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JNMM Journal of Nuclear Materials Management

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Mission Statement

The Institute of Nuclear Materials Management is dedicated to the safe, secure and effective stewardship of nuclear materials and related technologies through the advancement of scientific knowledge, technical skills, policy dialogue, professional capabilities, and best practices.

INMM INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

President's Message

By Corey Hinderstein
INMM President

"So, what do you do?"

It is a question I am asked hundreds of times per year in social situations, and one that I am no better at answering now than I was when I started in this field more than 20 years ago. I have heard that this question is uniquely "Washingtonian," and that people in other parts of the United States and the rest of the world are less eager to get to know a stranger through his or her professional identity. Somehow I think that is not entirely true, even if DC cocktail partygoers are prime offenders. My bet is that most of you have faced this question too.

INMM members, and JNMM readers, are a diverse group. But one thing that we all have in common is that we deal in complicated, often technical, mostly difficult, and extremely important work. Practitioners in the field of nuclear materials management spend their days contemplating what many other people can't or don't want to try to understand – whether designing verification for a deal with North Korea or designing packaging to protect the public from potentially-harmful effects of radiation so that we can continue to reap the positive benefits of nuclear energy.

How do you answer the question so that your friend, neighbor or family member can understand what is so important that you have devoted your life, and more than half your waking hours, to pursue it? How do you answer the question so that they can care about what we care about?

I have made the case in this space that nuclear material management experts are more important now than ever, and that expertise must be valued if we are to solve the great challenges that confront the global community. But we can't expect the general public, starting with our social circles and extending to our national leaderships, to understand if we can't communicate it succinctly, clearly, and with vocabulary they understand. If done well, the answer can convey the dedication and fierce sense of mission that I know you share, and may even inspire someone to look more closely at a news article to see where your work fits in or to ask you a question they have had in mind for a long time with no one to direct it to.

The need for better communication about who we are and what we do is a challenge the INMM leadership has recognized, and we are working to improve our communications both with members and the broader pubic audience.

Here is my challenge to each of you: Let's start small, with each of us crafting a better answer to the persistent question. Students, please join in by sharing how you can best describe your career ambition. When you come up with a good answer, share it with the rest of us. Go to www.facebook.com/INMMHQ or tag @inmmtweets on Twitter. Use the hashtag #INMMWhatIDo so that we can follow along. I look forward to reading about the amazing array of missions that INMM members are pursuing around the world, and picking up good ideas on how to answer the next time I am asked.

So, INMM members and other readers…tell me, what do you do?

Keeping Up-to-Date with Workshops

By Markku Koskelo
JNMM Technical Editor

The JNMM editorial team has a number of contributed manuscripts in various stages of review. However, none of them have reached a point of being ready for publication at this time. Meanwhile, there have been two very interesting INMM sponsored workshops. The INMM has encouraged the membership and the regional chapters to organize workshops for quite some time. Workshops allow for focused topics to be discussed in a comfortable small scale setting. Workshops can also potentially reduce the travel costs for participants, something that continues to be an issue for all of us. Organizing a workshop takes time and effort and while there are certain workshops that continue to be successful year after year, organizing a workshop on a new topic is no simple matter.

The Novel Technologies, Techniques, and Methods for Safeguards and Arms Control Verification Workshop that was held In Albuquerque, New Mexico, August 29–30, 2017 is such a new workshop. It was organized jointly by the Institute of Nuclear Materials Management (INMM) Southwest Chapter and the INMM International Safeguards and Nonproliferation & Arms Control Technical Divisions, with support from Sandia National Laboratories (SNL). A total of 99 people registered for the workshop, from U.S. Department of Energy National Laboratories, the State Department, the Defense Threat Reduction Agency, universities, international organizations and industry. The structure of the two-day workshop included oral presentations, posters and table top exercises and was very successful. Kudos to the organizing committee for a job well done. Please see the article composed by the key members of the organizing team for further details.

The Spent Fuel Management Seminar was held in Alexandria, Virginia, January 23-25, 2018. This is an example of a long running series of workshops on a dedicated topic - the 33th annual such workshop in fact. This seminar was sponsored by the Institute of Nuclear Materials Management (INMM), in partnership with the U.S. Nuclear Infrastructure Council (NIC), and drew about 100 participants this year. There were representatives from Bulgaria, China, Japan, Spain, Sweden, South Korea and the United States, and the seminar featured presentations by key global industry experts. Please see the summary article by Carlyn Greene for further details on the talks and comments covered in this seminar.

Book Review Editor, Mark Maiello, provides us with a comprehensive review of the book, "Analytical Methods for Nonproliferation" by Edward C. Morse. Unlike many other more general books on matters of interest for the INMM membership, this text is designed — according to the preface — for advanced undergraduate and graduate students of nuclear engineering. For office use, be warned that the mathematical side of the book is rigorous and that derivations must be completed by the curious, ambitious and well-practiced reader. It's a classroom reference book first and foremost, and a reference for those skilled enough to use it.

In his column, "Taking the Long View in a Time of Great Uncertainty— Perhaps Not in My Lifetime", Jack Jekowski, Industry News Editor and chair of the INMM Strategic Planning Committee, gives us an interesting discussion between the nuclear security policies of the Obama administration versus the Trump administration. Given that he wrote his article a few weeks ago before the news that Mr. Trump pulled the United States out of the Joint Comprehensive Plan of Action (JCPOA) with Iran, I can only admire the clarity of his crystal ball.

Should you have any comments or questions, feel free to contact me.

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INMM Novel Technologies Workshop Encourages Safeguards and Arms Control Researchers to Think Beyond Traditional Verification Measures

Zoe Gastelum, Heidi Smartt, Alexander Solodov, Sharon DeLand, Eric Wallace, Meili Swanson and Steven Horowitz
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Abstract

This paper describes a workshop held in August 2017 by the INMM Southwest Chapter, in partnership with the International Safeguards and Nonproliferation & Arms Control Technical Divisions. The Novel Technologies, Techniques, and Methods for Safeguards and Arms Control Verification Workshop was conducted on the campus of Sandia National Laboratories and included 99 participants spanning U.S. government agencies, national regulators, national laboratories and research centers, academia and the nuclear industry. The purpose of the workshop was to discuss the development and application of new and emerging technologies and techniques for safeguards and arms control verification.

Introduction

The Novel Technologies, Techniques, and Methods for Safeguards and Arms Control Verification Workshop (hereafter referred to as the "Novel Technologies Workshop") was organized jointly by the Institute of Nuclear Materials Management (INMM) Southwest Chapter and the INMM International Safeguards and Nonproliferation & Arms Control Technical Divisions, with support from Sandia National Laboratories (SNL). The workshop aimed to convene policy and technology practitioners, ranging from students and early career professionals to senior experts, to discuss the development and application of new and emerging technologies and techniques for safeguards and arms control verification. Elicited discussion topics included containment and surveillance, cyber and information security, radiation detection, new information sources, information analysis, satellite imagery, additive manufacturing, emerging nuclear fuel cycle facilities, nuclear material accountancy, multilateral negotiations and verification regimes.

The workshop was held on August 29–30, 2017, at the SNL Center for Global Security Cooperation (CGSC) in Albuquerque, NM. A total of 99 people registered for the workshop, from U.S. Department of Energy National Laboratories, the State Department, the Defense Threat Reduction Agency, universities, international organizations and industry partners. The workshop aimed to convene policy and technology professionals to identify and explore transformative approaches, methods and techniques for challenges currently facing the safeguards and arms control communities. The workshop facilitated 22 oral presentations, 17 posters and a series of safeguards and arms control tabletop exercises. The workshop included a keynote address delivered by Joseph Pilat of Los Alamos National Laboratory (LANL) and Kristin Hertz of SNL's Livermore, CA, location.

The workshop format was designed with a morning session of presentations followed by a poster session and tabletop exercises in the afternoon. The technical program focused on safeguards on the first day and arms control on the second day. The safeguards presentations included topics of interest, such as data analytics, the future of inspections and nuclear materials assay. The arms control presentations covered topics such as data authentication and certification and ubiquitous sensing. This paper will provide an overview of the presentations, posters and scenarios, as well as the key themes and conclusions from the organizing committee.

