operation history has shown how difficult and important it is to survey Pu inventory continuously.

A similar remote system to the SMMS is installed in the RRP. The SMMS has enabled great improvement of timeliness of inspection. Since data of the SMMS are transmitted to the inspector's room, random verification at the time of material accounting has resulted in a reduction of overall inspection efforts.

Near Real-time Material Accountancy (NRTA) and IIV

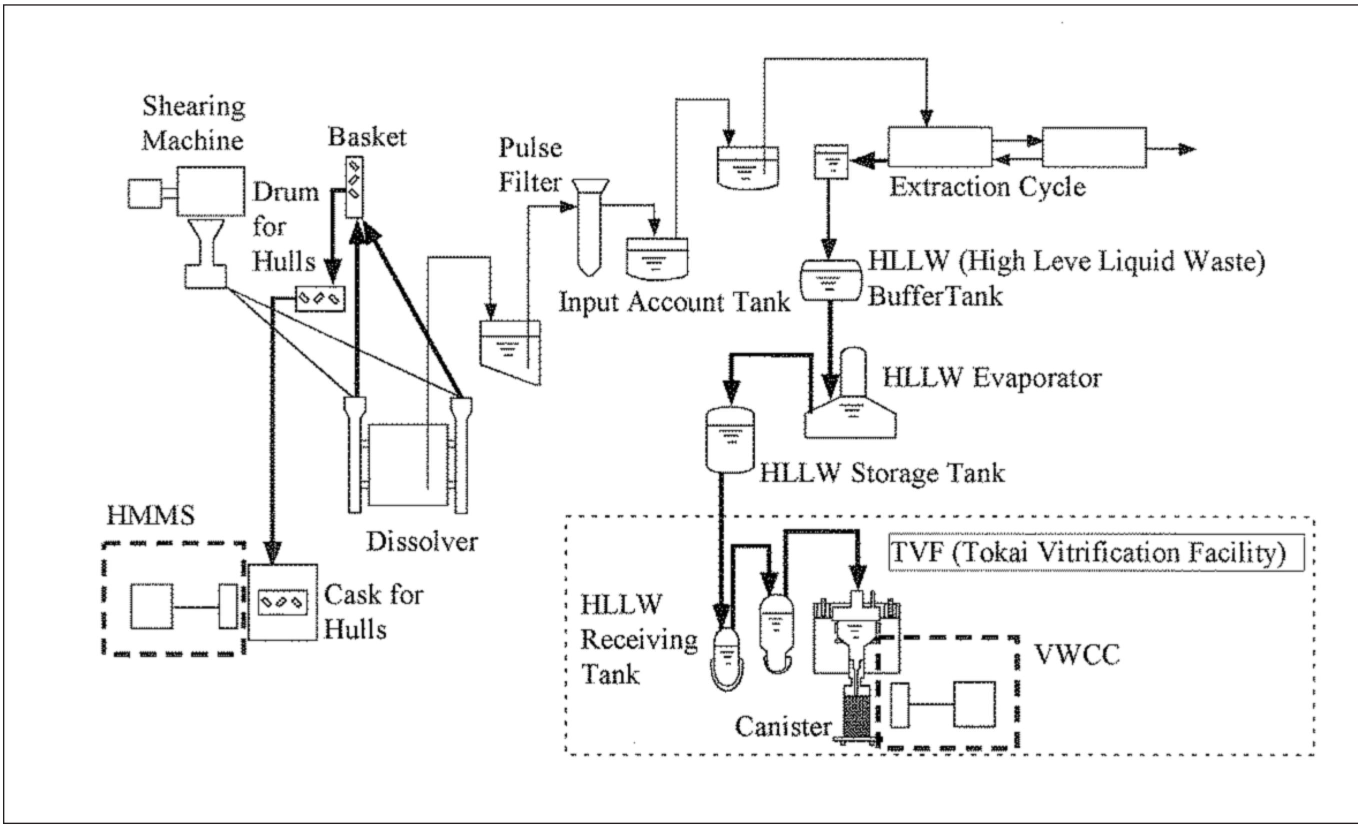
Material accountancy carried out at TRP aims to confirm that there is no abnormal loss of nuclear materials by determination of nuclear material balance while nuclear materials are being transferred and by a physical inventory during stopping and cleaning-out operations. NRTA is a method that complements the traditional material accountancy for timeliness and can detect significant anomalies in SG.

