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COOPERATION BETWEEN JAPAN AND UNITED STATES ON THE PHYSICAL PROTECTION OF NUCLEAR MATERIAL TRANSPORTATION

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ABSTRACT

The Japan Atomic Energy Agency (JAEA) and Sandia National Laboratories (SNL) are conducting a multi-year cooperative research and training program. The program is focused on JAEA's physical protection systems for transport of mixed oxide (MOX) fuel materials to establish the method for enhancing the physical protection measures for land transport of fissile nuclear materials. Recognizing, in general, that fissile materials are potentially attractive and venerable to theft or sabotage during transport, this collaborative effort is funded by JAEA.

This cooperative work has been implemented using a phased approach involving several major tasks. The first major task included the collection and analysis of baseline information regarding Japan's fissile material transportation system, a review of the legal infrastructure for protection of fissile material during transport, and the identification of potential threats to that infrastructure through a review of the open literature. As part of Task 1 work, a workshop was conducted on Design Basis Threat (DBT) and the Design and Evaluation Process Outline (DEPO) approach to physical protection.

Analysis of a physical protection system (PPS) was performed during the second major task of this collaborative work. This analysis included the creation of a hypothetical or "project" DBT. The project or hypothetical DBT was used to conduct a vulnerability assessment (VA) and consequence analysis (CA). A workshop was subsequently held at JAEA to review the results of the CA and VA.

Under the third major task, SNL and JAEA have evaluated possible upgrades to an existing transport system for MOX fuel. A workshop on Guidance and Recommendations for Increasing Delays during Transportation was conducted in conjunction with this task. The cooperative efforts and research conducted by JAEA and SNL have been very fruitful and have increased the understanding and perspectives of both organizations regarding design and evaluation of PPSs. This paper describes the general methodology and results of the cooperative activity without releasing sensitive information.

INTRODUCTION AND OVERVIEW

Japan is one of the world's major industrial democracies. Japan relies on other countries for almost 80% of its energy supply. To increase energy independence while reducing the emission of greenhouse gases, the Government of Japan (GOJ) has been devoting efforts to promote an ambitious program to expand the use of nuclear power, including fast breeder reactor technology. Recently, the GOJ has enhanced the Law regulating nuclear reactors and nuclear material, which requires nuclear operators to insure the physical protection of the transportation of nuclear fuel materials.

To help insure the physical protection of the transportation of nuclear fuel materials, the JAEA and SNL are conducting a multi-year cooperative research and training program. The program is focused on JAEA's physical protection systems for transport of MOX fuel materials. This collaborative effort is funded by JAEA with the work scope defined in Action Sheet 61 (AS-61) under an agreement between the U.S. Department of Energy/National Nuclear Security Administration and the JAEA.

This multi-year cooperation, research, and training program between Japan and the U.S. is implemented in three major steps, or tasks, that match the major steps outlined in the DEPO process. DEPO provides a process, using a series of steps, to design and evaluate PPSs. The three major steps in DEPO, corresponding to three of the four major tasks of this cooperative program, are:

- Collect and analyze baseline information to understand the overall system, targets, threats, and operations (Task 1)
- Analyze the performance of a PPS using a consequence analysis and vulnerability assessment (Task 2)
- Recommend Upgrades to the PPS (Task 3).

Figure 1 presents the DEPO and the major steps of this cooperative research and training program. In addition, there were a total of four training workshops conducted under Task 4 of AS-61. Although not a specific task, the protection of U.S. and Japanese information was a work element included in each of the four official tasks.

A PPS is a combination of administrative, operational, and technical measures taken to prevent the unauthorized access to an asset. For the transportation of nuclear materials, a PPS is needed to prevent theft or sabotage of these materials. There are several approaches for designing and evaluating PPSs including: the expert judgment approach, the feature-based approach and the performance-based approach. The effectiveness of a feature-based PPS is evaluated using a checklist. In contrast, the effectiveness of a performance-based PPS is evaluated by an analysis of the performance of the system against a defined adversary. The DEPO[1] provides a well-accepted process, or set of steps, for developing performance-based PPSs.