Safeguards Technical Session

Safeguards Papers

Keynote speaker Joseph Pilat of LANL framed the two-day workshop by providing an assessment of the current nonproliferation and arms control regime, the present state of U.S. capabilities and the future of U.S. involvement in international cooperation.

The safeguards topical presentations began with a session on emerging assay technologies, chaired by Alexander Solodov of SNL. The session featured a paper from Oregon State University, in which the researcher outlined his work on a novel configuration to identify and characterize Cherenkov radiation in an operating research reactor, which has direct applicability for performing inspections to determine the existence of plutonium diversion. Next, a paper from North Carolina State University (NC

State) presented research on the use of field-deployable portable air samplers. These air samplers provide rapid transuranic activity estimates. This data allows for a defensible and graded approach to understanding from an air sample the transuranic activities indicative of nuclear operations of arms control and safeguards interest. Oak Ridge National Laboratory gave an overview of its work on reimagining, adapting and extending various non-destructive assay techniques for greater safeguards measurement applications. Concluding the session, Lawrence Berkeley National Laboratory highlighted progress toward field-deployable instrumentation for uranium hexafluoride enrichment assay, enabling a timelier and logistically feasible analysis process.

The following session, chaired by Zoe Gastelum of SNL, focused on the future of the International Atomic Energy Agency (IAEA) inspections. A team from LANL explored the concrete applications of augmented reality tools for improving the safety, security and productivity of nuclear facility operations. Then, a speaker from Project Team Innovation focused on the human element of inspections, highlighting how online team behavioral assessments and facilitated video mastermind groups could be used to build trust and collaboration pathways between inspection teams and position IAEA teams to succeed. Shifting the focus to autonomous technology, SNL researchers provided an assessment of unmanned aerial systems safeguards applications, analyzed implementation challenges and proposed recommendations for future research. Touching on a recurring theme throughout the workshop, Argonne National Laboratory (ANL) drew attention to the IAEA's limited resources and the related benefits of remote monitoring as demands on the IAEA grow in volume and complexity. ANL explained that while technical support like equipment installation, maintenance and repair is necessary for remote monitoring, the ability to do these comes down to cooperation and trust between state authorities, regional authorities and facility operators.

The final safeguards oral presentation session was chaired by Maikael Thomas of SNL and focused on the implications of "big data" for the safeguards regime. A researcher from LANL warned against the dangers of "data overwhelm" potentially disrupting the IAEA's ability to ensure the peaceful use of nuclear material. Taking a broad look at emerging technologies coming out of the big data revolution, the LANL researcher discussed how the IAEA can be proactive in adopting approaches to prevent data overwhelm. Following that overview, Aquila Technologies specifically analyzed machine learning for image verification and surveillance, identified the applicable features of machine learning and evaluated how software tools could be adopted to mitigate data overload.

Safeguards Scenarios Activity

For most of the afternoon, the technical program focused on interactive safeguards scenarios. Workshop participants were provided with two hypothetical scenarios, named after popular movies, that described the world political situation and the state of the nuclear industry in 2050. During the exercise, participants analyzed approaches and techniques for safeguards verification in these future worlds. A set of questions was provided to help guide the conversation and scenario development.

Safeguards Scenarios Description

In the "Passengers" scenario, globalization and shared global visions have led to blurred State borders (similar to the current state of the EU). Technological progress has led to advancements in automation, connectivity and artificial intelligence, including in the nuclear industry. Small modular reactors (SMRs) have spread globally, and large (continental) reprocessing and fuel fabrication facilities are built to provide for the needs of the wide reactor network.

In the "Fury Road" scenario, State boundaries are strict, and there's a sense of distrust in the international system, including toward States, people and even electronics. This has led to less automation and connectivity, and to mostly analog-based systems, including for safeguards activities. Large reactors and processing facilities are present in developed States; however, they're isolated from neighbors.

Safeguards Scenario Outcomes

For the Passengers scenario, groups generally visualized significant developments in nuclear technology and the nuclear industry, including non-uranium (that is, thorium) fuel cycles and automated activities such as fuel transportation. Fusion is still predicted to be several decades away. Despite large amounts of nuclear fuel being used, highly efficient fuel cycles minimize waste and are centralized. For ultimate waste disposal, politically accepted disposition mechanisms such as deep underground disposal or vitrification are used effectively. There was some disagreement regarding whether the spread of SMR technology would lead to either fewer reactor types for more streamlined production or more diverse technologies.

In the international nuclear safeguards area, human inspectors are less involved in hands-on activities, but they still have a role in verifying and performing quality assurance on automated processes, either on site or remotely. Human inspectors may also conduct infrequent hands-on inspections in the case of anomalies or to verify the absence of clandestine activities. However, most inspection activities tend to occur remotely using unmanned systems. Autonomous robotic activities occur frequently, especially in hazardous areas, to protect human workers. Automation is verified and calibrated by human quality insurance inspectors, and redundant systems are in place to prevent single points of failure. Data transmission includes data authentication and encryption.

Groups discussing the Passengers scenario offered diverse opinions regarding containment and surveillance (C&S) approaches. While some suggested a more automated approach to specific activities, including cameras, seals with integrated sensors and real-time anomaly detection, others proposed that C&S occurs more at the system level rather than focusing on smaller processes. Nuclear material accountancy (NMA) is likely automated with periodic inspector verification. Safeguards by design (SBD) is almost always implemented to facilitate automated safeguards. Standardizing SMR and other facility designs may expedite the design information verification (DIV) process. Remote sensing focuses on identifying anomalies and is integrated into a global network. Some participants argued that operators would find inspectors less intrusive due to the seamless integration of technology with safeguards, while others thought that operators aren't needed at all due to automation and artificial intelligence. Safeguards analysts play an important role during the design phase of a facility. Mass data collection and analysis is used to detect undeclared activities, which are an increasing challenge due to the wide spread of nuclear technology. Groups contrasted regarding to what extent State, regional and global safeguards analysis may remain important; however, the focus may shift toward subnational actors rather than States.

Themes and predictions from the Fury Road scenario contrasted vastly with those of the first scenario. Most groups argued that advanced fuel cycles would be available to wealthier countries, while other groups did not believe non-uranium fuel cycles would exist, because technology had not developed. Reprocessing is important for wealthier States that seek to maximize individual resources. Traditional safeguards may occur on a quid pro quo basis between States with limited access, and the NPT may be obsolete in this scenario. In a bilateral inspection, the equipment may have to be that of the host State. There is a lack of automation due to a public distrust of technology and artificial intelligence, and inspectors are limited in their techniques and equipment based on the political relations. National technical means and spying with satellites or drones are used to collect data on other States. Satellites and drones play a large role in remote sensing to detect changes in a facility's design, construction or emissions. Protecting sensitive data from hackers, insider threats and spying from other States is crucial, and it is accomplished through encryption or physically transporting data on paper or a flash drive. C&S technologies such as seals and cameras are installed and verified on sites by human inspectors. Some groups emphasized the importance of C&S and NMA for domestic rather than international security and safeguards. Most measurements include visual inspections on site, possibly with random sampling. Design verification may be obsolete or conducted visually or manually through methods such as a tape measure. Meanwhile, cooperative remote monitoring, such as seismic, significantly diminishes or disappears completely. Due to the mistrust between States, operators are suspicious of inspectors and are uncooperative. Relations between States are fostered over time to build mutual trust. Safeguards conclusions are drawn from limited information on a State or facility level.

Arms Control Technical Session

Arms Control Session Summaries

On Day 2 of the Novel Technologies Workshop, there were three technical sessions on arms control and one special session on the arms control and safeguards cross-cutting issue of cyber-physical systems.