The NRTA of TRP started as TASTEX task F and then became JASPAS task JA-5 when data collection during field tests had just started. The field tests featured upgraded precision of measurement data and developments in the system concept which took into account waste materials such as hulls and vitrified waste.

The NRTA of TRP covers the separation and purification process. Necessary data are obtained by measurements of input, output and inventory. Since inventory in the Pu evaporator cannot be measured during operation, it is measured at the Pu output accountability tank when Pu in the concentrated solution is transferred to the tank. Non-measurable inventory in extractors is calculated by Pu concentrations of tanks related to NRTA in the process.

After several negotiations with the IAEA, the annual Physical Inventory Verification (PIV) was started with monthly IIVs; the IIV was introduced to improve timeliness and to satisfy the IAEA criterion of Pu amount less than one significant quantity and to ensure one to three weeks for detection. The IIV covers Pu evaporation and storage processes, which include 90 percent of the in-process inventory of Pu. The IIV complements the PIV by material balance using estimation of Pu amount of the related tanks in the separation and purification process at the cut-off time when Pu in the concentrated solution is transferred to the Pu output accountability tank. In addition, according to the IAEA's requirement, the formula for non-measurable inventory was calculated for each extraction cycle. Pu contents in the processes and equipment, such as pipes, adjustment tanks, oxidation tower, etc. are determined by their volumes and Pu concentrations. The Pu amount in extractors is calculated by an extraction calculation code and a primary approximation formula by least squares. The accuracy of the formula was improved using data collected during

Figure 3. Waste Monitoring HMMS (Hull Measurement Monitoring System) and VWCC (Virtified Waste Coincidence Counter)



operation.

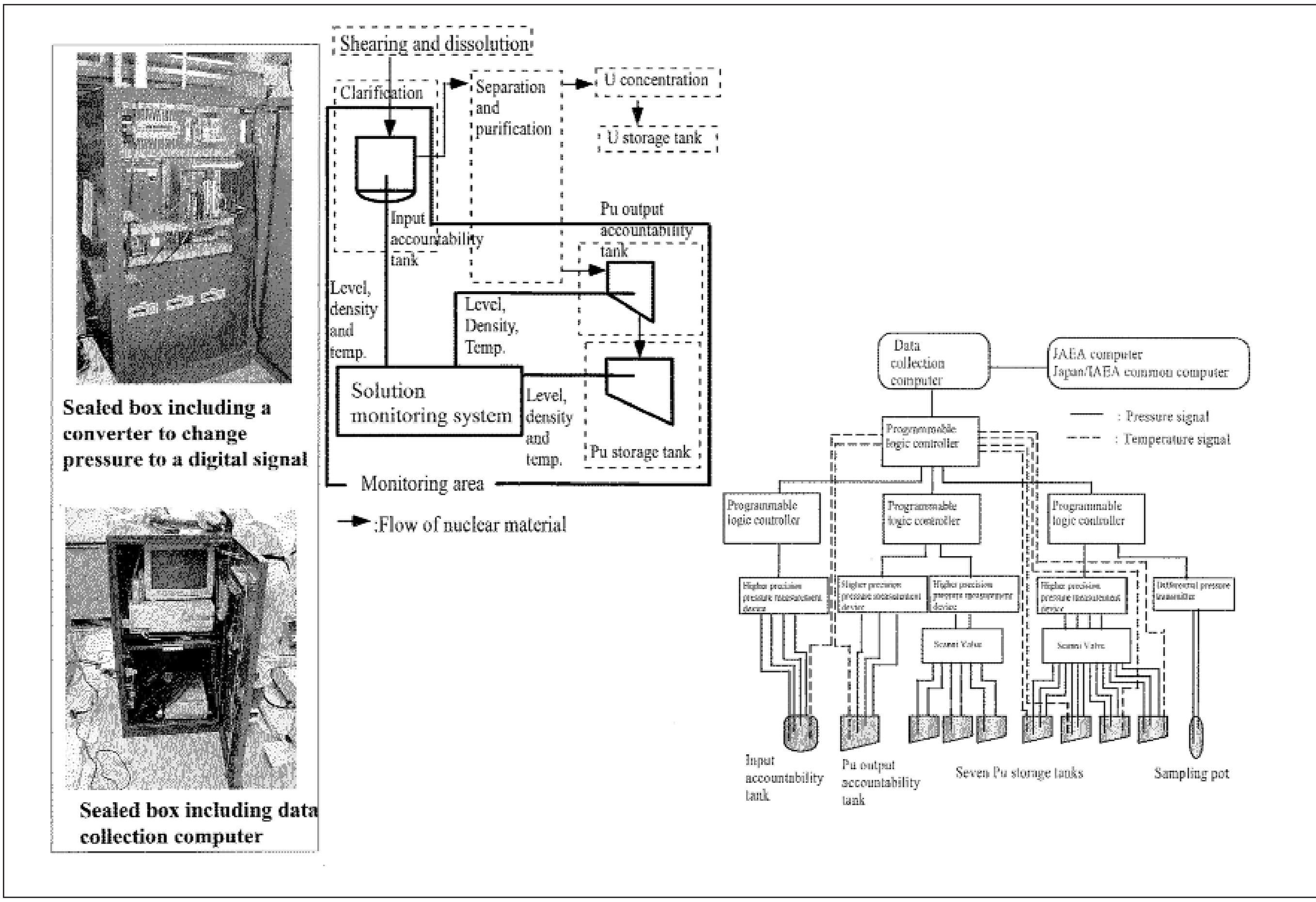
K-edge Densitometry for Plutonium Product Solution