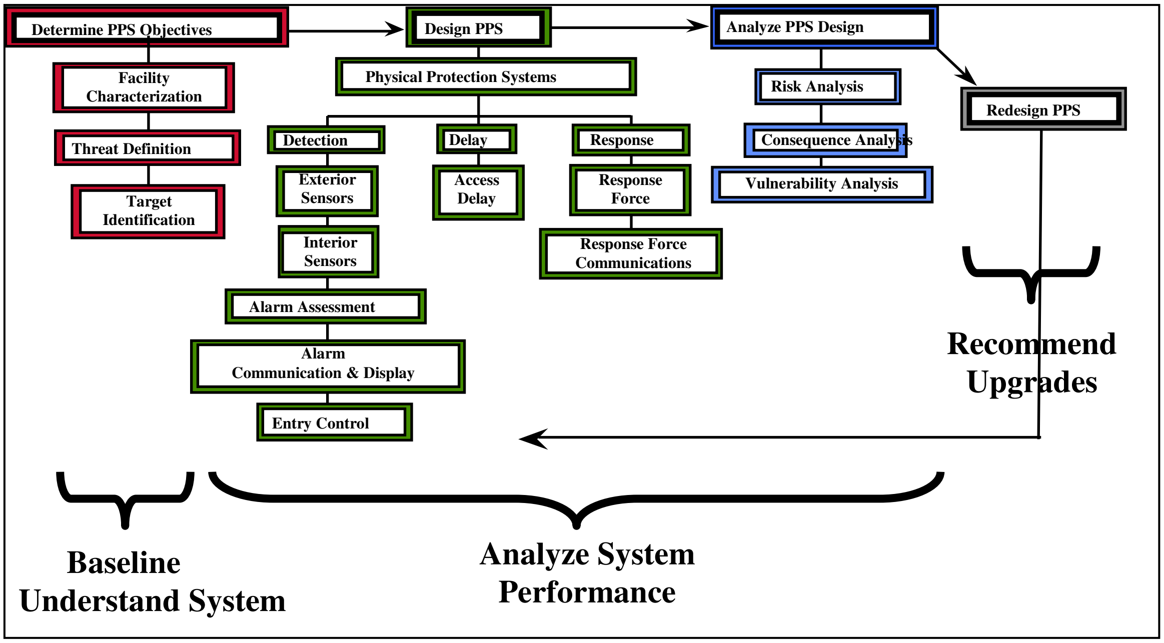


Figure 1. DEPO and Three Major Tasks of Action Sheet 61

BASELINE INFORMATION ON THE SYSTEM

Together, under Task 1, SNL and JAEA jointly collected and analyzed baseline data on Japan's nuclear fuel materials transportation system. This information is presented in the *Summary Report on Transportation of Nuclear Fuel Materials in Japan: Transportation Infrastructure, Threats Identified in Open Literature, and Physical Protection Regulations*. This report addresses three topical areas:

1. Overview of transportation infrastructure for nuclear fuel materials in Japan
2. Identification of threats through a review of the open literature
3. Review of regulations and requirements governing physical protection of transportation

Overview of Transportation Infrastructure for MOX

Mixed Oxide Fuel, composed of oxides of plutonium and oxides of uranium (PuO_2 + UO_2), is widely used in conventional light water reactors (LWRs) in Europe, where about one-third of the fuel assemblies are composed of MOX fuel and two-thirds of the fuel assemblies are composed of conventional U-235 fuel. The use of MOX in conventional LWRs is also known as "Pu-thermal."

MOX fuel can also be used in a Fast Breeder Reactor (FBR). Over longer time periods, a FBR creates more plutonium (through neutron capture) than is fissioned. In Japan, Monju is a prototype FBR used for establishment of commercial FBR technology. The MOX fuel used in a FBR contains about 16 to 21% plutonium. In the FBR cycle in Japan, MOX fuels are fabricated in JAEA's Tokai Works in Tokai-mura, Ibaraki Prefecture. The Tokai Works includes the Plutonium Fuel

Production Facility (PFPF) and the Tokai Reprocessing Plant (TRP). Figure 2 shows a schematic of the main domestic and international transport of nuclear fuel materials for the Japan FBR cycle.

In transporting MOX fuel materials by land, a convoy of several truck/trailers and accompanying security and emergency vehicles are organized to insure safe and secure transport operations. The transportation complies with local and national requirements for safety and security.

