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ABSTRACT

The threats of nuclear proliferation and nuclear terrorism call for international cooperation and improved measures to prevent, detect, and respond to incidents involving the illicit possession or use of nuclear or radiological materials. Nuclear forensic investigations provide a response and deterrent capability that requires the sharing of validated information on isotope measurements, chemical (trace element) compositions, and the physical form of matrices from across the nuclear fuel cycle as well as the processes used in their manufacture. Bi-lateral and multi-lateral engagement in nuclear forensics is essential to secure access to samples, data and subject matter expertise to attribute a terrorist nuclear event, determine the source of nuclear materials that could be used in an attack, identify those responsible, as well as verify declarations of the security of inventories of nuclear and radiological materials. National security sensitivities inherent in information sharing may complicate cooperation and will need to be addressed thoroughly. For this reason, a cooperation program is likely to require different mechanisms for engagement with existing United States nuclear forensic partners (Australia, France, European Commission, Brazil, and Argentina), newly emerging forensics partners (United Kingdom and Canada), and states where partnerships could begin (Russian Federation, China, Turkey, Kazakhstan, Central Asia, South Asia, and South Africa). Existing programs and approaches can be expanded incrementally to establish a worldwide capability in nonproliferation nuclear forensics.

INTRODUCTION

Nuclear forensics uses isotopic, chemical, and physical signatures to identify unknown nuclear materials, including their point or origin, their application, and the processes used to create them. Credible attribution of illicit or undeclared nuclear materials can create a new deterrence to counter the authorized diversion or use of nuclear/radiological materials. Signatures, in concert with other information, can provide insight into material origin and subsequent history. The same analytical and interpretative capabilities used to examine interdicted samples can also be employed to verify that declared nuclear programs are fully sanctioned. Nuclear forensics can also provide information to investigate suspected proliferant activities at undeclared sites. In the way nonproliferation nuclear forensics (NNF) supports safeguarding the nuclear fuel cycle by supplying information necessary for verification of declarations as well as attribution of illegally transferred materials.

Illicit trafficking of nuclear/radiological materials and the ensuing nuclear forensics investigations of interdicted samples are inherently international problems. No single country can hope to address this critical 21st century problem, even on a local scale, without global engagement. The United States has begun to develop international partnerships in nuclear forensics analysis. In particular, US leadership of the Nuclear Smuggling International Technical Working Group (ITWG) has promoted best practices multi-laterally to more than 30 states and international organizations (1). However more needs to be done particularly to establish lasting bi-lateral technical partnerships. The growing recognition of the importance of international engagement to accomplish both nuclear nonproliferation and counter-terrorism objectives underscores the need for a clearly articulated approach to international engagement that identifies and priorities potential foreign partners with respect to access to the international fuel cycle and joint scientific endeavors.

NUCLEAR NONPROLIFERATION AND NUCLEAR FORENSICS

The requirements for national programs in nuclear forensics exceed those of commercial and international verification regimes. Nuclear forensics investigations require the sharing of validated protocols not only on major and minor isotopes, chemical (trace element) compositions, and physical forms (grain size, sorting, admixtures) of the materials, but also the processes used in facilities that are part of the nuclear fuel cycle (see reference 2 for a complete technical discussion). Access to this broad suite of information is critical for the evaluation of the source and route of smuggled pieces. There is also a compelling need to ensure that states that conduct nuclear forensics measurements – either independently or cooperatively – have access to sufficient data for rigorous, high confidence, interpretation. The need to share data by necessity may infringe on proprietary or national security information that must be addressed at the outset of any exchange. While opportunities for international cooperation exist, the potential to reveal specific capabilities or methods used by states as part of their counter-terrorism and nonproliferation programs may complicate an unfettered exchange.

Comprehensive and effective international cooperation in nuclear forensics requires:

- Prioritization of data and samples that provide insights to the nuclear fuel cycle
- Identification of those states where improved capabilities for NNF is desired
- The extent to which technical cooperation and data sharing is possible subject to the need to protect sensitive information, and
- The development of guidelines for best practices required for global cooperation.

MECHANISMS FOR INTERNATIONAL NUCLEAR FORENSICS PARTNERSHIPS

To-date, international nuclear forensics partnerships have been built on existing bi-lateral agreements that reflect funding and programmatic priorities as well as an assessment of those states where cooperation is possible without undue complication. Multi-lateral agreements have also proven valuable due to their broad simultaneous access to international partners. Several approaches have been successfully utilized.

Informal outreach to states is often initiated though mutual exchanges at scientific conferences by non-governmental organizations (e.g., national academies of science or international scientific bodies – American Association for the Advancement of Science, Royal Society (UK), or the Institute for Nuclear Materials Management).

U.S. national laboratory technical cooperation with equivalent institutional counterparts typically involves *lab-to-lab contact or agreements* for particular samples and data, particularly relative to the identification of samples of mutual interest, comparison of analytical results and joint interpretation.

Bi-lateral government-to-government agreements are more formal information exchanges (e.g., National Nuclear Security Administration (NNSA) action sheets). So far these agreements have involved access to samples and data from the front-end of the nuclear fuel cycle (e.g., uranium mining and concentration).