Development and installation of the K-edge densitometer (KED) for measuring Pu concentration of the Pu solution was executed through TASTEX and JASPAS for on-site verification measurements as an inspection activity by inspectors. After successful implementation, a further updated KED[6] was installed in the TRP analytical laboratory in 1994 to improve performance, particularly regarding the stability of the X-ray source. The newer KED system was equipped with an X-ray generator that differs from the previous system with gamma-ray sources using radioactive isotopes such as ^{57}Co and ^{75}Se. To apply the improved KED system to SG measurements, one of the more difficult problems for authentication of the measurement system was control of the reference material for plutonium in the liquid state because of its evaporation and radiolysis properties. Thus TRP examined a solid-type plutonium reference material in a glass matrix that could be expected to retain stability for a long time. The experience of using the vitrified reference material led to confirmation of its effectiveness and long-term stability from numerous measurements in actual verification activities for plutonium nitrate products during reprocessing, PIV and IIV. As part of the authentication of KED and verification of the operator's measurement system, a sample is taken by an inspector and sent to the IAEA and NMCC (Nuclear Material and Control Center) for destructive assay on a 10% random basis. Destructive assay results obtained from three parties (IAEA/NMCC/JAEA) have been used for the calibration of KED by comparison with the same set of KED measurement results. Consequently, the KED has greatly contributed to SG analysis of detecting gross defects in plutonium amounts with a measurement uncertainty less than 0.5%, and played one of the most important roles in carrying out SG activities in a timely manner at TRP.[7]

Vitrified Waste Coincidence Counter (VWCC)

The high level liquid waste (HLLW) stored in waste storage tanks is categorized as retained waste, which for efficiency is not normally subjected to inspection. However, when HLLW is changed from solution to solid in the Tokai Vitrfication Facility (TVF), inventory is accounted for again. Negotiations started with the IAEA in 1988 concerning clearer criteria on exemption from SG and rationalization of inspection. The IAEA prepared a guideline that the vitrified waste from HLLW can be determined as an exemption from SG. In addition, the IAEA required that a non-destructive assay system should be used to measure fissile material contents of the vitrified waste. Therefore, as shown in Figure 3, the development of such a system called the VWCC was started in collaboration with Los Alamos National Laboratory based on

Figure 4. Solution Measurement and Monitoring System (SMMS)



the research and development cooperative program between JAEA and DOE. Since the VWCC detects spontaneous neutrons from ^{244}Cm, amounts of U and Pu are calculated indirectly from ^{244}Cm/Pu and ^{244}Cm/U ratios that are obtained as analytical results for HLLW.

