Argonne Safeguards Research Program

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Abstract

Argonne National Laboratory has an active and growing safeguards research and analysis program which integrates more than seventy years of technical and policy expertise to develop innovative solutions to emerging safeguards challenges ranging from detecting undeclared nuclear activities to monitoring sensitive fuel cycle processes to addressing insider threats to developing rapid, portable field sample analysis. Enabling capabilities include extensive nuclear fuel cycle expertise in research and power reactors, aqueous reprocessing, and pyroprocessing; advanced modeling and simulation of fuel cycle and other systems; vulnerability assessments of physical security and nuclear safeguards devices and systems; analysis of nuclear and nuclear-related dual-use trade as potential indicators of nuclear activities; unique systems for monitoring nuclear material security and nuclear trafficking; recognized expertise and leadership in Additional Protocol implementation; and expertise in nuclear proliferation resistance evaluation.

Argonne employs these capabilities in support of the NNSA Office of Defense Nuclear Nonproliferation's Office of Research and Development Proliferation Detection and Office of Nonproliferation and Arms Control International Nuclear Safeguards five focus areas: policy and outreach; concepts and approaches; technology development; human resources; and international engagement. Argonne's past work includes examination of process monitoring for pyroprocessing and aqueous reprocessing, exploring safeguards approaches to very long term storage of spent fuel, and vulnerability assessments on over 1000 different security and safeguards devices, systems, and programs, including for the International Atomic Energy Agency (IAEA) and EURATOM. Additionally, Argonne provides training to the IAEA through the auspices of the U.S. Support Program for International Safeguards. Argonne is a designated IAEA training lab and coordinates IAEA training on nuclear security topics.

Argonne is well positioned for the future to support IAEA efforts to develop methodologies for information analysis for state level safeguards, to incorporate safeguards by design in advanced fuel cycle facilities, and to develop novel monitoring systems, tags and seals. This paper will provide an overview of the suite of capabilities Argonne has developed in support of international safeguards, how Argonne's capabilities are being leveraged to address emerging safeguards challenges, and opportunities for students and collaborators.

Introduction

Founded in 1943, Argonne National Laboratory is a direct descendent of Enrico Fermi's Metallurgical Laboratory and is one the world's premier multidisciplinary R&D centers. Argonne applies a unique blend of world-class facilities, science and engineering to address important scientific and societal needs.

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Designated as America's first national laboratory in 1946, Argonne continues to pursue its original mission to perform research and development for safe, secure, and sustainable nuclear energy including research and development for nonproliferation and international nuclear safeguards. Recent improved integration of Argonne's technical and policy expertise has resulted in substantial growth in the safeguards research program, opening new areas and opportunities for investigation.

Central to its safeguards research program is Argonne's recognized, leading expertise in nuclear fuel cycle processes and facilities particularly regarding civilian nuclear power-related technologies. The remainder of this paper provides a survey of safeguards projects underway which leverage this fuel cycle and policy expertise and highlights of other relevant capabilities that can contribute to innovative solutions for emerging safeguards challenges.

Integration of Fuel Cycle and Nonproliferation Expertise

Organizationally, Argonne formed the Energy and Global Security (EGS) Directorate, bringing together two Divisions conducting international safeguards research: the Nuclear Engineering (NE) Division and the Global Security Sciences (GSS) Division. These divisions work closely together to leverage both technical nuclear fuel cycle expertise and nonproliferation expertise for international safeguards. NE has longstanding expertise in advanced and experimental nuclear fuel cycles, including aqueous reprocessing and pyroprocessing and advanced power and research reactor concepts, as well as in the destructive analysis of nuclear materials. Among other things, GSS has wide-ranging expertise in the proliferation analysis of nuclear technologies, the use of strategic trade data and information analysis techniques, and in providing training on nonproliferation topics.

Argonne's international safeguards research focuses on three key aspects: 1) Analysis, 2) Technology Development, and 3) Capacity Building.

Analysis

Argonne performs a variety of analyses related to nonproliferation and safeguards policy, concepts and approaches as well as analysis of existing and emerging technologies for proliferation risks and vulnerabilities. The following are examples of safeguards-related analysis.