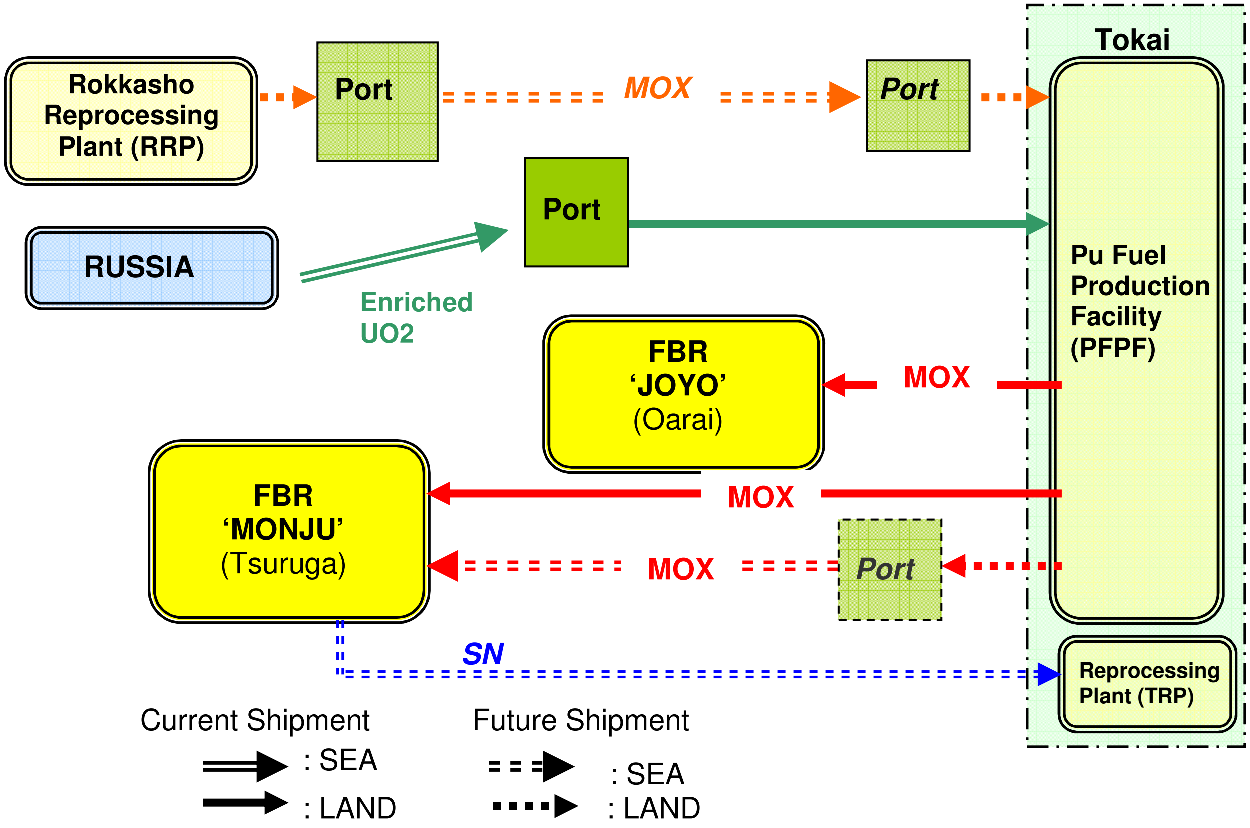


Figure 2. Schematic of FBR MOX Transport in Japan

Threats Identified in the Open Literature

The open literature was reviewed to gather information on possible threats of sabotage and theft during the transportation of nuclear fuel materials in Japan. In looking at threats, two facts distinguish Japan from many other industrialized countries. First, the population of Japan is composed of 99% ethnic Japanese people, and second, the crime rate is well below the threshold of concern for other industrialized countries. These factors are taken into consideration in developing Japan's approach to managing threats and security.

Information from the open literature was categorized according to the schema in *The Design and Evaluation of Physical Protection Systems* (Garcia, 2001). According to Garcia, adversaries can be categorized into three broad groups: outsiders, insiders, and outsiders working in collusion with insiders. Outsiders might include terrorists, criminals, or extremists. An insider is defined as anyone that possesses knowledge of operations or security systems and has unescorted access to facilities or security interests.

