Stanton Nuclear Security Fellows Seminar

PANEL 2: Nuclear Trade and Safeguards

1. Brian Henderson, MIT NSE

A Technical Assessment of the Nuclear Smuggling Threat to Inform Interdiction Policy for Commercial Cargo

The rise of non-state actors, such as al Qaeda, attempting to acquire either materials for a nuclear weapon or a warhead itself led to the concern that commercial cargo containers loaded in foreign ports constitute a vulnerable pathway for the delivery of a nuclear weapon to a target in the United States. Setting aside the human impact, long-term disruption to international trade, and political implications of a nuclear terrorist attack, a nuclear detonation in a large US port or city would likely incur immediate economic costs on the order of trillions of dollars[1]. Following the 9/11 terrorist attacks, the United States and international groups such as the World Customs Organization began to implement programs specifically for the preventing nuclear smuggling in stream-of-commerce cargo. In particular, the 9/11 Commission Act of 2007 mandates that all US-bound cargo containers be scanned by both passive radiation detection and x-ray imaging systems at their ports-of-origin[2]. In the decade since this mandate, however, the Department of Homeland Security (DHS) agencies tasked with implementing systems for compliance with this law have made very little progress. Congress has extended the deadline for compliance three times, with DHS officials claiming a lack of funding and authority to install systems in foreign ports and the absence of clear goals around which to develop interdiction systems and the concerns of shippers that nuclear detection programs will interrupt their operations[3].

My project will focus on addressing the technical questions surrounding this issue to develop clear recommendations for standards of nuclear detection in cargo and assess the capabilities of existing and near-future detection technologies to meet these standards and provide a means of achieving nuclear smuggling deterrence. My analysis assess the amounts and configurations of nuclear materials that interdiction systems should target, the effects and importance of smugglers' knowledge of the physics and technology of nuclear detection, and examine the capabilities and vulnerabilities of existing radiation detection and x-ray imaging technologies for cargo. Additionally, based on the results of my preliminary work, I expect to outline a framework that utilizes existing commercial technologies to achieve the

1 C. Meade and R. C. Molander, Considering the Effects of a Catastrophic Terrorist Attack. Santa Monica, CA: RAND Corporation, 2006.

2 "Implementing Recommendations of the 9/11 Commission Act of 2007, §1701." 110th Congress. Public Law 53, 2007.

3 S. L. Caldwell, "Supply Chain Security: Container Security Programs Have Matured, but Uncertainty Persists over the Future of 100 Percent Scanning." Testimony Before the Sub-committee on Border and Maritime Security, Committee on Homeland Security, House of Representatives, February 7, 2012.

primary goals of the 9/11 Commission Act mandate more quickly and at lower cost than systems requiring novel technologies.

Methods

The first element of the project will focus on clearly defining the nuclear smuggling threat at which interdiction systems should target. Current cargo inspection standards predominantly focus on the detection of other types of smuggling (firearms, drugs, tax-evasion, etc.)[4]. Comparison to standards based on other interdiction scenarios and the vagueness surrounding the essential properties of smuggled nuclear threats have caused difficulties in assessing both the absolute and relative efficacy of systems designed to combat nuclear smuggling. I will examine the technical aspects of nuclear weapon construction and the practical considerations relevant to a terrorist acquiring and assembling nuclear material to establish minimum material amounts and configurations that a system should detect in order to act as a deterrent.

The second portion of the project will assess the capabilities of existing systems to detect the standard threat configurations developed in the first part of the project. While a number of technologies exist in varying stages of development, the only widely deployed systems dedicated to detecting nuclear materials in cargo consist of passive detectors, known as radiation portal monitors, that identify the presence of radioactive materials by detecting the radiation emitted from smuggled objects[5]. By modeling these passive detection systems and the radioactive signatures of nuclear materials using analytical calculations and physics simulation software[6], I will establish that passive systems are capable of detecting nuclear threats in cargo when the smuggler has made no effort to mask the radioactive signatures of the material. For the case of an intelligent smuggler, I will use the simulation models to determine the minimum amounts and arrangements of radiation shielding required to mask the presence of different types of nuclear threats given different configurations of portal monitors.