Multi-lateral cooperation has proved effective due to its transparency and global scale; the Nuclear Smuggling International Technical Working Group (ITWG) and affiliation with the International Atomic Energy Agency provide access to expertise and experience of many nations with legacy and emerging interest in the nuclear fuel cycle. Often these multi-lateral forums spur bi-lateral technical cooperation to address specific requirements (e.g. trace element signatures in uranium, training in nuclear forensics).

ELEMENTS OF TECHNICAL COLLABORATION

Ultimately the objectives of international engagement in NNF are to provide partners with technical expertise to improve the security of inventories of nuclear and radiological materials through the use of forensic tools to identify threat materials originating internally or externally. Additionally, engagement also provides access to samples of the international nuclear fuel cycle essential to enabling comparisons when interdicted samples are encountered and subsequently analyzed. Technical cooperation and sampling forms the basis for developing NNF as an effective deterrent. These include:

1) Access to data and high priority samples from across the nuclear fuels cycle (i.e., uranium ore, uranium ore concentrate – U_3O_8, UF_4, UF_6, low enriched uranium fuel (< 20% atom enrichment in ^{235}U), highly enriched uranium fuel ($\geq$ 20% atom enrichment in ^{235}U), reprocessed plutonium, mixed uranium and plutonium oxide fuel - MOX). These activities include physical access to the samples as well as associated nuclear forensic analysis of isotopic, chemical, and physical signatures. Important is collaboration with subject matter experts who can relate the measured signatures back to the processes responsible for their introduction and persistence.

2) Cooperative research and development to develop and enhance analytical techniques used in nuclear forensic analysis as well as identify and evaluate

nuclear materials signatures. Critical scientific questions remain for nuclear forensics; most pressing is the ability to identify and measure isotopic, chemical, and physical signatures that relate to the origin and history of nuclear and radiological materials. The relationship between empirical signatures and the processes used for their production is not well understood and requires further investigation.

3) International scientific engagement to promote NNF best practice. Peer-to-peer collaboration utilizes nuclear forensics as a common language and builds confidence through discussion of 'lessons learned' in response as well as expert review of advanced methods for measurements of uranium and plutonium bearing on source, age, and use history.

In devising a program for engagement in NNF, a graded or incremental approach allows for initial partnerships with allies on topics of mutual scientific interest and transitions gradually to future potential partnerships with more sensitive countries where the need for cooperation in nuclear forensics has been identified but not the exact mechanism. In developing criteria for engagement, political or threat assessments that could affect the outcome have not been considered.

FOREIGN PARTNERS: EXISTING COOPERATION WITH ALLIES

With abundant natural and/or technical resources and interest in the nuclear fuel cycle, Australia, France, European Commission, Brazil, and Argentina have existing partnerships in nuclear forensics with the United States.

With an extensive network of civilian nuclear power reactors and a nuclear weapons program, France has an active program in nuclear forensics that has centered on the ITWG but is now in the process of bi-lateral and multi-lateral expansion (3). Technical elements include improved analytical methods, quality assurance, and enhanced techniques for data interpretation. The European Commission – Joint Research Center is also a key ally in nuclear forensics through its research program in the field of nuclear safeguards and nuclear security with a focus on understanding and resolving scientific issues related to analysis and interpretation of nuclear forensic signatures (4).

Australia is currently a large supplier of the world's uranium ore concentrate (approximately 10,000 metric tons per year) with a strong interest in nuclear nonproliferation and the application of advanced analytical techniques and databases in pursuit of nuclear forensic science. Australian law enforcement is now working with nuclear experts to develop a national response program for nuclear threats that includes nuclear forensics. With a strong interest in nonproliferation, Brazil and Argentina are also currently active in technical safeguards and have radiochemical and measurement capabilities that can be readily adapted for a strong program in nuclear forensics. Brazil has been active in the ITWG.

FOREIGN PARTNERS: NEWLY EMERGING

The United Kingdom is a long-standing technical and strategic partner on nuclear weapons development. Through its leadership in the ITWG and other exchanges, the United Kingdom recognizes the importance of samples and data that relate to the nuclear fuel cycle that enable meaningful nuclear forensic comparisons. An agreement to share information across a spectrum of nuclear forensics and nonproliferation topics would benefit international nuclear security objectives.

Bi-lateral exchanges in nuclear forensics are now on-going between the United States and Canada. Given the substantive reserves of uranium in Canada and Canada's presence as a major producer of uranium ore concentrate (approximately 11,000 metric tons per year), the opportunity to access samples of mutual interest promises important scientific return. Ultimately, these arrangements should be expanded to foster multi-lateral cooperation in nuclear forensics between the United States, Australia, Canada, and the United Kingdom with a focus on the front-end of the nuclear fuel cycle.

FOREIGN PARTNERS: KEY FUTURE STATES

Complete and comprehensive nonproliferation nuclear forensics involves states – some former adversaries - that have existing former Cold War inventories of nuclear or radiological materials or are poised or will continue to develop their own nuclear fuel cycle into the 21st century to meet energy and security needs. In many cases, engagement with sensitive countries involves a longer-term strategy with specific targets identified for cooperation. While cooperation is sought with these states, specific plans for engagement are still being devised.