Known terrorist groups in Japan comprise the Red Army, Chukaku-Ha, Seikijuku, and Aum Shinrikyo ("the one who has attained supreme truth"). Of these groups, Aum Shinsen is the most well known. Aum Shinsen no Kai was formed in 1984 by Shoko Asahara. In 1994, Aum's terrorist group release of 12 liters of sarin at the Matsumoto Castle exposed 600 people, hospitalizing 58 residents and killing seven people.

Aum also attacked Tokyo's subway system on March 20, 1995. Five attackers punctured a total of eight of eleven bags of sarin in the subway. In total, 5,510 casualties reported to medical centers, and 12 people were killed. After the Tokyo subway attack, the government arrested over 200 members of Aum. Asahara was convicted in 2004, and subsequently was sentenced to the death penalty. At the time of the infamous subway attack, Aum was a well established organization with millions of U.S. dollars in resources, substantial amounts of weapons, and a membership of thousands of people with intellectual and technical capabilities.

The 2004 Madrid train bombings exemplify the actions of terrorists against countries that support U.S. policy. Seven people with suspected links to al-Qaeda were arrested in Japan at the beginning of June 2004. Japan's support, as a part of the alliance with the U.S. in its war on terrorism and former war in Iraq, may make Japan a target for both international and domestic terrorists.

Japan holds several grievances against North Korea including the kidnappings of 11 Japanese in the early 1980s. In 1998, North Korea launched a long-range Taepodong Missile over the Japanese islands, and in 2006 North Korea detonated a small nuclear weapon. As an example of a possible terrorist threat, Japanese coast guard patrol boats chased and exchanged fire with one suspected North Korean spy ship disguised as a Chinese fishing boat in 2001. The confrontation ended when the unidentified boat sank inside China's exclusive economic zone. Dozens of automatic weapons, a surface-to-air missile launcher, and an underwater scooter capable of carrying three people were found in the sunken ship, along with the bodies of ten people on board.

Review of Regulations

The Japanese, U.S., and International Atomic Energy Agency (IAEA) regulations, requirements and recommendations governing the physical protection of transportation were reviewed in the Task 1 work. The IAEA states that "The transport operation is probably the most vulnerable to attempted theft or sabotage of nuclear material." The IAEA's recommendations for reducing this vulnerability with the physical protection of nuclear materials during transportation are given in *Physical Protection of Nuclear Material and Nuclear Facilities* (INFCIRC/225/Rev. 4). Guidance to assure consistent and rigorous application of the IAEA recommendations is provided by the IAEA's *Guidance and Considerations for the Implementation of INFCIRC/225/Rev.4, The Physical Protection of Nuclear Material and Nuclear Facilities* (IAEA-TECDOC-967 (Rev.1)).

With respect to the issue of transporting nuclear materials, the *Convention on the Physical Protection of Nuclear Material (INFCIRC/274 Rev.1*) obligates parties to make specific arrangements and meet defined standards of physical protection for international shipments of nuclear material, as well as cooperate in the recovery of stolen nuclear material. The IAEA recommends a graded approach in which the physical protection measures are matched to the "value" of the nuclear asset. In implementing the graded approach, the IAEA categorizes fissile materials into Categories I, II, and III "quantities," with Category I quantities requiring the greatest protective measures.

There are several ministries in Japan that deal with nuclear materials and activities. Under "The Reactor Regulation Law" the Ministry of Economy, Trade and Industry (METI) is responsible for regulating commercial nuclear cycle activities and relevant transport packages used for shipment in Japan. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) is responsible for licensing and regulating research and development of nuclear activities and related transport packages. The Ministry of Land, Infrastructure and Transport (MLIT) is responsible for licensing and regulating transport method of nuclear materials. The Japanese regulatory system uses a graded categorization system that is basically the same as the categorization system of the IAEA's INFCIRC/225. Regulations for the safe control of the transport of nuclear materials are determined based on the mode of transport (land, sea, or air).