The first session, chaired by Jay Brotz of SNL, included five presentations on novel approaches for arms control verification. This session spanned physical sensing equipment and information barriers, novel declaration and verification approaches, and sociological examinations of nonproliferation negotiations. One paper from Cardiff University highlighted the unique contributions of both scientists and policymakers to treaty negotiation and implementation, touching on multiple areas of interplay between the two communities that lead to more robust international agreements. In another paper, researchers from Pacific Northwest National Laboratory (PNNL) described a new verification approach that relies on declarations of national security complex activities and infrastructure, which the PNNL team tested using a simulation of a hypothetical country to determine its potential effectiveness for arms control verification. The session also featured a paper from the University of California, Berkeley, which described self-organizing networks of multimodal sensors that could be used to verify the absence of undeclared nuclear materials or activities.

Jennifer Tanner of PNNL chaired a session on data authentication and certification for arms control, which featured two papers that built on the joint Department of Energy and Department of Defense Authentication Task Force (ATF) activities in 2000. One paper, presented by PNNL, described work to expand and better utilize the ATF's standards-based approach for data authentication and certification, while the other paper, by PNNL and Milagro Consulting, proposed a novel system architecture to provide the assurances of data authenticity and confidentiality to both the monitoring party and the host state. Jennifer Tanner also chaired a session on ubiquitous sensing that included a paper from NC State that focused on the use of environmental materials as "ubiquitous dosimeters" that could be used to support retrospective imaging of radiation sources to support nuclear forensics.

The arms control day also included a special session, chaired by Morag Smith of LANL, on cybersecurity as it relates to the exploitation of hardware in Internet-connected devices. The focus was on devices that have full computer-like capabilities but are difficult to protect in the manner that we currently apply to desktop and laptop computers — for example, Internet of Things devices like thermostats and baby monitors. One paper from researchers at LANL described the new and evolving threat space provided by myriad Internet-connected devices, whereas another LANL paper outlined a novel approach to detecting malware by monitoring a device's volatile memory.

Arms Control Scenario Summary

Workshop participants were provided with three futuristic scenarios and asked to evaluate how each would impact verification opportunities and challenges. For each of the three futuristic scenarios, participants evaluated three potential arms control applications: (1) verifying limits on stockpiles of warhead or fissile materials, (2) confirming that a presented item is what it is declared to be (warhead or fissile material) and (3) verifying that an item has been dismantled. The futuristic scenarios were designed to explore the impact of two key uncertainties in the types of monitoring approaches that may be needed in the future. These uncertainties were the level and quantity of information required by the Inspecting Party, and the ability to address host safety and security concerns with respect to using technology.

The first scenario was the *Less Is Better* future, where the information needed by the Inspecting Party is on the minimalist end of the spectrum, but non-zero. A global environment exists in which there is more overall transparency, so that additional information is available by different means. In addition, while many novel technologies have matured, the means for assuring confidence in them in a high-consequence environment has not evolved as rapidly, and the host is cautious about using technical solutions.

The second scenario was the *Pushing the Boundaries* future, where the information needed by the Inspecting Party is on the maximalist end of the spectrum. This entails rigorous confirmation of declarations and potentially cooperative inspections of undeclared infrastructure. A global environment exists in which there are significant levels of mistrust as to stockpiles and strategic intentions. In addition, while many novel technologies have matured, the means for assuring confidence in them in a high-consequence environment has not evolved as rapidly, and the host is cautious about using technical solutions.

Finally, the third scenario was the *Absolute Certainty* future, where the information needed by the Inspecting Party is also on the maximalist end of the spectrum. This entails rigorous confirmation of declarations and potentially cooperative inspections of undeclared infrastructure. A global environment exists in which there are significant levels of mistrust as to stockpiles and strategic intentions. In addition, the means for assuring confidence in novel and advanced technologies in a high-consequence environment has matured as the technologies themselves have matured. While the host still has significant safety and security considerations, solutions exist to meet these concerns.

Arms Control Scenario Outcomes

Verification approaches in the *Less Is Better* scenario were generally low-tech and, in some cases, used continuous inspector presence and visual confirmation instead of technology. Initial declarations, container counting, seals, serial number verification and random sampling were important techniques for verifying limits on stockpiles. Continuous inspector presence, tracing provenance of items and maintaining continuous knowledge of an item's chain of custody were all valuable for item verification. For dismantlement, a "black box" or "room within a room" approach was proposed, with fixed-mass input and output measurements for verification. Novel ideas included using anomaly detectors to help monitor the black box.

In the *Pushing the Boundaries* future, limits on warheads or material were verified through (1) assessing a material balance across the lifecycle (production, stockpile, dismantlement) and (2) measuring attributes and templates on stockpiled items. Novel approaches to equipment authentication included third-party verification or exchange of monitoring equipment (assuming inspector-provided instrument and host-provided information barrier). For item verification, active seals with tracking and historical records were used to provide continuous knowledge of the item. Active seals would require lifetime batteries and data authentication. To verify dismantlement, inspectors could use limited viewing (shrouding) or videography for visual observation. Radiation measurements were also used, and information barriers were added to protect sensitive information. Mass balances and templates for comparison were seen as potentially useful to verify removal of all components. Machine learning was also proposed for assessing movements during the dismantlement processes and providing a true/false output to the inspector. Novel ideas included the use of video surveillance to track and analyze vehicle traffic, smart materials to aid in change detection in the dismantlement environment and uniquely shaped containers for different types of dismantled components.

In the *Absolute Certainty* future, the primary issue in verifying limits was assessing the accuracy of a State's initial declarations. As in the previous scenario, taking a full lifecycle approach was important. Several techniques were proposed to monitor warhead containers, including seals, video surveillance, human intelligence and accelerometers. Human intelligence and collection of disparate data were seen as important to detect undeclared activities. While specific properties of the item — such as mass, geometry, components and isotopics — were verified for item identification, this data was protected with effective information barriers. For dismantlement, low-resolution sensing and a black box methodology were used to verify key inputs and outputs while protecting the dismantlement process itself from disclosure. The outputs were then tracked for future monitoring, and inspectors were granted access to unclassified components. Participants noted that, for this futuristic scenario, unfortunately, as verification technology matures, so will technology with the ability to deceive. Novel ideas included using artificial intelligence as an impartial third party that could be used as an information barrier.

Overall, all the participants were actively engaged in the scenario exercise, and several of the teams drew explicitly on ideas from presentations given in the morning session. The scope of information collected and the level of technology used increased as information needs increased. Thus, teams addressing needs for high-inspection information found that verifying across the full weapon and material lifecycle would be important. Also notable was that multiple teams addressing the *Pushing the Boundaries* and *Absolute Certainty* scenarios suggested using a neutral third party to verify (authenticate) equipment.

Poster Session Summary

The Novel Technologies workshop also included two poster sessions, which focused on international nuclear safeguards and arms control.

The safeguards poster session included 10 posters on safeguards topics, including the development of sensors mounted on unmanned aerial vehicles (UAVs); safeguards approaches for new or emerging nuclear fuel cycle facilities; advanced tag and seal technologies, including inexpensive tags and remotely monitored seals; rapid in-field measurement techniques; and safeguards data integration and visualization techniques.

The arms control poster session included seven posters, which focused on radiation detection and imaging technologies, advanced modeling approaches and the use of biometric tracking for security and access control. Public ledger technologies (block chain) to support chain of custody tracking throughout the warhead lifecycle were also called out as a new concept to watch in the arms control monitoring and reporting arena.

While some posters had strong applications specific to nuclear arms control or international safeguards, some of the advanced and emerging technology themes discussed in each poster session could feasibly be applied to either topic area. One such example was an update on the use of ultra-high-resolution microcalorimeters for safeguards and arms control verification. The poster session also included two papers on combining UAVs or drones with radiation measurements or video imaging for safeguards or arms control purposes. However, most of the posters presented rather new concepts in the context of the objectives for this workshop.

The poster sessions allowed researchers to engage in additional discussions outside the time limits of a traditional oral presentation session and included professional networking opportunities for all attendees.

Conclusion

Overall, the workshop was successful. The participants engaged in presentations and poster sessions on innovative new methods and technologies for safeguards and arms control. By allowing the participants to discuss the extremes of society (the Passengers and Fury Road scenarios) in relation to the safeguards regime, the discussions generated interesting "out-of-the-box" solutions.