This system consists of: 1) five He_3 neutron detectors installed near the in-cell measurement point of vitrified waste; 2) a shift register installed outside of the cell; 3) a digital camera that records the identification numbers on vitrified waste canisters to be measured; and 4) a computer that controls these devices. The system is designed so that the vitrified waste is measured in an unattended mode and the inspector can verify measurements by a regular collection of data stored in the computer. A check table where a smear sample of the vitrified waste is taken was selected as the measurement point, because a longer measurement time is possible and there are no other vitrified wastes kept near it. The detectors and control cabinet are sealed because they are inspection devices.[8]

Characteristics of the VWCC are that the TVF operation is not interrupted because vitrified waste is measured by a continuous process and the vitrified waste does not need to be transferred again.

This system has resulted in improved timeliness of inspection by collecting continuous data. In addition, eliminating the need for attendance by an inspector for the measurement of vitrified waste has resulted in a reduction of inspection efforts. Furthermore, exemption from the SG was established by determining the amount of nuclear material in the vitrified waste which has led to more efficient inspection.

Discussion

TRP was the first application of international surveillance by the IAEA to a reprocessing plant used solely in the nuclear fuel cycle of a non-nuclear weapon state. The C/S systems have been influenced by changes in the U.S. political situation and international conditions. Next, seven items are discussed as the TRP contributions to the SG technology for reprocessing plants for peaceful uses of nuclear energy.

SG Technologies at TRP

Construction of TRP had already been finished when statements of U.S. President Gerald Ford in October 1976 and President Jimmy Carter in April 1977 encouraged intensifying SG technologies.

Therefore, it was not easy to satisfy IAEA requirements, because there were limits in modifications of hardware. The selection of inspection points based on the FA was restricted, because French design of TRP had to be protected. In addition, there were some confrontations during negotiations on the framework of the SG technology between Japan and the IAEA concerning interpretation of the principle "not interfering in TRP operation." Under these circumstances, both parties sought a realistic mutual agreement point.

Technology developments at TRP to satisfy IAEA requirements were as follows: 1) improvement of measurement precision; 2) establishment of the independent verification system, i.e. authentication; 3) adoption of continuous surveillance technology for improved inspection effectiveness; and 4) implementation of an unattended mode for improved inspection efficiency.

These activities contributed to promoting international trust in the IAEA's nuclear nonproliferation policy and the IAEA affirmed the introduction of Integrated SG in Japan.

Concept of Nuclear Material Accountancy at TRP

Since there are instruments to measure solution level and density, sampling equipment in most of the process towers and tanks, and equipment for high precision analysis of samples in the TRP, it is a complete facility that is likely to deal with all of the IAEA's requirements with comparative easiness.

In addition, a foundation to solve future problems in management of nuclear materials at TRP has been established by applying the complete batch follow-up system. Consideration has been given to using the equipment capacity of the TRP as a basis to determine input amount and estimate nuclear diversion, define calculations of shipper-receiver difference, and clarify measurement of one significant quantity (=8 kg Pu) and the definition of inventory difference.

IAEA's Inspections

The effort spent by TRP for coordination of inspection of FKMP is more than that of IKMP because inspections are carried out continuously during the TRP operation. While most of the effort for the FKMP regards input and Pu product output accounts, that of IKMP is for physical inventory.

TRP's Cooperation with IAEA Inspectors

It has already been mentioned that the IAEA's 24-hour inspections schedule during TRP operations could only be maintained by sincere cooperation by all participants. TRP prepared a coordinating system for IAEA inspections and cooperated with the inspectors fully, which is undoubtedly one reason why TRP could be evaluated highly for keeping transparency in nuclear material control.

Value of Technology Development at TRP

The Japanese Government and JAEA invested huge funds and much manpower in the TASTEX and JASPAS plans and then in validation of applicability of results of the plans. The results obtained have contributed not only to reduce inspection efforts but also to introduce the possibility that a remote monitoring system would be able to play an important role in advancing the IAEA's nuclear nonproliferation policy.

In addition, the technologies to identify nuclear materials by hull monitoring and the VWCC whose technologies were established by a Japan-U.S. cooperation program have contributed important results from the viewpoint of enhancement of transparency to nuclear materials in wastes.

TRP's Contribution to Establish the SG Technologies of RRP

Applications of SG technologies used at TRP will make a direct contribution to operations at RRP. In addition, the complete utilization of DIQ/DIV in a large scale reprocessing plant SG program for RRP will be based on experiences at TRP.[9]

TRP concluded a technical cooperation agreement with RRP and performed a variety of technology transfers through this agreement. Specifically, technical guidance by dispatch of engineers was done, education and training of RRP engineers was done, and opportunities for technology acquisition were given. In particular, a SG information liaison committee was set up between TRP and RRP, and persons could exchange technical know-how and carry out deliberations on items of technology transfer.