Making Use of Safeguards-Relevant Information for Analysis

One of the challenges facing the IAEA Department of Safeguards is integrating a variety of data streams – state declared information, verification data, and other sources of information – to support safeguards evaluation. Argonne is involved in research projects that seek to provide insights for how to best utilize all available safeguards-relevant information streams, open source information in particular, to support robust state evaluation. Recent projects conducted by Argonne in partnership with other U.S. National Laboratories examined the role of open source trade data in supporting safeguards evaluation, the various resources available at the IAEA outside the Department of Safeguards that could support safeguards, and the utility of open source information in preparing for Complementary Access. Additionally, Argonne is involved in an IAEA Support Program request to gather open source information related to the nuclear fuel cycle that can be used to support the development of a natural language processing and big-data analytic tool that will be used to automatically sort open source information according to the categories of the IAEA Physical Model.[1]

[1] The IAEA Physical Model is an internal multi-volume analytical tool that identifies, describes, and characterizes nuclear fuel cycle technologies and processes, and is used by the IAEA's Department of Safeguards in its analysis of the nuclear activities of states.

New Safeguards Concepts and Approaches

Argonne is involved in the development of new safeguards concepts and approaches. Argonne leverages its knowledge of emerging nuclear fuel cycle designs and concepts to produce forward-looking analyses of the proliferation impact of proposed designs. These analyses are designed to enable early consideration of safeguards implications, well in advance of a decision to construct the facility type.

Argonne recently began a multi-laboratory project to examine potential uses of unmanned aerial systems (UAS) in safeguards implementation. The goal of the initial effort is modest, as it seeks to merely identify applications that could have benefits over current verification approaches; however, this modest effort will enable technology developers to focus resources where there is the greatest promise for achieving advances in safeguards implementation – either by identifying efficiencies achievable with UAS or by identifying new safeguards verification capabilities that are made possible by UAS.

Vulnerability Assessments

Argonne's Vulnerability Assessment Team (VAT) evaluates a wide range of physical security devices utilizing the unique Adversarial Vulnerability Assessment approach. This approach is employed to understand the fundamental issues behind any given security application, and to discover and demonstrate security vulnerabilities, as well as practical countermeasures. This approach has repeatedly resulted in the discovery of surprising, easy-to-exploit vulnerabilities that are typically totally overlooked by security managers, designers, manufacturers, and vendors, as well as other vulnerability assessors using more conventional techniques.

The VAT has conducted vulnerability assessments on over approximately 1000 different physical security and nuclear safeguards devices, systems, and programs. For example, VAT personnel were the very first to demonstrate civilian code GPS spoofing in 2002. The team has reviewed inexpensive (a few $0.01 for some Tamper Indicative seals) to expensive (up to $50K for some safeguards monitoring systems), low technology through very high technology systems, both passive and electronic, and commercial as well as government systems and devices. Without exception, there are always flaws that can be compromised, and more importantly can be addressed and mitigated.

Vulnerability assessment (VA) is a critical step in the development and testing of verification hardware and approaches to nuclear safeguards. The purpose of an assessment is not to demonstrate that a particular verification effort is vulnerable to compromise but more to act as a thorough peer-review of the devices and approaches employed. The true purpose of this effort is to make stakeholders aware of potential vulnerabilities so that hardware can be improved, or so that an overall verification approach can be refined to cover potential gaps. The VAT, therefore, seeks to work with national laboratories or international partners to make collaborative improvements in verification approaches to improve confidence in verification activities.

Technology Development

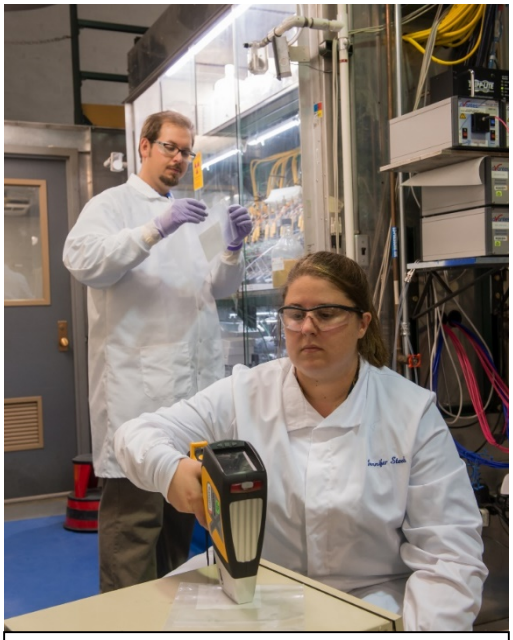
Argonne seeks to develop science- and engineering-based solutions to address critical safeguards needs such as novel approaches to improve safeguards for chemical processes in the nuclear fuel cycle and techniques for preliminary analysis of safeguards samples. Below are some examples of past and current safeguards technology development projects and other safeguards-relevant technical capabilities.

UV-vis Spectroscopy of Aqueous Streams

Argonne, in collaboration with Savannah River National Laboratory, designed, developed and tested a molecular spectroscopic technique based on COTS components to monitor actinide, transition metal concentrations in aqueous streams in real time. Both high (feed and product) and low (waste) concentration streams can be monitored. The system can operate in both qualitative and quantitative modes. The former is useful for screening process chemistry, which is generally not monitored with traditional quantitative techniques while the latter can be used, in conjunction with established destructive analyses, to provide real time estimates of material in process [Smith 2014-1].