Most of the discussions and key take-aways listed below were captured during the hands-on tabletop exercise:

- Cooperation and trust are essential elements for the successful implementation of novel technologies.
- Emerging technologies enable a range of assay methods to be discovered, reimagined and adapted for various environments and applications. While technology is rapidly advancing and is a greater part of everyday life than ever before, humans are still central to the safeguards regime. Novel technologies can be leveraged to augment the human element that underpins safeguards and arms control verification regimes.
- Data is a double-edged sword. Verification bodies require accurate, relevant data to reach sound conclusions, but too much data could threaten to overwhelm the ability to manage, verify and act on insights from that data.
- Novel technologies and new ideas need to address constraints on resource — including time, people, computational load and measurement opportunities — to improve the ability of relevant institutions and governments to verify international safeguards, arms control agreements and future nonproliferation treaties or agreements.

Keywords

Safeguards, arms control, novel, emerging, innovative, workshop

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Meili Swanson — *Meili Swanson is a staff member at Sandia National Laboratories, where she supports the International Nonproliferation Export Control Program (INECP). In May 2016, she graduated from the University of Georgia with a BA in international affairs and a master's degree in international policy. Her interest in international relations began at the age of seven months old, when she was adopted from China by her American mother. Since then, her nonproliferation experiences have included completing a Richard B. Russell Fellowship at the Center for International Trade and Security and a research internship with TradeSecure, LLC.*

Steven Horowitz — *Steven Horowitz is a nuclear engineer in the International Nuclear Security Engineering Department at Sandia National Laboratories in Albuquerque. Before working at SNL,* *Steven received his master's degree in international affairs from the Bush School of Government and Public Service at Texas A&M University, where he worked as a graduate assistant researching topics in international security, such as nuclear strategy. Steven also has an MS in nuclear engineering from Texas A&M University, where he completed his master's thesis on post-detonation nuclear forensics.*

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Highlights of the 33rd Annual INMM Spent Fuel Management Seminar

Carlyn Greene, Senior Vice President, Spent Fuel
Ux Consulting Company

Introduction

Each January, nuclear professionals look forward to gathering in Washington, D.C., to network; learn about spent fuel management practices worldwide, new developments in the field and emerging issues; and discuss the effects of politics and public perception on programs around the world. The 33rd annual Spent Fuel Management Seminar, sponsored by the Institute of Nuclear Materials Management (INMM), in partnership with the U.S. Nuclear Infrastructure Council (NIC), drew about 100 participants. There were representatives from Bulgaria, China, Japan, Spain, Sweden, South Korea and the United States, and the seminar featured presentations by key global industry experts. Topics included the status of global spent fuel management, international transportation of spent fuel, the politics of spent fuel management in the United States, spent fuel technology projects and consolidated storage initiatives. Corey Hinderstein, president of INMM, noted in her opening remarks that "dealing with the back end of the fuel cycle is part and parcel to responsible nuclear stewardship."

The 2017 conference had a decidedly optimistic tone about the U.S. spent fuel management program, with presenters and participants exuding confidence that the newly installed Trump administration and Congress would resurrect the Yucca Mountain, NV, program. NIC Executive Director David Blee said in his opening remarks in 2017 that after "eight years in the wilderness, we will see a renewed focus on Yucca Mountain" in the coming months, and that the NIC is "working to make Yucca Mountain great again." The tone of the 2018 conference was more of reduced expectations and disappointment that the status quo still reigns with regard to the waste disposal program, but progress is being made in other areas, such as private initiatives to build interim storage facilities. Blee admitted in his 2018 opening remarks that last year, many people thought we were "off to the races," but now that is still to be determined. He added later that the hope and change from last year has morphed into a sober assessment of where the United States stands today in nuclear waste management

Overview

Ray Furstenau, Associate Principal Deputy Assistant Secretary in the Department of Energy's Office of Nuclear Energy (DOE/NE), said in his keynote presentation that this administration brings new opportunities for nuclear, and with Secretary of Energy Rick Perry strongly supporting nuclear energy, there is "unambiguous" support for nuclear power in this administration. Furstenau contended that the administration recognizes the importance of nuclear energy today and in the future, as it will enhance energy security, economic prosperity, global security and environmental sustainability.

Furstenau primarily spoke about nuclear power in general. He emphasized that the United States could see anywhere from 74 to 117 nuclear units operating by 2030. The key to maintaining the current 99 reactors in operation or reaching toward that lofty goal of 117 operating reactors is to get the cost of nuclear to be competitive with natural gas and other electricity generation sources. NE focuses on three main pillars: maintaining the existing fleet, the advanced reactor pipeline and the fuel cycle infrastructure, which includes the back end.

To maintain the existing fleet of reactors, the DOE is working with the Electric Power Research Institute (EPRI) on an R&D program to extend the operating life of light water reactors (LWRs). The DOE is also working with industry in a cost-share program to develop accident-tolerant fuels.

Furstenau said the DOE/NE is building public–private partnerships and that it provides the nuclear industry with access to the technical, regulatory and financial support necessary to move innovative nuclear energy technologies toward commercialization of advanced reactors in an accelerated and cost-effective manner. Small modular reactors (SMRs), for example, can offer greater affordability than the larger reactor designs and provide a number of energy and environmental benefits. "Microreactors" can provide some of the same benefits as SMRs with even greater siting flexibility. Microreactors can also be used to power remote operating bases and data centers, and can be useful for disaster relief, such as for the recent state-wide and long-lasting power outage in Puerto Rico.

Fuel cycle infrastructure includes the entire nuclear fuel cycle, from uranium supply to final disposal of spent fuel. Furstenau emphasized that spent fuel recycling technology R&D is still going on, and he noted that the United States needs to resolve the uncertainty about the management of the nuclear waste (including spent fuel). He mentioned LWR recycle, advanced reactors, interim storage and permanent disposal.

When asked what is happening in the DOE/NE regarding the push to get funding for restarting the Yucca Mountain licensing proceedings, Furstenau just said that the DOE/NE has laid out its priorities, which are to restart the proceedings and move forward with interim storage. President Trump requested $120 million for those purposes in his fiscal year (FY) 2018 budget request, and the DOE is waiting on Congress to act on the budget. Furstenau would not specify if the DOE will ask for more funding for Yucca Mountain in the FY 2019 budget request, which should be released in the coming weeks.

U.S. Political Landscape – the Status Quo

Despite the strong support for nuclear energy, several speakers on a panel titled "Spent Fuel Political Landscape" relayed concerns that the government has continued its inaction on spent fuel issues. **Katrina McMurrian, Executive Director of the Nuclear Waste Strategy Coalition (NWSC)**, said that the organization's members have the following priorities:

- Funding the Yucca Mountain program, beginning with the remaining months in FY 2018.
- Changing how nuclear waste management is financed to ensure funding is available for the long term, rather than subject to annual appropriations.
- Passing legislation, particularly H.R. 3053, the *Nuclear Waste Policy Amendments Act of 2017*, which includes several important measures that could get the nuclear waste disposal program back on track, including the following:
    - Restarting the Nuclear Regulatory Commission (NRC) review of the Yucca Mountain license application.
    - Reforming the Nuclear Waste Fund (NWF) to protect ratepayers' investment for the disposal of spent fuel to ensure that the NWF is used for its intended purpose.
    - Authorizing the DOE to pursue consolidated storage of utility spent fuel.
    - Increasing the statutory limit on the amount of waste that can be disposed of at Yucca Mountain from 70,000 metric tons to 110,000 metric tons.

Six organizations — the American Nuclear Society, the Decommissioning Plant Coalition, the National Association of Regulatory Utility Commissioners (NARUC), the Nuclear Energy Institute (NEI), the NIC and the NWSC — have urged Congress to appropriate funds in FY 2018 for three critical elements of an effective nuclear waste program:

- Completion of the Yucca Mountain licensing review;
- Implementation of a pilot consolidated interim storage facility with priority for stranded reactor fuel; and
- Preparation for spent fuel and defense high-level waste (HLW) transportation.