Regulations governing transportation of nuclear fuel materials in the U.S. are as follows. Control of the production and use of fissile materials is delegated to the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE). The U.S. NRC is responsible for regulating "commercial" nuclear fuel cycle activities, and the U.S. NRC may delegate their licensing authorities for by-product, source, and less than critical quantities of special nuclear materials (SNMs) to "Agreement States." There are relatively few commercial shipments of Category 1 quantities of SNMs in the U.S. The U.S. DOE is responsible for regulating U.S. "atomic energy defense" transportation activities related to the U.S. nuclear weapons program.

The U.S. NRC's 10 CFR 73.1(a) states that PPSs to protect "formula quantities" of strategic SNMs transport shall be designed to protect against a Design Basis Threat. A "formula quantity" of strategic SNMs is the same as an IAEA Category I quantity. Since 1977, the U.S. NRC has required that PPSs be designed to protect against a DBT. The NRC's DBT for protection of formula quantities of strategic SNMs is defined in 73.1(a)(1) for radiological sabotage and in 73.1(a)(2) for theft of strategic quantities of SNMs. The DBT provides an objective measure to design and evaluate the effectiveness of PPSs.

In addition to the DBT, the "general performance objectives requirements" and the "performance capability requirements" under the U.S. NRC's 10 CFR 73.26 requires transportation PPS for formula quantities of strategic SNMs to include systems, components and procedures. Examples of these include:

- The transportation shall include armed escorts, armed response personnel, a movement control center, and communications with local law enforcement authorities.
- Armed escort personnel must be qualified for duty in accordance with Appendix B of 10 CFR 73. Armed escorts shall requalify at least every 12 months.
- Armed escorts and armed response force personnel armament shall include handguns, shotguns, and semiautomatic rifles, as described in Appendix B of 10 CFR 73.

The U.S. DOE is responsible for regulating U.S. atomic energy defense transportation activities. The U.S. DOE implements its authority through a set of Directives, DOE Orders, and regulations. The most relevant of these is DOE Order 470.1, *Safeguards and Security Program.* A revised version of DOE Order 470.1 (DOE O 470.1A) is available. In general terms, the DOE uses a graded approach, which means that the highest level of protection is given to activities and materials whose theft and/or compromise would seriously affect U.S. national security. DOE PPSs must be based on the results of vulnerability and risk analyses designed to provide graded protection in accordance with an asset's importance. To determine the appropriate level of protection against risk, DOE must consider the nature of the threat, the vulnerability of the potential target, and the potential consequences of an adversarial act.

In summary, baseline information regarding Japan's fissile material transportation system was gathered and analyzed during the Task 1 work. This work included a review of Japan's MOX fuel transportation infrastructure, a review of the legal infrastructure for protection of fissile material during transport, and the identification of potential threats to that infrastructure through a review of the open literature.

ANALYSIS OF SYSTEM PERFORMANCE

Task 2 of this collaborative work used a combination of hypothetical and real circumstances to demonstrate techniques for the quantitative analysis of the performance of PPSs. Performance-based analysis of a PPS requires quantification of the overall risk, where "risk" (R) is summarized by the following:

$$R = P_A * C * (1 - (P_I * P_N))$$

Where:

P_A = probability of attack, which is typically set to 1
C = consequence, assuming the theft of sabotage is successful
P_I = probability the response force would interrupt the attack
P_N = probability the response force would neutralize the attackers.

When the probability of attack (P_A) is assumed to be one, the risk that is calculated is a "conditional risk." In this risk equation, the probability of interruption (P_I) is a function of additional variables including: the probability of detection; the delay in the system, and the response force time.

The probability of the response force neutralizing the adversary (P_N) can be estimated several ways, including the use of software tools such as the Neutralization Model in the Analytic System and Software for Evaluating Safeguards and Security (ASSESS), and the Neutralization Model of the Joint Conflict and Tactical Simulation (JCATS) software. Quantification of risk requires quantification of the capabilities of the adversary (via a DBT) and completion of both a CA and a VA.

Design Basis Threat

A DBT is defined by the IAEA as the attributes and characteristics of potential insider, and/or external, adversaries who might attempt unauthorized removal or sabotage of nuclear material. For this AS-61 work, a "hypothetical project DBT" was developed using results from the Task 1 review of threats identified in the open literature, and a review of the publically available DBT presented in U.S NRC's 10 CFR 73.1(a) regulations. This "project DBT" is not an actual DBT and was developed only for research and training purpose. A multi-day Task 4 Training Workshop on DBT was held in Japan in January of 2005 (see Figure 3).