Techniques for Prescreening IAEA Environmental Swipe Samples

In collaboration with Oak Ridge National Laboratory, Argonne conducted a survey and feasibility testing of several techniques that could determine the presence, amount or chemical form of safeguards relevant materials (e.g., actinides, chemicals indicative of reprocessing activities, etc.) on an Environmental Swipe Sample (ESS) preferably without opening or violating the double containment packaging [Steeb, 2015]. The goal of this project was to identify those techniques that could effectively triage samples for further analysis. This initial effort led to a second phase to further investigate two techniques that show promise, confocal Raman microscopy and ion mobility mass spectrometry. The Raman technique creates a map of a particular molecular stretch that corresponds to the molecule of interest (e.g., UO_2^{2+}) and is being developed to work through the bag if possible. Ion mobility mass spectrometry requires direct access to the sample as it uses a soft ionization source to volatilize chemical species on the ESS and produce a mass fragmentation pattern. This pattern can then be used to identify the compounds.



Argonne scientists test the utility of a handheld X-Ray Fluorescence instrument for prescreening Environmental Swipe Samples

Investigation of Laser Induced Breakdown Spectroscopy for molten salt monitoring

Argonne was part of a multi-laboratory team tasked with investigating the utility of using Laser Induced Breakdown Spectroscopy (LIBS) to monitor the concentration of various chemical species in a molten salt bath. LIBS works on the same principles as Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES), a common analytical technique, though the plasma is generated at the surface of the sample. Multiple technical obstacles were identified and solutions were proposed and tested by the various research teams. Argonne led the development of using an open path laser delivery system, rather than fiber optic delivery, and was able to successfully collect spectra from solid samples placed at a distance comparable to the required working distance in a molten salt system [Smith 2014-2].

Development of the handheld Cristallini sampler

Argonne is currently adapting the Cristallini method, developed by the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), which replaces the cryogenic collection of uranium hexafluoride samples with a passive, vacuum driven deposition of material on an alumina substrate. This method has several benefits as it eliminates the need for cryogenic materials, reduces the sample size and

eliminates the need to ship samples of toxic hexafluoride gas. Argonne is working to develop a portable version of the system, which is currently a facility modification, to allow the method to be utilized at any enrichment or conversion facility including on-site tank storage. This system would then be controlled and maintained by the IAEA (or other inspection agency) thus eliminating the need for facilities to provide materials during sample collections.

Future Areas of Safeguards Technology Research

Argonne leverages unique expertise for international safeguards applications. Argonne is the lead lab for converting research reactors from designs that raise proliferation or nuclear security concerns to designs that present lesser concern and continue to provide peaceful benefits. Argonne seeks to apply this expertise to develop modifications or monitoring technologies that further improve the ability to safeguard these facilities.

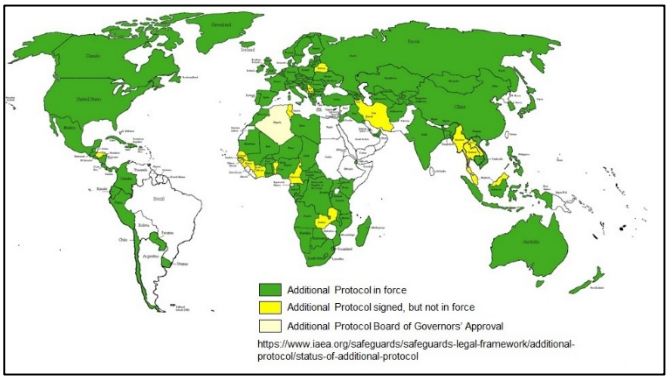
Argonne also has a significant energy storage research and development program primarily focused on developing battery technologies necessary to support renewable energy. Argonne can use this expertise to identify batteries, either on the market or emerging that could enable improvements to unattended monitoring systems. Other work that Argonne proposes which exploits Argonne's strengths and capabilities includes making better use of open source trade data for safeguards analysis, developing novel uses of Geographic Information Systems to improve visualization of nuclear material flows, and constructing novel approaches for improving the effectiveness and efficiency of environmental sample analysis.

Capacity Building

Argonne supports policy implementation to strengthen global nonproliferation efforts through targeted capacity building activities including consultations and training on international safeguards, both in the US and internationally, such as assistance to partners in implementing the Additional Protocol and developing the next generation of international safeguards professionals.