McMurrian noted that the NWSC, on behalf of its members, transmitted a letter to Congress last October that asked Senators to provide leadership to ensure that the DOE "honors its commitments" under the Nuclear Waste Policy Act (NWPA) and the Standard Contract with utilities "to remove and dispose of" spent fuel and HLW "that is currently stored at operating and shutdown reactor sites — as well as the DOE's federal facilities — in 37 states and over 100 communities."

The letter points out that the DOE has "consistently failed to meet these obligations, harming electric consumers served by nuclear-generating utilities as well as all U.S. taxpayers." The NWSC urged Congress to appropriate funds in FY 2018 for the three components of a nuclear waste program that McMurrian detailed in her presentation.

The NWSC represents the "collective interests of member state utility regulators, state consumer advocates, state energy and radiation control officials, tribal governments, local governments, electric utilities with operating and shutdown nuclear reactors and other public and private sector experts on nuclear waste policy matters."

Eric Knox, Vice President of Strategic Development for Nuclear and Environment at AECOM, also acknowledged the "great expectations" of a year ago. Knox said the bipartisan passage of H.R. 3053, which was introduced by Congressman John Shimkus (R-Ill.), a strong supporter of Yucca, was significant. So many Congressional votes, Knox observed, follow along partisan lines, but this bill cleared the House Energy and Commerce Committee nearly unanimously by a vote of 49-4. Knox asserted that Yucca Mountain has strong bipartisan support among all representatives in the House. Like McMurrian before him, Knox said the bill is a good one because it would advance the Yucca Mountain program, and it also includes provisions for interim storage — something the House has previously resisted without progress on Yucca Mountain. He asked for a show of hands in the audience as to how many people thought it would pass if presented for a vote in the full House. The overwhelming majority of conference participants thought it would. However, only two people thought the bill would be presented to the full House for a vote before the midterm elections this November. Knox is skeptical that much will happen in the Senate this year related to Yucca Mountain. Senate Majority Leader Mitch McConnell is focused on maintaining a Republican majority and likely will not want to raise the controversial issue before the midterm elections in November 2018. McConnell supports Nevada Senator Dean Heller, who is an opponent of Yucca Mountain. Heller has made it clear that he cannot win the primary if Yucca Mountain goes forward. Heller was trailing his primary opponent, Danny Tarkanian earlier this year, but the issue became moot, however, when Tarkanian, who supports the Yucca Mountain licensing process, decided to end his Senate bid at the request of President Trump so that Sen. Heller would not face an opponent in the primary. Tarkanian is running instead for the House seat in Nevada's 3rd Congressional District. The primary is June 12.

Transportation

"Without transportation there is no nuclear industry," said **John Mulkern, Secretary General of the World Nuclear Transport Institute (WNTI).** Mulkern emphasized that radioactive materials are safely transported by sea, air, road and rail, but the past impeccable safety record does not guarantee an equally safe record in the future unless the industry remains diligent. The transportation of radioactive materials has been going on for decades. In more than 50 years, not a single incident has occurred that caused significant radiological damage to people or the environment. About 20 million transports of radioactive materials take place around the world each year.

WNTI was established 20 years ago by three companies — AREVA, International Nuclear Services and the Federation of Electric Power Companies of Japan. In 2018, WNTI has approximately 50 member companies from a wide range of industry sectors, including radioisotope producers, major utilities, fuel producers, transport companies, package designers, package producers and more. WNTI is headquartered in London, but has representatives in the United States, Japan, South Africa, Australasia and China.

WNTI promotes several key principles related to the safety and security of transporting nuclear materials:

- Safety in protecting people and the environment from the hazards of the materials.
- Security in protecting the material from malicious acts or diversion.
- Safety that's inherent in the packages, because the more hazardous/sensitive the radioactive content is, the more robust the package/cask will be.
- In-depth safety, including a series of barriers between the material transported and the public/environment.
- In-depth defense through strength, compliance and organization.

A WNTI Back End Transport Working Group (BET WG) has been working for more than seven years on topics known to be issues for industry, stakeholder groups and regulators. The focus has changed to reflect the move from spent fuel transports to cleanup and decommissioning, including cask decommissioning, waste transport regulation framework, waste inventory characterization and dual-purpose casks.

The International Atomic Energy Agency (IAEA) has established standards for transportation packages based on the characteristics of the nuclear material to be transported. Spent fuel, mixed oxide (MOX) fuel and vitrified HLW are all ground shipped in specially designed Type B packages, referred to as *casks* or *flasks*. Shipping nuclear materials by sea requires specialized vessels that also must meet strict regulations.

The transport of radioactive material is governed by several safety regulations, including SSR-6, "Regulations for the Safe Transport of Radioactive Material." For transport by sea, the International Maritime Organization (IMO) established the "International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes on Board Ships (INF Code)."

WNTI is preparing a new document related to the transport regulations that will include a gap analysis for transportation after long-term storage, and topics related to storage and transportation cask aging management.

Robert Quinn of Westinghouse Electric Company noted that the United States could be embarking on the opportunity to consolidate the storage of spent fuel from so-called stranded reactor sites (sites that have been fully decommissioned except for the spent fuel still in storage at an on-site independent spent fuel storage installation [ISFSI]) to a common centralized location sometime in the next decade. However, Quinn emphasized the importance of preparing the path forward so that when a consolidated storage facility is licensed and built, there are no roadblocks to moving the fuel to the facility. Transfer equipment, transportation casks, heavy haul trucks and rail cars that meet Association of American Railroads (AAR) standards must be purchased; rail and heavy haul routes must be planned; and public outreach must be conducted. Challenges to these steps include Congress passing legislation that will authorize the DOE to store spent fuel on an

Figure 1. Cask Test Transportation Route from Spain to the United States and Return

interim basis, and industry and the NRC confirming that there are no regulatory gaps and ensuring that transportation certificates of compliance (CoCs) are up to date. A component that must not be ignored is the need for public confidence that this material can be safely transported thousands of miles. As Mulkern also emphasized, to secure public acceptance, the fact that the nuclear industry has been transporting nuclear materials for more than 70 years is a testament to the effectiveness of the regulatory requirements and processes for spent fuel transportation, which are adequate and well proven, and the industry's implementation of these requirements in partnership with regional and local governments. Shipping spent fuel from nuclear plant sites to a centralized location is not an "overwhelming challenge"; Quinn stressed that these shipments would represent just a minimal increase in the annual shipments of radioactive materials, and an infinitesimally small amount of shipments compared to the transportation of other hazardous materials.

Stefan Anton of Holtec International noted the "perceived concern" that if the United States were to begin a large-scale transportation program to a centralized interim storage facility or a repository, not enough transportation casks would be available. He stressed that Holtec alone has a large range of transport casks that could be used and that the United States has sufficient experience in cask transportation to conduct a large-scale campaign. He also asserted that transporting high burnup fuel is safe, and ongoing research is demonstrating that high burnup fuel does not behave significantly differently than non-high burnup fuel. Even so, transportation casks systems have been developed and approved by the NRC that address the concerns.

Jeff England of NAC International described some of the upfront work that must be done to prepare a canister for transportation. He emphasized the importance of verifying details of the contents of a transportation package, including that the package was built in accordance with the drawings, the type and form of materials that can be included in a package and the maximum quantity of material per package. Before a shipment can take place, all of those items must be verified. He noted that just because something is stored in a dry cask does not mean it automatically meets the requirements for transportation — for example, heat loads and cool times are different for storage than for transportation; definitions and requirements for damaged and undamaged fuel are different for storage than for transportation. This verification is a time-consuming but critical step that must be completed before shipment.

R&D

Much research is being conducted to confirm that spent fuel can be stored safely for very long periods of time, then transported safely and possibly stored again in another location, such as a consolidated interim storage facility — known as a "storage-transport-storage" scenario.