Kazakhstan and other Central Asia republics (e.g., Tajikistan, Kyrgyzstan, and Uzbekistan) historically supplied the majority of uranium to the military and civilian nuclear fuel cycle of he former Soviet Union, and subsequently, to emerging republics throughout Eastern Europe as well as Russia. In particular, Kazakhstan wants to become an end-to-end supplier to the nuclear power industry with a strong commitment to future fuel-cycle nonproliferation as well as basic research and education. Bi-lateral partnerships with Tajikistan, Kyrgyzstan, and Uzbekistan have focused on introducing nuclear forensic best practice to these states potentially affected by illicit trafficking as well as the successful return of uranium ore tailings and uranium ore concentrate sources in these states. In particular the Institute for Nuclear Physics in Uzbekistan already pursues a nascent program in nuclear forensics case-work and is interested in a more expansive capability.

Russia has over 1000 metric tons of HEU and more than 100 metric tons of plutonium residual from former Cold war inventories. Besides on-going efforts to design an effective structure of a database for Russian and US research reactors at the All-Russian Institute for Technical Physics in Snezhinsk, nuclear forensics studies have been pursued in partnership with the A.A. Bochvar All-Russian Research Institute of Inorganic Materials. Recently a cooperative program has been initiated between the United States and counterpart Russian defense ministries to explore the feasibility of bi-lateral nuclear forensic data exchanges (5). While there has been progress, more remains to elevate nuclear forensics within Russia as part of their response to nuclear terrorism and proliferation threats.

China is also an important partner for future NNF engagement. Topics of common interest include analytical techniques for nuclear forensic analysis, databases for nuclear forensics, national-level experience in response to episodes of illicit trafficking, education and training issues in nuclear forensics, and characteristics of uranium ore concentrates. The Chinese have also expressed interest in the activities of the ITWG.

Other states including Turkey, India, Pakistan, and South Africa are candidates for enhanced national programs in nuclear forensics. These states either currently possess or had a nuclear weapons program (e.g., India, Pakistan, and South Africa), are located along nuclear smuggling routes (e.g., Turkey), or are situated in regions where there are significant concerns about terrorism. One specific example deserves mention. Turkey and the United States have experience with a successful model for nuclear forensics cooperation through partnering in nuclear forensic casework investigations that allowed US scientists access to nuclear forensics data collected by Turkish atomic energy officials from an interdicted sample. Scientists from both countries successfully devised a plan of investigation and collaborated on the interpretation and reporting of the results.

Table 1. Summary of Technical Cooperation in Nuclear Forensics by State

State	Existing Cooperation	Emerging Cooperation	Future Cooperation
Argentina	Yes		
Australia	Yes		
Brazil	Yes		
Canada		Yes	
China			Yes
European Commission	Yes		
France	Yes		
India			Yes
Kazakhstan		Yes	
Pakistan			Yes
Russia			Yes
South Africa			Yes
Turkey			Yes
United Kingdom		Yes	
Uzbekistan		Yes	

CONCLUSIONS

International partnerships are essential to advance nonproliferation nuclear forensics that may provide insight to the origin of diverted nuclear material as well as verify declarations of permissible nuclear activities including production of fissionable nuclear materials (e.g., highly enriched uranium and plutonium). However for nuclear forensics to offer maximum capability as a deterrent function, a mechanism needs to be developed that allows sharing of nuclear forensics samples and data to facilitate comparison of known to suspect samples. The concept of an international library of nuclear forensic samples is not new. Experts in the field (6) complemented by a American Physical Society (APS) / American Association for the Advancement of Science (AAAS) working group on nuclear forensics (7) advocated for a database that would include characteristics of fissile materials, related process information, and information on the storage of these materials. The foremost challenge to an international databank is that – by definition – a library is built upon exchange of information. All international partners must agree on a mechanism to exchange samples and data without revealing sensitive or national security information critical to national defense. Presently efforts are underway to develop a directory of nuclear forensics libraries available around the world that can respond to queries without compromise of restricted data or samples. Dialogue concerning the structure and management of such a directory including political, scientific, administrative, and operational considerations has been initiated among interested parties.

Nuclear forensics benefits from a lasting strategy for international engagement with key partner states. Due to the nature of the threat, no one state can successfully implement a comprehensive nuclear forensics regime on its own. Successful international cooperation must be sustained over the span of years to effectively build credibility and return samples and data of critical interest. This cooperation will require different approaches for allies, emerging states, and sensitive countries. The role of personal relationships involving science and technology as a common language cannot be underestimated in this context. Peer-to-peer exchanges have proven extremely valuable in international nuclear forensics. To start, existing programs or arrangements readily provide points of entry or contact with individual countries and serve as the foundation for an expanded program. Continued interest among nations and multi-national organizations in nonproliferation nuclear forensics remains strong and requires a comprehensive strategy to meet international security objectives.

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