International Engagement on Safeguards

Argonne provides support to the DOE/NNSA International Nuclear Safeguards Engagement Program (INSEP), a program designed to work with international partners to improve the effectiveness and efficiency of safeguards implementation. Argonne supports INSEP in several primary areas: Additional Protocol (AP) implementation and outreach, Quality Management Systems (QMS) implementation, managing INSEP training materials, and engagement on technical safeguards issues.



Argonne began supporting INSEP's Additional Protocol (AP) international outreach efforts in 2007, and has since become a coordinator of outreach on the AP. Argonne experts have worked with over 20 countries to help them prepare for AP ratification, as well as assisting with effective implementation after ratification. Argonne has hosted regional INSEP workshops on the AP to encourage the sharing of best practices across IAEA member states. Some of the work Argonne has led includes working with states to understand AP reporting requirements, helping to prepare for IAEA complementary access, and providing information to the IAEA.

Argonne recently became involved in INSEP's Quality Management Systems (QMS) efforts. The goal of these efforts is to assist states with meeting their safeguards obligations by helping them to develop a single, coherent management system that ensures that they are able to consistently provide high quality safeguards information to the IAEA on schedule.

Finally, INSEP has adopted the Systematic Approach to Training (SAT) to ensure that the training assistance it provides meets the needs of its partners in a way that ensures the highest levels of quality and consistency. Argonne has worked with INSEP's SAT team to develop the training program manual and training materials database that will underpin the SAT effort. Going forward, Argonne will maintain a role in ensuring that INSEP's training materials maintain high levels of technical accuracy and consistency.

Argonne scientists and engineers are involved in collaborative technical work with partner countries. Recent work has included the provision of training on inductively coupled plasma mass spectrometry analysis of destructive analysis samples, as well technical input into ongoing discussions regarding pyroprocessing process monitoring for safeguards. Other work has included collaborative work to explore safeguards approaches for advanced reactor designs such as pebble bed reactors.

Additional Protocol Training for U.S. National Laboratory Staff
Argonne developed and hosts a web-based training for U.S. National Laboratory employees charged with submitting information in support of the annual U.S. Additional Protocol (AP) update declaration to the IAEA. The course consists of six training modules. The first module provides learners with basic information on the AP, including the DOE responsibilities under the AP. The second and third modules cover the process of preparing, review, and approving declarable items for submission to the DOE. The fourth module trains learners on how to prepare for and host potential complementary access visits by the IAEA. The fifth module identifies the process by which those responsible for doing so should update declaration items. Finally, the sixth module discusses security issues regarding the AP declaration process. Together, these modules provide training to new staff supporting the AP, as well as useful refresher training given the annual nature of AP reporting.

IAEA Export-Import Information Training Course
For the past 7 years, Argonne instructors and subject matter experts have conducted a biannual Export-Import Information Training Course (EXIM) for the IAEA's Department of Safeguards. EXIM is designed to familiarize IAEA safeguards staff with the origins and safeguards uses of export and import trade information, export controls in theory and in practice, and materials and equipment subject to export controls, with emphasis on their potential value as indicators of nuclear activities. The purpose of the course is to enhance the ability of IAEA safeguards staff to appropriately incorporate trade information into the State evaluation process, including industrial capability assessments and acquisition pathway analysis.

Training the Next Generation
Argonne is involved in training the next generation of U.S. international safeguards specialists. Argonne launched a safeguards focused internship program in 2014 and continues to seek interns to support both technical and policy related safeguards efforts. Furthermore, Argonne is developing relationships with universities to incorporate safeguards and nonproliferation topics in their academic courses. In 2016, Argonne and the University of Chicago piloted a course on nonproliferation, focusing on nonproliferation regimes, export controls, and international safeguards. Argonne is also developing relationships with the

University of Georgia, Middlebury Institute of International Studies, and Texas A&M University, among others, with the goal of leveraging shared expertise to mutual benefit.

Also, Argonne hosts two Nonproliferation Seminars per year, one in Washington DC, and one at Argonne National Laboratory. These seminars are aimed at staff in the U.S. government and at National Laboratories. They focus on providing an overview of the commercial nuclear fuel cycle and the interplay between nuclear industry and various nonproliferation regimes.

Opportunities

International nuclear safeguards is inherently an interdisciplinary endeavor. Argonne's safeguards research team consists of a diverse cadre of scientists, engineers, international affairs specialists, and policy analysts. A safeguards career can be a rewarding nontraditional application of technical degree as well as an impactful application of policy degree, not only for students and entry level employees, but also for mid-career and experienced professionals. Argonne values our partnerships with other institutions including universities, nongovernmental organizations and the DOE/NNSA national laboratories. Collaboration is not just desirable, but also necessary to achieve the goals of innovative, effective and efficient safeguards systems.

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