SG in RRP are not much different from those in TRP. That is, measurement of a nuclear material is fundamentally an important SG means, and is used with the C/S systems as an important supplementary means. About actual methodology, as shown in Figure 1, a suitable nuclear material balance area is prepared and during a clean out operation, PIT is carried out once per year by common type material accountancy. The volumes of inventories of U and Pu are measured, and material balances are calculated and evaluated from measurement of the values and the amounts of U and Pu movements. Furthermore, calculation and evaluation of material balance by NRTA are done from the values and the measurements of the amount of Pu movements obtained in IIV, 1 time or more, per month, when the plant is being operated.

The remote surveillance and monitoring techniques shown in Figure 1 as an execution means of SG, such as FTPV, SMMS, HMMS, and VWCC, are similarly built and used also for RRP. As well, RRP uses the KED.

The analytical laboratory for samples taken by the IAEA was built as an on-site laboratory adjacent to RRP, reflecting the lessons learned from TRP that timeliness is very important.

Moreover, from experiences on the material accountancy in TRP, in order to perform proper management of the amount of Pu, nuclear loss that originated from the radioactive decay of Pu-241 was included and recorded as inventory change contained in SRD and inventory difference and the necessity for this was reported to RRP as a procedure to follow there.

TRP's Contribution to SG Field and Future Role

When a reprocessing plant under international control is needed in some areas outside Japan where nuclear activities are expanding, the independent verification, continuous surveillance technology and unattended inspection will become even more important for effectively and efficiently implementing the IAEA's SG.

Conclusions

The following summarizes events and findings from this history of the establishment of SG for TRP during the past thirty years.

When TRP was faced with an abrupt change in U.S. nuclear proliferation policy just before TRP's hot test, the Japanese government was forced to enter tough negotiations with the United States on reprocessing and to accept SG and inspections by the IAEA. Cooperative efforts at TRP by the Japanese government and IAEA inspectors have been higher than those at other nuclear facilities, and they were achieved with higher transparency and stricter surveillance of nuclear material movements.

The basic purpose of the SG, with their accompanying SG technologies, has been to verify if proliferation could be prevented by a combination of nuclear material accountancy and C/S systems. The accountancy of TRP has been carried out thoroughly using devices with tamper resistant functions. In addition, device precision has been improved. Although a little improvement was needed from the viewpoint of C/S, the FA could be successfully prepared between Japan and the IAEA. Several surveillance and monitoring devices were developed and applied to inspections. They were for the surveillance system in SF receiving and storage areas, monitoring of solution movement in input and output accountability tanks and Pu storage tanks, and recording identification numbers on vitrified waste containers. Many experiences in the development at TRP are being reflected in the establishment of SG technologies at RRP, which is a large commercial nuclear fuel reprocessing plant in northern Japan.

In this period, the basis for the IAEA's inspections in an independent verification system was established. This included securing authentication, establishing remote monitoring technologies and unattended monitoring and surveillance systems, and improving analysis precision. In addition, another important aspect of the IAEA's inspection was in assuring timeliness for verification of proliferation of nuclear materials. From this, PIV and IIV were introduced as well as NRTA.

Now TRP has finished its contract-based reprocessing operations for utility companies and is moving ahead to research and development on reprocessing mixed oxide spent fuels. Introduction of SG technologies to prevent proliferation of nuclear materials will be necessary because use of nuclear power plants, which are important for the global environment, is expected to increase. A future role in which TRP will contribute to acceptance of facilities in other countries accepting 24-hour inspections will be extremely important.

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Acknowledgments

The authors would like to acknowledge the contributions of the following individuals for their support in providing the data that made this paper possible: Takeshi Osabe, Tetsuo Ohtani, Tsuyoshi Hayakawa, Toshiaki Hiyama, Naohiro Suyama, Masayuki Iwanaga, Yusuke Kuno, Akira Kurosawa, and Tetsuo Kozaka.