Sylvia Saltzstein of Sandia National Laboratories (SNL) presented the results of testing led by SNL with the Pacific Northwest National Laboratory (PNNL) on behalf of the DOE to validate the assumption that spent fuel will maintain its integrity during normal conditions of transport (NCT). Three series of tests using three surrogate pressurized water reactor (PWR) assemblies were conducted: truck data on a vertical acceleration shaker table, an over-the-road truck test and truck/rail data on a commercial seismic shaker with six degrees of freedom. International partners contributed valuable hardware and expertise and shared in the cost. Equipos Nucleares S.A. (ENSA) supplied an ENSA ENUN 32P rail cask for a series of transport tests. Three surrogate assemblies were loaded in the cask, which was instrumented with 77 accelerometers/strain gauges. The instrumentation/battery box contained two 40-channel data acquisition systems, 20 batteries and 1.25 miles of cable.

The casks were transported via a 16-axle, 110-foot-long heavy-haul truck that drove across northern Spain in June 2017; a coastal sea shipment took place from Santander, Spain, via Rotterdam in the Netherlands to Zeebrugge, Belgium in June; and an ocean transport from Europe to the Port of Baltimore took place in July, followed by a commercial rail shipment on a 12-axle railcar from Baltimore to Pueblo, Colorado, where eight different tests were conducted at the Transportation Technology Center in August. The trip to return the cask to ENSA took the same route (See Figure 1 for the transit route and Figure 2 for a photo of the transportation cask in the rail transport mode.) Data was collected throughout all legs of the transport, as well as during transfers between legs. In total, data was collected over 54 days, during which time 8 terabytes of data were collected over 9,458 miles in seven countries and 12 states in the United States.

The overall conclusion reached is that "the realistic stresses [that] fuel experiences due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding. We only have limited rail data, which most likely will be the prevailing transportation mode."

The coming year will be spent analyzing the data and developing a model that will allow the team to relate the results to different storage and transportation systems. Frequency transmission,

Figure 2. Railroad Transport Mode of the Test Cask in the United States

instantaneous versus gross loading and system behavior will be examined, and the model will be refined to allow the test participants to relate the results to other storage and transportation systems, as well as other fuel mechanical properties.

The photo below shows the ENSA cask after being transferred by crane from the trailer to the 12-axle railcar. The picture is prior to lashing (welding) and reconnection of the instrumentation system. The photos are taken from Saltzstein's presentation.

In addition to the DOE, SNL and ENSA, cask test participants included Argonne National Laboratory (ANL), Empresa Nacional de Residuous Radioactive S.A. (Enresa), ENUSA Industries Avanzandas S.A., Coordinadora Internacional de Cargas S.A., PNNL, Transportation Technology Center, Korea Radioactive Waste Agency (KORAD), Korea Atomic Energy Research Institute (KAERI) and Korea Nuclear Fuel Company (KNFC).

Keith Waldrop of the Electric Power Research Institute (EPRI) and **Dave Tomlinson of Dominion Energy** discussed recent milestones of the DOE/EPRI-sponsored High Burnup Data Project. The project is obtaining additional data about high burnup fuel in storage to support the aging management plans required to be in CoC renewals for dry casks. This project will provide data from actual fuel stored in an actual cask under real conditions — not just from laboratory testing.

The high burnup fuel was loaded into a TN-32B cask that was instrumented with 63 thermocouples for data collection. The cask was placed into service on the storage pad at Dominion's North Anna Power Station in November 2017. The initial condition of the fuel is known, and the fuel will remain in storage for about 10 years. Periodic temperature measurements and gas samples will be obtained and used in an application submitted to the NRC to certify the TN-32B cask for transportation. The fuel's post-storage condition will be determined by reopening the cask and examining the fuel. Once that data is obtained, the cask will be closed again, and the fuel will remain in storage while data continues to be collected. The cask may be reopened later to collect additional data on the fuel's condition.

Other members of the research team include Orano, Westinghouse, NAC International and several DOE national laboratories.

Select Country Highlights

Representatives from five countries — Bulgaria, China, Korea, Sweden and the United States — presented their respective country-level spent fuel management programs. Leading into a session on global spent fuel initiatives, **Nigel Mote, Executive Director of the U.S. Nuclear Waste Technical Review Board (NWTRB),** presented an overview of spent fuel management programs. His presentation included a informative summary table of the type of storage (location and wet or dry), whether the canisters are in bolted or welded casks and the disposal policy of each country. Mote also noted that R&D is underway to support extended spent fuel storage. The areas of research include facility degradation/aging management, cask/canister drying, bolt and seal performance, fuel assembly/cladding/fuel performance, damaged fuel handling and computer modeling.

Carlyn Greene, Senior Vice President of the Ux Consulting Company (UxC), provided a high-level overview of spent fuel management policies in the United States, highlighting political developments (or lack thereof) and the status of dry storage. The Nuclear Power Outlook (NPO) and UxC Requirements Model (URM) report estimates future nuclear reactor requirements and spent fuel discharges. UxC projected that the world's nuclear power programs will discharge a total of approximately 56,000 MT of spent fuel through 2030. Less than 30% of that will be reprocessed, and the rest placed into storage or in a repository if one is available before then. In UxC's Nuclear Industry Value Chain report, the company estimated the overall dry cask storage market size to be about $12.4 billion in 2015 U.S. dollars from 2015 through 2030.

In the United States, not much changed in 2017 in terms of policy. Commercial spent fuel continues to be safely stored at reactor sites around the country. The NRC continues to regulate its storage. The federal government continues to reimburse utilities, using the taxpayer-funded Department of Justice Judgment Fund, for the cost to store the spent fuel at the reactor sites. Studies are ongoing that will confirm the safety of spent fuel in dry storage for up to 300 years. As mentioned above, an EPRI-led team is studying the performance of high burnup fuel that has been in storage for at least 40 years to ensure it can be safely transported after storage. That study is sponsored by the DOE. A key milestone of that study took place in November 2016 when a specially instrumented cask was loaded with high burnup spent fuel from the North Anna Power Station, where it will remain in storage and be monitored.

The focus of U.S. spent fuel management changed in 2017 under President Donald Trump, from one of consent-based siting of a repository that is anywhere except Yucca Mountain, Nevada, to restarting the Yucca Mountain licensing proceedings that were terminated in 2009. President Trump included $120 million in his FY 2018 budget request to advance the nuclear waste management program by restarting the licensing proceedings and establishing an interim storage program. Since both the executive and legislative branches of government — at least in the House of Representatives — support Yucca Mountain, 2017 began with much optimism that progress would be made toward nuclear waste disposal, such as implementing legislation and appropriations. However, little has changed, except for the budget request. The DOE has abandoned the pursuit of a separate repository for defense waste and deep borehole disposal of some types of waste that would be amenable to that type of disposal.

As has been the case for the past several years, in 2017 legislation was introduced in Congress that would give the DOE clear authority to store spent fuel at an interim storage facility, but that legislation never made it out of committee. However, optimism is once again high that a bill will clear the House this year. The bill considered most likely to pass the House — and perhaps even the Senate in some form — is one submitted by Congressman John Shimkus (R-Ill.), called the Nuclear Waste Policy Amendments Act (H.R. 3053). It cleared the House Energy and Commerce Committee with bipartisan approval in a vote of 49-4. At least eight other bills were introduced in either the House or Senate in 2017, and two have been introduced in 2018, but these bills have not advanced and are not expected to.

Enthusiasm continued in 2017 about the possibility of one or more consolidated interim storage facilities (CISFs) becoming operational in the early part of the next decade. A second application for a privately built facility was submitted to the NRC in March by Holtec International. Holtec has partnered with the Eddy-Lea Energy Alliance (ELEA) to build near Carlsbad, New Mexico, a CISF that's designed to store up to 10,000 HI-STORM UMAX (underground, maximum capacity) storage systems at full capacity. The facility would be built in as many as 20 phases. (In late February, the NRC determined the application was complete enough to begin a detailed technical review and placed the application on the docket.) In January 2017, the NRC accepted Waste Control Specialists' (WCS) application for a CISF that it had submitted in April 2016. In April 2017, the company asked the NRC to suspend its review of that application until a buyer for the financially strapped company could be identified and a sale closed. The WCS facility is designed to store up to 40,000 MT of spent fuel. The application referenced storage systems designed and built by TN Americas and NAC International.