Figure 3. Design Basis Threat Training Workshop

Consequence Analysis Methodology

A Consequence Analysis estimates the consequences of a theft or sabotage, assuming the attempt was successful. Consequence can be measured many ways and the CA must specify the metrics to be used to evaluate the consequence. For example, the radiation dose to a reasonably maximally exposed individual, and a population dose, are common measures of consequence for a sabotage attack.

Over the past 20 years, SNL has developed a CA Methodology for quantifying the consequences of sabotage against nuclear materials in transport. The CA Methodology is divided into six steps:

1. Identify the sabotage scenarios
2. Identify how consequence will be measured
3. Assess loading and material responses
4. Estimate source term that is released to the environment
5. Estimate consequence
6. Relate consequence to a specified threshold level.

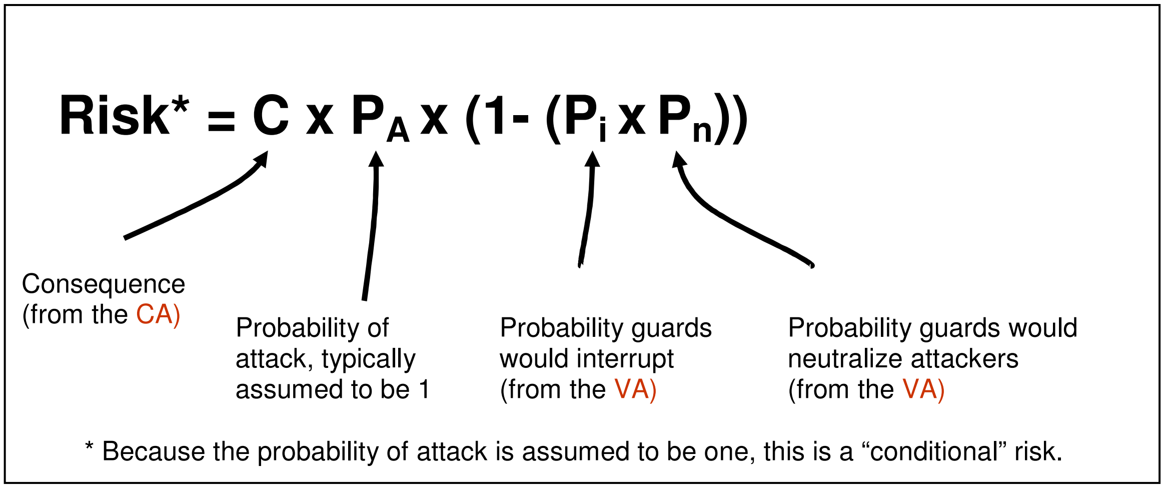
Vulnerability Assessment Methodology

A VA estimates the likelihood that a theft or sabotage will be successful. SNL has developed and refined a VA Methodology over the last thirty years. It can be described in many ways, but perhaps the most intuitive is the Design and Evaluation Process Outline, or DEPO (as shown in Figure 1). Key steps in the VA Methodology include the identification of theft and sabotage scenarios, construction of adversarial task timelines, assessing the response force time, and analyzing the probability that the adversaries would be neutralized before the adversaries could completed their task.

Theft and sabotage scenarios need to be representative of a range of possible adversary actions. The theft or sabotage scenario is decomposed into small individual steps, and an adversary task timeline is built using databases and experience. For example, five seconds might be needed for an adversary to remove an ordinary, exterior padlock.

CA and VA Analysis

Figure 4 shows the relationship between the risk equation the CA and the VA. Those relationships were explored during a CA and VA Methodology Training Workshop that was conducted at JAEA in January 2006. .



$$\text{Risk}^* = C \times P_A \times (1- (P_i \times P_n))$$

* Because the probability of attack is assumed to be one, this is a “conditional” risk.

Figure 4. Relationship between Risk Equation, CA, and VA

The CA and VA Methodologies were demonstrated in Task 2 by using a combination of hypothetical and real circumstances. Both theft and sabotage scenarios were analyzed. One of the sabotage scenarios involved the use of an M3 conical shaped charge. A subsequent workshop was held at JAEA in September of 2006 to review the results of the CA and VA work and analysis.