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Security Risk Assessment and Management

Betty E. Biringer, Rudolph V. Matalucci, and Sharon L. O'Connor, Wiley & Sons, 2007.
ISBN-13: 978-0-471-79352.6

Vulnerability Assessment of Physical Protection Systems

Mary Lynn Garcia, Butterworth-Heinemann, 2006.
ISBN-13: 978-0-7506-7788-2.

By Walter Kane
Book Review Editor

In December 1941, and sixty years later, in September 2001, the American people learned a hard lesson—that wide oceans no longer protected them against an attack by a foreign enemy. There were additional lessons—the bombing of the federal building in Oklahoma City (we note, the first such attack of this type occurred in New York City in the 1920s when an anarchist parked a horse with a wagon loaded with dynamite in front of a bank and set it off, killing about thirty people—the first truck bomb in our country was a horse and wagon), and overseas, the Bhopal disaster, where an enemy pumped 1,200 gallons of water into a tank of sodium isocyanate, killing several thousand people. In addition, our national infrastructure, which includes a widely dispersed power grid, a chemical industry with large quantities of hazardous chemicals, our nuclear power stations, and above all, our nuclear defense complex, where the loss of even a few kilograms of fissile materials could have disastrous consequences, is viewed as possessing substantial vulnerabilities to an attack or subversion by dangerous adversaries.

In this context, the two manuals, Security Risk Assessment and Management, by Betty E. Biringer, Rudolph V. Matalucci, and Sharon L. O'Connor, and Vulnerability Assessment of Physical Protection Systems, by Mary Lynn Garcia, have special significance. These two works are the culmination of decades of work by U.S. Department of Energy (DOE) personnel, especially at Sandia National Laboratories, in developing a systems approach to addressing these problems, specifically identifying, quantifying, and minimizing risk to a facility or system. The approach developed is widely applicable, not only to the systems cited, but, for example, to natural disasters including violent storms, floods, and earthquakes.

While it is clearly desirable to address and minimize the risks cited, or others, the problem is what in mathematics is known as an extremum problem where you strive to minimize risk but the resources available for the task are finite. The problem then reduces to carrying out an analysis that will provide the greatest reduction in risk with the resources available. In our society, this task is often performed badly. Perceptions of risk are politicized and resources misdirected. For example, we spend $1 billion on asbestos remediation to prevent one fatality from that source and less than $30,000 to prevent one traffic fatality.

The first manual, Security Risk Assessment and Management, provides the logical steps for this process. It begins by defining risk as

$$R = Pa \bullet (1 - P_E).C$$

where R is the risk, PA is the probability of an attack by the adversary, PE is the effectiveness of the system, i.e., the probability that the adversary's attempt will be defeated, and C represents the consequences of the adversary's actions.

The major steps of the analysis are:

- Facility characterization
- Threat analysis
- Consequence analysis
- System effectiveness assessment
- Risk estimation
- Comparison of estimated risk levels
- Risk reduction strategies

In the first half of the manual, each of these steps is addressed in detail. A number of these steps are evidently linked together. For example, if the threat analysis indicates that the adversary has the ability and intent to use high explosives, a detailed engineering study of the facility structure must be carried out, as well as a study of the ability of the adversary to approach the facility, and the corresponding blast effects. Because the threat analysis depends heavily on assessments of human behavior, which have enormous uncertainties, it is often the practice to omit the probability of an attack from the analysis, i.e., the first coefficient PA in the risk equation, and calculate the conditional probability that, in the event of an attack, the adversary will be successful. When the analysis arrives at an estimation of the risk, the values obtained are compared with those which are considered acceptable. (The risk is never identically zero!) If the risk is considered to be unacceptable, then various risk reduction strategies are studied and those that are most cost effective are selected.

The second half of the material consists of detailed worksheets and examples where the methodology is applied to specific situations. These provide guidance on performing the analysis on a variety of different facilities and in different situations. These examples have high utility for the individual practitioner or for a training course.

The second manual, "Vulnerability Assessment of Physical Protection

Systems," utilizes the same doctrine as the first, but it addresses in detail the evaluation of the effectiveness of the various elements of a physical protection system in detecting, delaying, and neutralizing the actions of an adversary. This includes not only determining the effectiveness of existing elements, but also considering upgrades. The principal elements considered are:

- Intrusion detection
- Alarm assessment
- Entry control
- Alarm communications and display
- Delay subsystems
- Response subsystem

Both of these manuals are valuable resources, not only for the physical security practitioner in the DOE community, but for a much wider group as well, including all those who are concerned with the evaluation and management of risk. Worthwhile companion texts would be comparable manuals specifically addressing the protection of fissile materials and the conduction of tests and exercises in the evaluation of individual detection elements.