After assessing the capabilities of passive detection systems, I will develop and test the key hypothesis of my work: that the nuclear smuggling detection problem may be recast as detecting the ignorant smuggler by passive detection, and that the best approach to detecting shielded nuclear materials smuggled by an intelligent adversary consists of searching for the shielding required to mask the material from passive detection, rather than directly targeting the nuclear material itself. The latter portion of this hypothesis is true if the materials configurations required to shield threats represent sufficiently dense and large anomalies such that existing cargo imaging systems can detect them and distinguish them from other dense cargoes. Additionally, configurations that mimic nuclear shielding in x-ray images must occur sufficiently rarely in stream-of-commerce cargo that an acceptably low rate of false positives will occur if systems flag cargo in this fashion. I plan to use a large database of cargo images provided by Dutch

4 American National Standard for Determination of the Imaging Performance of X-ray and Gamma-ray systems for Cargo and Vehicle Security Screening, ANSI N42.46–2008, 2008, pp. 1–26.

5 R. T. Kouzes, J. C. McDonald, D. M. Strachan, and S. M. Bowyer, eds., *Radiation Detection and Interdiction and U.S. Borders*. New York: Oxford University Press, 2011.

6 S. Agostinelli *et al.*, "GEANT4: A simulation toolkit," Nucl. Instrum. Meth., vol. A 506, pp. 250–303, 2003

customs and Rapiscan Systems to establish the frequency of such false positives by analyzing the images for occurrence of materials that resemble the configurations required to shield the radiation of nuclear threats. While the essentially idea of searching for "hardness" in cargo as a means of detecting nuclear material smuggling is not completely new[7], this study will determine for the first time whether the strategy is feasible by examining whether nuclear shielding scenarios are sufficiently unique in cargo images to permit such a concept of operation. The analysis of the Dutch customs dataset, while specific to the European export cargo stream from which it originates, will provide a valuable test case for the hypothesis, and if successful may lead to the analysis of other image sets. It may be the case that this strategy works well for some cargo streams but not others, based on the typical manifests of cargo at different ports and at different times.

Preliminary Answer

My preliminary work supports the idea that successful nuclear smuggling interdiction systems may be developed primarily with existing technologies. A change in the approach by the United States government and international partners towards nuclear smuggling interdiction that focuses on the capabilities of existing commercially produced imaging systems and passive detectors could achieve threat deterrence sooner and at lower cost than the continued development of novel systems. This approach has several additional advantages, including simplifying the operation of scanning systems by port authorities relative to novel technologies, the overlap of general x-ray imaging with the other interdiction goals of shippers and customs agencies, and reductions of deployment and maintenance costs.

Context

The space of other approaches to the nuclear smuggling interdiction problem is quite large, ranging from the deployment of complex active interrogation systems that target specific signatures of nuclear materials to abandonment of the 9/11 Commission Act mandate. My goal is to construct an analysis grounded in the technical aspects of the nuclear detection problem to demonstrate that nuclear smuggling interdiction is likely possible with existing technologies, and that such an approach would be considerably more amenable to shipping companies and port authorities than the continued focus on more complex systems. I view the key contribution of this work, regardless of the outcome of the cargo density analysis, to be the establishment of answers to several technical questions critical to developing policies for combating nuclear smuggling. The lack of answers to these questions has inhibited the development of both policy and technologies for cargo security, and has led to inefficient allocation of funds over the past decade.

Policy Implications

My goal is to derive several policy recommendations from this work, including:

- Establishment of standards for nuclear smuggling detection to provide a clear framework for the

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7 G. M. Gaukler *et al.*, "Detecting nuclear materials smuggling: using radiography to improve container inspection policies," Annals of Operations Research, vol. 187, pp. 65–87, Jul 2011.

development and assessment of technologies.

- Direct recommendations for improving radiation portal monitors and determination of priorities for funding future detection systems.
- A proposal for a system capable of nuclear smuggling deterrence for commercial cargo, pending the results of the stream-of-commerce cargo image analysis.
- Recommendations for additions to the information collected by the Customs-Trade Partnership Against Terrorism (C-TPAT) program from trusted shippers, to reduce false positive rates for nuclear smuggling detection.