Together, the CA and VA provide a great deal of information to the decision-maker in identifying ways that an adversary might attempt to steal or sabotage MOX fuel materials in transit, by quantifying the possible consequences of successful attacks, and by quantifying the likelihood that the attackers would be stopped by the response force. As a generalization, for the transport of fresh MOX fuel, the quantitative risk is relatively high for theft, and relatively low for sabotage. Using the experience gained from nuclear accidents as an analogue, the political consequences and cleanup cost consequences of sabotage could be very significant. Although not part of this study, such consequences also need to be evaluated by decision makers as part of their comprehensive approach to safe and secure transportation of nuclear materials.

RECOMMEND UPGRADES

Approaches and techniques to mitigate transportation system vulnerabilities were examined and recommended in Task 3. From the broad set of recommended upgrades, the Task 3 work focused on adding more delay to the PPS. “Delay” is the element of a PPS designed to impede adversary penetration into or exit from a fixed-site’s protected area or a material transport truck. Delay can be accomplished by passive physical barriers, activated delays, or responders. The task time to breach a barrier is considered delay only if it occurs after detection and assessment, and only after notification of the response force.

The recommendations for adding more delay were provided in two reports, “General Access Delay Concepts and Guidance,” and “Transportation Specific Guidance for Adding Delays to a Transporter.” The general guidance for adding delays begins with a reminder that, given sufficient time and equipment, any barrier can be breached. The report reviews the tools available to the adversary for breaching delays. These tools include hand tools, power tools (including battery powered), pneumatic tools, hydraulic tools, weapons (e.g., armor piercing rounds), thermal tools (e.g., a burn bar), explosives, vehicles (for ramming, towing), and heavy equipment (backhoes, cranes and bulldozers for crushing, tearing apart physical protection delays in a transportation system).

General delay concepts include:

- Forcing adversaries to perform a number of sequential operations, rather than operations in parallel
- Making the vault or other barrier layers fit very closely to the target item minimizes the room for adversaries to insert tools (intimate containment)
- Balancing the design for all attack paths and methods
- Using a combination of active and passive delay features.

The report on general access delay concepts provides unclassified examples of both passive and active delays. The concept of adding more than 30 minutes of delay to a transporter is addressed, and an example of the time and costs to design and build a truck with significant access delay is included.

Specific issues in designing delay into transportation systems include vehicle weight limits, vehicle dimensions, providing access to load the cargo, robust locks, doors, and tie-downs, immobilization to prevent driving away with the cargo. Delay design also includes safety features for the operators, the use of a command and control system, ballistic protection, providing for vehicle maintenance, and making all systems road worthy.

The upgrade second report provides specific recommendations for conceptual design for upgrading a transporter vehicle in Japan. This work culminated with a Task 4 Delay and Response Workshop held in Japan in June 2007.

SUMMARY

JAEA and SNL are concluding a multi-year cooperative research and training program focused on JAEA's PPSs for protection of the transport of MOX fuel materials. This cooperative work has been implemented using a phased approach involving several major tasks.

The first major task included the collection and analysis of baseline information regarding Japan's fissile material transportation system, a review of the legal infrastructure for protection of fissile material during transport, and the identification of potential threats to that infrastructure through a review of the open literature.

During the second major task, hypothetical and real circumstances were used to demonstrate techniques for the quantitative analysis of the performance of PPSs. A "project" or hypothetical DBT was used to conduct a CA and a VA. The results of the CA and VA were used to calculate overall PPS effectiveness (conditional risk) for several theft and sabotage scenarios.

Under the third major task, SNL and JAEA evaluated possible upgrades to an existing transport system for MOX fuel, with an emphasis on adding additional delays.

Additionally, four related training workshops were held in Japan:

- DBT and DEPO
- CA and VA Methodologies
- Review of CA and VA Results
- Guidance and Recommendations for Increasing Delays during Transportation.

These cooperative activities have been very beneficial to both organizations, and augmented JAEA's specific awareness and capabilities for the physical protection of their transportation of fissile materials.

REFERENCES

Garcia, Mary Lynn, 2001, *The Design and Evaluation of Physical Protection Systems,* Butterworth-Heinemann Publishing, Woburn MA, USA.