On March 13, 2018, Orano US and WCS announced their intent to form a joint venture that will ask the NRC to resume its review of the CISF license application. The joint venture is expected to be established in the second quarter of 2018, after which the newly created company will formally ask the NRC to resume the license application review.

In the United States, every nuclear reactor except for Three Mile Island Unit 1, Shearon Harris and Wolf Creek either has dry storage implemented or has near-term plans to implement it. Currently, 79 ISFSIs have been licensed in the United States. Three new ISFSIs began operations in 2016 (V.C. Summer, Watts Bar and Clinton), and one began operations in 2017 at Crystal River Unit 3. Loading operations began there in June 2017, and by mid-January 2018, all 39 NUHOMS systems were in service. South Texas Project is planning to have an ISFSI in operation in 2019. At the end of 2017, UxC reported that 2,720 casks were in service, storing approximately 113,800 spent fuel assemblies. In 2017, about 250 casks were loaded, and in 2018 UxC expects that more than 275 casks will likely be placed into service at U.S. commercial reactor sites.

Six reactors have closed since 2013, and eight more are scheduled to close between 2019 and 2025. Transferring the spent fuel from the pool to dry storage is an important decommissioning milestone. Out of the 2,270 casks in service at the end of 2017, 463 are in use at permanently shut-down reactor sites. Some sites, such as Big Rock Point in Michigan and the Yankee sites, have nothing left of the former reactor site except the ISFSI.

In conclusion, UxC predicts the dry storage market will see steady growth in the United States and globally for the next several decades because of decommissioning plants, delays in repository programs and delays in reprocessing plants in countries that are pursuing this approach. With premature shutdowns, the number of storage casks required in the near term will increase as the entirety of the spent fuel pool, including the reactor core, is offloaded to dry storage.

Angelaki Gotsev provided an overview of spent fuel management in the Republic of Bulgaria, which has one operating nuclear power plant — the Kozloduy Nuclear Power Plant (KNPP). The two operating reactors, Units 5 and 6, have a combined power output of about 2,000 MWe, which is about one-third of the country's electricity supply. Bulgaria had planned to build a second plant at Belene, but this project was cancelled in 2012. Bulgaria announced earlier this year it could launch a tender process to sell the plant but keep part ownership in it.

The Kozloduy plant housed six reactors, but the first four reactors, Russian-built VVER-440 reactors, were shut down in accordance with European Union (EU) accession negotiations. Units 1 and 2 were closed at the end of 2002, and Units 3 and 4 were closed at the end of 2006. The decommissioning of Kozloduy 1–4 is expected to be completed by 2030. The remaining two reactors at Kozloduy — Units 5 and 6 — are VVER-1000 reactors that produce about 45 tons of spent fuel each year, which is stored in spent fuel pools at the reactor site, and in a separate Wet Spent Fuel Storage Facility (WSFSF) on the Kozloduy site until the assemblies are shipped to Russia for reprocessing.

Under the 2002 agreement with Russia to accept the Kozloduy spent fuel back for reprocessing, Bulgaria has been paying $600 per kilogram of spent fuel, which, at 45 tons per year, equals about $27 million per year. Russia has recently increased the fee by more than $33 million, and Kozloduy expects the fee will be increased again when contracts are signed in the future.

The WSFSF, with four pools, was commissioned on the site of the Kozloduy plant in 1989 to provide additional space to store spent fuel from VVER-440 and VVER-1000 reactors. The spent fuel assemblies are stored under water in transport baskets. The last return of spent fuel from VVER-440 reactors was carried out under the initial contract condition with Russia. Since then, all spent fuel from Units 1–4 has been transferred to the WSFSF for temporary storage. The capacity for VVER-1000 fuel is sufficient until the end of 2030.

A dry storage facility for fuel from the VVER-440 reactors was built and commissioned in 2012, and a 10-year license was issued in January 2016. It has a design lifetime of 50 years and a capacity of 72 CONSTOR 440/84 casks, each of which can store 84 VVER-440 assemblies (6,048 assemblies).

Geological disposal in Bulgaria is considered the most suitable option for the long-term isolation of HLW and long-lived radioactive waste. A program for investigation and construction of a deep geological disposal facility has been developed, but no final cost has been estimated.

Dr. Anders Sjöland of the Swedish Nuclear Fuel and Waste Management Company (SKB) said that the country's nuclear plants, which generate about 45% of Sweden's electricity, have discharged about 12,000 MT of spent fuel. Sweden has a Final Repository for Short-Lived Radioactive Waste (SFR) and a central interim storage facility (pool) for spent nuclear fuel (called "Clab").

SKB is owned by the Swedish utilities — Vattenfall (36%), Forsmarks Kraftgrupp (30%), OKG Aktiebolag (22%) and Sydkraft Nuclear Power AB (12%). SKB is responsible for research, technical development, siting, construction, operation and communication. Funding of decommissioning and waste management in Sweden is financed by a 0.04 SEK per kilowatt hour (kWh) of nuclear electricity, which is placed into a fund. The Swedish Nuclear Safety Authority (SSM) sets the amount of the fee per kWh. At the end of 2014, this fund had about 56 billion SEK (US$6.8 billion).

In 2016, Vattenfall announced its decision to close Ringhals 1 and 2, citing increased taxation on nuclear power as one reason. Oskarshamn 1 and 2 are now permanently shut down as well. The Swedish nuclear regulator, SSM, recalculated the nuclear waste fee for the period between 2015 and 2018, and a new energy agreement that calls for the gradual abolishment of the special nuclear power tax could mean that Sweden's remaining six reactors will remain in operation.

Sweden's reactors are located along the coast, so spent fuel and SFR are transported to Clab and to the SFR repository by ship in specially designed transport containers. The Clab facility has the capacity to store 8,000 MT of spent fuel, but SKB has applied to increase this capacity to 11,000 MT, because the 8,000 MT capacity could be reached in 2022. The increased capacity will primarily be accomplished by increasing the density of the spent fuel racks and by removing non-fuel items from the pools. The Clab facility could be expanded to add a third pool, but that is not in the current application. The second pool at Clab increased the capacity from 5,000 MT to the current 8,000 MT.

Sweden transports about 200 MT of spent fuel and about 1,000 cubic meters of operational waste each year. A new transport ship, the *Sigrid*, will replace the *Sigyn*, which has been used to transport these materials since 1982.

SKB submitted its license application for a spent fuel repository at Forsmark and an encapsulation plant in Oskarshamn in March 2011 and has provided extensive additional information to both the SSM and the Environmental Court in response to questions. SKB applied for the following:

- To continue interim storage of spent fuel and reactor core components on an interim basis; the maximum amount of spent fuel is 6,000 MT.
- To construct and operate a facility (Clink) to store spent fuel and for encapsulation of spent fuel; the capacity of Clink would be approximately 200 canisters per year.
- To construct and operate a facility for the final disposal of spent fuel that is currently stored in Clab, and future spent fuel discharges that will be generated from the currently operating reactors. The repository would have a design capacity of 6,000 canisters, corresponding to 12,000 MT of spent fuel. It would operate for 60 years, followed by decommissioning and closure. The canisters would be buried at a depth of 400 to 700 meters.
- Final disposal according to the KBS-3 method with vertical placement of the canisters (KBS-3V). The KBS-3 method is based on three protective barriers: copper canisters, Bentonite clay and the Swedish bedrock, which is more than 900 million years old.
- Water operations that are needed to build and operate the facilities.
- Storage for rock aggregate.