Weaknesses and Request for Feedback

Given that my work will predominantly focus on the technical aspects of this problem, I view the most vulnerable part of the project to consist of making sure I maintain contact with the broader idea of preventing nuclear terrorist attacks. Cargo containers, while a particularly vulnerable smuggling vector, are by no means the only method of conducting such attacks. I would appreciate feedback regarding how to incorporate the relative likelihood of other smuggling methods in my assessments of the cost effectiveness of cargo-specific interdiction systems. Additionally, there remain a number of questions regarding the international political cooperation required to implement a global nuclear interdiction network that I do not intend to directly address, and insight regarding this issue would be helpful.

2. Taka Daitoku, MIT SSP

The Rise of the Nuclear Moratorium State: Japan's Recourse to Latency

1. On what issue are you working and why is it important?

-My study examines the way in which Japan created what I term a nuclear(-weapons) moratorium state during the premiership of Sato Eisaku (1964-72)—developing sufficient technological and economic capabilities to quickly produce nuclear weapons if necessary, while at the same time committing to the prevention of further proliferation.

-Japan's nuclear behavior has since been a key factor in assessing the credibility of U.S. nuclear and extended deterrence and the 1968 Non-Proliferation Treaty (NPT).

-The Japanese path to latency has served as a "model" for emerging nuclear(-armed) countries, such as Brazil, Iran, and North/South Korea

2. What is the big question that you are seeking to answer about that issue?

-Will the "Japan model/option" make the world safe?

3. How are you going to answer your question? What methods will you use and what evidence or cases will you explore?

-The research relies chiefly on recently-available archival and personal records in Tokyo.

4. What is your answer to the question you are asking? That is, what is your argument or conclusion even if it is still tentative at this point?

-Fast**-**growing Japan aspired to raise its nuclear potential on the assumption that it should go nuclear timely in case of emergency as well as gain a degree of leverage vis-à-vis nuclear-armed states and achieve energy self-sufficiency.

5. How does your work fit into the existing work on your subject?

<u>5-1. What alternative arguments or explanations exist and why is your answer superior?</u>

-Previous scholarship has tended to explore the ways in which Japan accepted a non-nuclear status between the 1960s and 1970s in return for an extended nuclear guarantee from the United States and a freezing of the nuclear status quo through the NPT regime.

-Few of those investigations seriously considered Japan's nuclear hedging to have also originated in that same decade. Consequently, they do not fully explain why Japan delayed acceding to the NPT regime for nearly a decade and why it has periodically surveyed its technological potential to develop an atomic bomb, particularly since the nuclear arming of the People's Republic of China in 1964.

5-2. How does your work add to or change our understanding of the issue you are studying?

-The project presents an alternative to the liberal understanding of the history of post-1945 Japanese grand strategy—the "Yoshida doctrine" that highlights Tokyo's pursuit of economic growth under the U.S. nuclear umbrella.

5-3. What do you see as your most important contribution?

-Japan specialists have now found a third "Japan model" to analyze in the history of the post-1945 world in addition to the "trading state" and the "developmental state."

6. What policy implications flow from your work?

-Japan's nuclear behavior has been, is, and will be a key factor in assessing the credibility of U.S. nuclear and extended deterrence and the NPT regime.

7. What do you think is the weakest or most vulnerable aspect of your study and what sort of feedback would be most useful to you?

-It pays insufficient attention to the Japan-U.S. Nuclear Cooperation Agreement of 1955 through which Washington has sought to control Tokyo's growing nuclear power. It thereby overestimates the margin of choice for Japanese decisionmakers in the 1960s and after.

3. Seungmin Woo, Texas A&M

Can Pyroprocess[8] Reduce Proliferation Risk of a Closed Nuclear Fuel Cycle?

- On what issue are you working and why is it important?