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

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DOE Announces Policy for Managing Excess Uranium

In March 2008, the U.S. Department of Energy (DOE) issued a policy statement on managing its excess uranium inventory, providing the framework within which DOE will make decisions concerning future use and disposition of its inventory. In 2008, DOE will continue its ongoing program for downblending excess highly enriched uranium (HEU) into low enriched uranium (LEU), evaluate the benefits of enriching a portion of its excess natural uranium into LEU, and complete an analysis on enriching and/or selling some of its depleted uranium. Specific transactions are expected to occur in the near future. The DOE will review the impacts of particular sales and transfers from its excess uranium inventory on the market and the domestic uranium industry, before undertaking these sales and transfers.

The policy statement commits DOE to manage its excess uranium inventories in a manner that is consistent with all applicable legal requirements; maintains sufficient uranium inventories at all times to meet the current and reasonably foreseeable needs of departmental missions; undertakes transactions involving non-U.S. government entities in a transparent and competitive manner, unless the Secretary of Energy determines in writing that overriding departmental mission needs dictate otherwise; and is consistent with and supportive of the maintenance of a strong domestic nuclear industry.

The DOE has a significant inventory of depleted, natural and enriched uranium that exceeds U.S. defense needs. This uranium is equivalent to approximately 59,000 metric tons of natural uranium. DOE's uranium inventory is expensive to maintain and secure, and is in various forms, many of which are not readily usable.

DOE Amends Decision for the Remediation of the Moab Uranium Mill Tailings

The U.S. Department of Energy (DOE) announced in February 2008 an amendment to its 2005 Record of Decision (ROD) for the Moab Uranium Mill Tailings Remedial Action (UMTRA) Project to allow for the use of truck or rail in transporting residual radioactive materials from the Moab site in Utah. These materials will be relocated to a new disposal site thirty miles north at Crescent Junction, Utah.

Since the Record of Decision was signed, a highway expansion and the cost of rail upgrades have made truck transport the optimal method for beginning to relocate the tailings. Further, increased flexibility and competition between transporters will achieve cost efficiencies, which will help accelerate the completion of the UMTRA project and reduce long-term risk. All other aspects of DOE's original ROD, including conducting active remediation of contaminated groundwater at the Moab site, remain unchanged.

U.S./Russian Leaders Discuss Nuclear Security Progress

U.S. and Russian leaders met in February to discuss U.S.-Russian efforts to keep nuclear weapons and weapons material out of the hands of terrorists. U.S. Energy Secretary Samuel W. Bodman and Russian Federal Atomic Energy Agency (Rosatom) Director Sergey Kiriyenko discussed progress made and next steps to shut down Russia plutonium reactors this year, dispose of sixty-eight metric tons of plutonium, and advance cooperation to expand the use of civilian nuclear energy through the Global Nuclear Energy Partnership.

The United States and Russia are two of the original members of the Global Nuclear Energy Partnership, along with China, France, and Japan. The twenty GNEP partner nations share the common vision for the expansion of nuclear energy for peaceful purposes worldwide in a safe and secure manner. GNEP, a voluntary partnership, aims to accelerate development and deployment of advanced fuel cycle technologies to encourage clean development and prosperity worldwide, improve the environment, and reduce the risk of nuclear proliferation. GNEP, first announced by President Bush in February 2006, includes countries with a wide range of experience related to nuclear power, including: Australia, Bulgaria, Canada, Ghana, Hungary, Italy, Jordan, Kazakhstan, Lithuania, Poland, Republic of Korea, Romania, Senegal, Slovenia, and Ukraine.

Two Independent Assessments Find Yucca Project on Track

The U.S. Department of Energy (DOE) Director of the Office of Civilian Radioactive Waste Management (OCRWM) in December 2007 released two independent assessments addressing areas critical to the overall success of the Yucca Mountain repository program that concluded that the Yucca Mountain Project's current QA and engineering processes and procedures are consistent with standard nuclear industry practices.