- If advanced nuclear fuel cycles become a significant part of the future energy infrastructure, understanding how to enhance the security of the facilities that store and process nuclear material is critical. There are two concerns that need to be addressed from a proliferation perspective: (1) diversion of nuclear material by a state and (2) stealing of nuclear material by non-state actors. An appropriate nuclear material accountancy and control (NMAC) protocol can help policymakers better address both of these concerns. In the context of nuclear security, the potential adversary is either an 'outsider' or an 'insider.' The insider poses a particularly serious threat due to their familiarity with the facility, allowing them greater ability to clandestinely plan and execute malevolent activities. Appropriate NMAC and uncertainty quantification are important to prevent a state from diverting nuclear material. Also, an insider who is responsible for material accounting and reporting to the state or a regulatory body knows the weakness in the system's NMAC. This insider attempts and deliberates to perform malicious acts such as manipulating the measured data of special nuclear material (SNM). Knowledge of the weakness in NMAC methods could help to successfully carry out the malicious act. Though all nuclear facilities require security protocols, a reprocessing plant for used nuclear fuel is an especially attractive target because it contains highly desirable nuclear materials. For example, the pure transuranic (TRU)- or uranium (U)-ingots obtained from reprocessing destined for reuse in nuclear fuels could be stolen for use in nuclear devices. Thorough material accountancy for the nuclear materials in a reprocessing facility is therefore critical to ensuring its security.

  The reprocessing technology can be categorized by an aqueous process (e.g. PUREX) and a non-aqueous process (e.g. pyroprocess). Currently the most commonly used nuclear fuel reprocessing method is PUREX. In contrast, a pyroprocess system can offer some key economic and non-proliferation-related advantages, but safeguards, material accountancy, and security for the pyroprocess have <u>not</u> yet been fully developed. This study will compare that safeguardability and proliferation risk of the pyroprocess with more conventional PUREX reprocessing.

- This study is important to make an informed policy decision in the near term (5 years) and in long term (25 years) on whether the use of nuclear material (low enriched uranium) in a non-recyclable mode is better than using it in a recycling mode by utilizing reprocessing. Or is an appropriate combination of enrichment and the pyroprocess better for nuclear safeguards in countries with closed nuclear fuel cycle programs? The policy issues this study will address include: (1) whether the enrichment technology is more proliferation resistant than the pyroprocess technology, (2) the possibility that non-state actors or insiders could obtain the SNM from the pyroprocess facility, and (3) the chance of the state using the pyroprocess to divert materials to build nuclear weapons.

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[8] The pyroprocess is a non-aqueous process to recover U and TRU from used nuclear fuel for recycling.

Answers to these questions will help policymakers in the United States and elsewhere decide which technologies can or should be exported worldwide to responsible countries for peaceful uses of nuclear energy.

- What is the big question that you are seeking to answer about that issue?

- A large amount of SNM is generated and treated in nuclear facilities.[9] Given the proliferation risks posed by each facility and process, this study addresses the following big question: <u>is enrichment technology more proliferation resistant than pyroprocess technology?</u>

- To answer this question, one needs to study the safeguardability and proliferation resistance characteristics of pyroprocess technology. One of the main concerns with respect to nuclear material safeguards is NMAC with utmost accuracy and precision to meet the International Atomic Energy Agency's (IAEA) objectives. One suggested method of Pu accounting in the pyroprocess is the Pu-to-^{244}Cm ratio method. The ^{244}Cm mass is determined by neutron counting. The ^{244}Cm mass is multiplied by the Pu-to-^{244}Cm ratio to measure the Pu mass. The ratio is evaluated in the head-end process. It is assumed that the ratio will not vary during the key-pyroprocess. Therefore, accurate evaluation of the ratio in the head-end process is necessary. However, there are significant uncertainties in determining the ratio during the head-end process caused by the inherent characteristics of the used fuel. A state could divert Pu hiding within the material measurement uncertainties. If an insider utilized detailed information about the nuclide non-uniformity to set the Pu-to-^{244}Cm ratio, the resulting Pu mass can be over- or underestimated. Moreover, the value of the ^{244}Cm mass used to calculate the Pu mass by the Pu-to-^{244}Cm ratio method could be manipulated by the removal or replacement of neutron sources in the pyroprocess. By exploiting these weaknesses in Pu accounting, an insider or State could clandestinely respectively steal or divert Pu.

- How are you going to answer your question? What methods will you use and what evidence or cases will you explore?