These independent reviews provide information and findings that will help ensure the Yucca Mountain Project has effective quality assurance and engineering programs that meet the highest standards of the nuclear industry. Independent assessments are a standard tool used by the nuclear industry to review processes and procedures to determine where improvements can be made. The Yucca Mountain site was approved by Congress and the President in 2002 as the location for the nation's first permanent spent nuclear fuel and high-level radioactive waste geologic repository. The department plans to submit its license application for authorization to construct the repository to the Nuclear Regulatory Commission no later than June 30, 2008.

InfoZen Inc. conducted a comprehensive, independent review of three individual QA program plans written and implemented by OCRWM, its M&O contractor Bechtel SAIC (BSC), and its lead laboratory, Sandia National Laboratories. In the course of its review, the assessment team saw evidence of significant improvements and tangible successes in correcting historical quality related problems. InfoZen concludes that the three QA program plans are being "implemented consistent with standard nuclear industry practices and to the extent expected given the current status of the Yucca Mountain Project."

Longenecker & Associates, Inc. conducted an independent assessment of the engineering processes and procedures for OCRWM and BSC. This assessment concludes that the policies and procedures are adequate, the implementing organizations are structured appropriately for the work, and there are no major barriers that will prevent successful completion of the engineering work. In addition, the assessment team found that personnel at all levels of the organization were knowledgeable of the procedures and committed to their effective use. Several strengths and good practices were noted by the assessment team, including proactive resolution of emergent issues, participation by construction and operations personnel during the design process, and consistency of the BSC training program with current industry best practices. This assessment also identifies opportunities for improvement, including configuration management, the streamlining of processes and procedures and other related areas.

First Phase of Nuclear Material Consolidation Complete

Special nuclear material quantities requiring the highest level of security protection have been removed from the National Nuclear Security Administration's (NNSA) Sandia National Laboratories. This move completes the first phase in NNSA's efforts to consolidate special nuclear material at five sites by 2012.

Sandia National Laboratories is the first NNSA site to reduce its on-site inventory of nuclear materials below the level requiring "category I and II" protection. These security categories require the highest level of security to protect material that includes plutonium and highly enriched uranium.

The U.S. and Estonia Cooperate to Prevent Smuggling of Nuclear and Radioactive Material

The United States and Estonia announced in February an agreement to coordinate efforts to prevent nuclear smuggling by installing radiation detection equipment at multiple border crossings in Estonia. The agreement expands on similar U.S.-Estonian cooperation.

The U.S. Department of Energy's National Nuclear Security Administration (NNSA) has been working with the Estonian Tax and Customs Board over the past several years to maintain previously installed radiation detection equipment. The agreement between NNSA and the Estonian Tax and Customs Board will allow NNSA to install new, improved radiation detection and integrated communications equipment at multiple border crossings, airports, and seaports in Estonia, as well as to provide related training on the use of this equipment.

NNSA's Second Line of Defense Program works collaboratively with foreign governments at border crossings, airports, seaports, and other points of entry to install specialized radiation detection equipment and train officials to detect smuggled nuclear and other radioactive materials. Similar equipment has been installed at more than 160 sites around the world.

Nearly 13,000 Nuclear Weapons-Worth of Russian Uranium Converted to Peaceful Use

Nearly 13,000 nuclear weapons-worth of Russian highly enriched uranium (HEU) has been converted to fuel for use in American nuclear power plants, according to the National Nuclear Security Administration (NNSA) at the U.S. Department of Energy. The announcement came in late February marking the fifteenth anniversary of the signing of the agreement that began this work.

Thus far 322 metric tons (710,000 lbs.) of HEU from Soviet-era dismantled nuclear weapons has been eliminated from Russia's stockpile. The HEU is converted into low enriched uranium (LEU) in Russia and sold to the United States, where it is made into nuclear fuel. NNSA actively monitors the process to ensure that Russian weapons-derived HEU is eliminated under an historic government-to-government nonproliferation agreement.

In 1993, the United States and the Russia Federation committed to irreversibly eliminate 500 metric tons of excess HEU from dismantled Russian nuclear weapons by converting it into fuel for U.S. commercial power reactors under the HEU Purchase Agreement. This executive agreement helps Russia eliminate excess weapons-usable material that could be targeted by terrorists for potential theft or diversion. The resulting fuel supplies almost half of all U.S. nuclear energy and provides ten percent of America's total electric power each year.

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