- The tasks proposed under this issue can be summarized as:

<u>Task 1: Development of scenario for smuggling Pu material in the pyroprocess:</u>

a) Development of the scenarios for manipulating NMAC in the head-end process.

b) Development of the scenarios for replacing nuclear material with any other neutron sources.

    a. The numerical code simulations to verify the possibility of replacement effect of nuclear material with neutron sources in the pyroprocess.

[9] Based on the SWU (separative work unit) evaluation, which is a unit that defines the effort required in the uranium enrichment process, the SWU capacity needed to annually feed one pressurized water reactor (PWR) is 815kg-^{235}U/year (11 SQs (significant quantity)), approximately 98,100 kg-SWU. Using that capacity of enrichment, 457 kg-^{235}U (18 SQs) with 90wt% ^{235}U could be also achieved. Moreover, the annual production of Pu by the standard PWR is 246 kg-Pu (31 SQ).

<u>Task 2: Proliferation risk analysis</u>:

a) Evaluating the expectation of Pu Material Unaccounted For (MUF) by manipulating the ratio.

b) Evaluation of detection probabilities or Type-I (false positive) and Type-II (false negative) errors using the error hypothesis testing method.

c) Probabilistic analysis for feasibility of replacing nuclear material with neutron sources by the event tree analysis and the pathway analysis.

- The proliferation risks for the pyroprocess facility will be compared to that for other nuclear facilities, for instance, a uranium enrichment facility.

- What is your answer to the question you are asking? That is, what is your argument or conclusion even if it is still tentative at this point?

- This study will identify an estimate of the probability that sensitive nuclear materials will be diverted by the state or non-state actors.

- We are expecting that used fuel recycle utilizing pyroprocess technology will be advantageous or equally useful as an open fuel cycle with non-recyclable uranium enrichment technology. Based on preliminary calculations, I expect an appropriate combination of enrichment and pyroprocess technology will be better, from the security standpoint, for pursuing closed nuclear fuel cycle.

- How does your work fit into the existing work on your subject?

  - What alternative arguments or explanations exist and why is your answer superior?

  - The previous papers show the pyroprocess system has the advantage in terms of proliferation resistance, since all TRU are recovered together without further separation process. However, the proliferation resistance and nuclear security based on NMAC in pyroprocess have not been discussed from a state's diversion and criminal (insider and outsider) theft perspectives.

  - How does your work add to or change our understanding of the issue you are studying?

  - This study can help to understand the strategy and procedure of legally manipulating the Pu mass in pyroprocess while the Pu-to-^{244}Cm-ratio method is being applied. Moreover, this study will suggest concepts and plans of countermeasures to surmount the proliferation and security risks in pyroprocess and will allow the comparison with uranium enrichment proliferation risks.

  - What do you see as your most important contribution?

  - Developing an appropriate NMAC procedure for pyroprocess is the focus of the study, which is expected to reduce risks of diversion and misuse of SNM. Subsequently the proliferation risks of pyroprocess will be compared with that of an uranium enrichment facility to support an informed decision on the use of these two (pyroprocess and enrichment) in closed nuclear fuel cycles.

- What policy implications flow from your work? What concrete recommendations can you offer to policymakers?

- Around thirty countries currently operate nuclear power plants. States should make a decision whether to dispose a large amount of used fuel in a geological repository or reuse the resources contained in the used fuel by reprocessing. Among those countries, Russia, China, India, Japan, and several European countries reprocess used nuclear fuel, but other governments have not yet come around to seeing used fuel as a resource. This study is aimed at reviewing and improving the NMAC procedures of pyroprocess to assess its proliferation potential and compare it with that of uranium enrichment facility. Such a study will inform the policy decision makers in considering or not considering the addition of pyroprocess as a future option of the nuclear waste management as well as for the reduced use of uranium enrichment.

- What do you think is the weakest or most vulnerable aspect of your study and what sort of feedback would be most useful to you?

- Model safeguards approaches exist with IAEA for uranium enrichment facility, nuclear power plants, and PUREX system facility. However, there is not such a model safeguards approach for a commercial scale pyroprocess facility. The lack of information and experiences with a commercial pyroprocess system would be the weakness of this study in validating the risks. The feedback or comments from the researchers and developers for the pyroprocess technology would be sought to alleviate this vulnerability.