SKB's application is being reviewed according to the Nuclear Act and the Environmental Code. Hearings by the Environmental Court took place in fall 2017. SKB needs five approvals to start construction — approval from SSM, the Environmental Court, the governments of Östhammar and Oskarshamn and, finally, the federal government. On January 23, 2018, the Environmental Court and SSM released their judgments. SSM, which reviewed the application to ensure compliance with the Nuclear Activities Act, recommended to the government that SKB be allowed to construct the repository. The Environmental Court, which reviewed the application to ensure compliance with Sweden's Environmental Code, approved much of the application, including issues related to the site, rock, buffer and environmental impact assessment. It also approved the proposed encapsulation plant in Oskarshamn and the increased capacity for the interim storage facility at Clab. However, the Court asked for additional information regarding the protective properties of the copper canisters to be used in the repository and for information about who will be responsible for the long-term safety of the repository. Dr. Sjöland had just received word of these decisions a few hours before his presentation. He said that SKB must now submit documentation that shows the repository fulfills the requirements of the Environmental Act to allay the Court's concerns regarding the canisters' potential for corrosion. SKB must also clarify who will be responsible for the facility in the long term, in keeping with the Environmental Act. A referendum was to be held on March 4 in Östhammar, but it was cancelled as a result of the Court's decision. SKB had hoped that the government would issue a construction permit this year, but the court decision will likely result in a delay.

The Swedish government requested an independent NEA review to support SSM's review. The NEA concluded that, from an international perspective, the site "is sufficient and credible for the licensing decision at hand. SKB's spent fuel disposal program is a mature programme — at the same time innovative and implementing best practice — capable in principle to fulfil the industrial and safety-related requirements that will be relevant for the next licensing steps." NEA also noted that a challenge will be to broaden the basis for the scientific evidence that supports long-term safety, so additional research is needed to support the next licensing steps.

Neighboring Finland received governmental approval to begin construction of its KBS-3 repository in fall 2015 and is now about 10 years ahead of Sweden in the repository schedule, primarily because the Finnish schedule for implementation is set in law. Finland adopted the KBS-3 method, which SKB developed.

Dr. Sjöland also addressed how Sweden handles failed fuel. SKB is leading the work to handle the approximately 500 failed fuel rods from all the nuclear power plants in Swden. These rods are immediately treated to be in a form that will be acceptable in a disposal facility. Two methods are used to treat the failed fuel — the Studsvik method and the Westinghouse Quiver method. The first step, which began in 2015 and will continue through 2019, is to empty all the power plants of failed fuel rods, then treat the failed fuel rods at the Clab storage facility. No untreated failed fuel will be placed in the final repository. In the Studsvik method, the failed rods are brought to a hot cell in a Studsvik facility, cut up, dried and encapsulated, then transported to Clab. The Westinghouse Quiver method calls for the failed rods to be put into quivers, then dried. This work is done on site at the power plant, and then the full quivers are transported to Clab. Some of the failure categories include broken top and/or bottom plug missing; cracks; debris fretting; pinholes; broken rods stuck in skeleton; and pieces of fuel rods placed in purpose-built storage canisters. All failed fuel rods are stored in the pools of the nuclear power plants.

KP Lau of Fraser Energy Consulting noted that policies implemented in China to reduce coal-fired generation have resulted in blue skies over Beijing, and nuclear power production is on the rise. China currently has 39 reactors in operation, with a combined generating capacity of 36 gigawatts (GWe). Twenty more reactors with a combined generating capacity of 21 GWe are under construction. Under the 13th Five Year Plan (2016–2020), China plans to have 58 GWe in operation and an additional 30 GWe under construction. By 2035, China will have more nuclear power plants in operation than any another country in the world, and by 2050, the country intends to have almost 200 nuclear plants in operation. Except for two CANDU reactors, China's reactors are PWRs with an approximate power capacity of 1,000 MWe. China also intends to have a commercial reprocessing demonstration plant in operation by 2035.

China has had a closed fuel cycle strategy since 1987. Spent fuel is stored at the reactor sites, which have about 20 years' storage capacity on site, with the exception of the Daya Bay plant, where the spent fuel pool has reached its capacity. Spent fuel from the Daya Bay plant is transported twice a year to the Central Wet Storage Facility in Gansu, which is in the Lanzhou Nuclear Fuel Complex. The first phase of this facility was completed in 1998 with a capacity of 550 tons. A second phase will add another 550 tons, and a third phase will add an additional 550 tons and include a reprocessing facility. The central storage facility is 3,700 kilometers (2,300 miles) from the Daya Bay plant. The spent fuel is transported via sea and rail in five-ton transportation casks that have been purchased from the United States (NAC International) and Spain (Ensa), but China is developing its own transportation casks. Casks with a capacity of 20 tons are in the R&D phase, and casks that can transport 50 and 120 tons are envisioned for the future. Dry storage is in use at the Qinshan plant, which is a CANDU reactor.

A small-scale pilot reprocessing facility near the Central Wet Storage Facility was completed in 2010 but has not operated consistently. A multipurpose reprocessing pilot plant is being built next to the central storage facility and has a throughput of 300 kilograms per year. In accordance with an agreement with Orano, a commercial-scale reprocessing facility with a capacity of 800 tons per year is planned to be built at a coastal site, but negotiations with France are still underway. Earlier this month, Orano and CNNC signed another agreement for the project, which reaffirmed their commitment to complete the negotiations and to launch the project this year.

China is planning to have a deep geological repository in operation by 2050 to store vitrified HLW at a depth of 500 meters. Three candidate sites have been identified in the Gansu province — all in granite. A study of the proposed sites will be done by 2020. An underground research laboratory will be built and operated for 20 years, with construction of the disposal facility beginning in 2040.

Woo-seok Choi, Director of RAM Transport and Storage at KAERI, said that more than 448,150 spent fuel assemblies are in storage at spent fuel pools at South Korea's five operating nuclear plants (the four-unit Wolsong plant, the six-unit Hanbit plant, the six-unit Hanul plant, the three-unit Kori plant and the two-unit Shin Wolsong plant). Korea has three additional reactors under construction at Shin-Hanul and two more planned at that site, plus three more reactors under construction at the Shin-Kori site.

In June 2015, the Public Engagement Commission on Spent Nuclear Fuel (PECOS) submitted a recommendation to the national government after collecting opinions from the public about spent fuel management policies. About 370,000 people participated. PECOS recommended that an underground research laboratory (URL) should be built for R&D about spent fuel disposal, with a goal of having a final repository operating by 2051.

In July 2016, the Atomic Energy Commission determined the national plan for HLW management. Korea intends to have a site selected by 2028 and to begin interim storage operations in 2035, with repository operations beginning in 2052. An underground research laboratory (URL) should be sited by 2020, and R&D on spent fuel disposal should begin by 2030. If on-site short-term storage is implemented, a storage fee will be paid to the region, and a "Foundation of Local Residents" will be organized.

KAERI has been performing evaluations for storage and transport conditions and will conduct a transportability assessment after storage based on data from the U.S. DOE and Ensa multimodal transportation test. A test will be planned for Korean sea transport conditions. KAERI is also conducting spent fuel R&D in the following areas: dual-purpose (KORAD 21) and concrete cask (KORAD 21C) development, seismic performance evaluation tests and analysis, heat removal performance tests and analysis, aircraft impact tests and analysis, metal seal accelerated test, and vibration and shock condition analysis.

Masumi Wataru of the Central Research Institute of Electric Power Industry (CRIEPI) discussed spent fuel management in Japan. The Cabinet approved the Basic Energy Plan in April 2014 and affirmed that nuclear power will continue to be an important baseload source of electricity and that the government will lead efforts to develop a final disposal facility for HLW. Before the accident at the Fukushima Daiichi Nuclear Power Plant in March 2011, nuclear power contributed close to 30% of Japan's power generation. In 2016, it contributed only 1.7%, as coal, oil and natural gas sources increased their contributions. By 2030, however, Japan intends for nuclear power to contribute 20–22% of nuclear generation, with coal, oil and natural gas dropping back down to close to 2010 levels.

The government announced the action plan for spent fuel management, which involves establishing a council between the government and the electric power companies, asking the electric power companies to draw up a plan to deal with spent fuel, strengthening regional measures for spent fuel and enhancing public understanding about spent fuel. The council last met on November 24, 2017. The electric power companies intend to secure an additional storage capacity of approximately 6,000 tons — 4,000 tons by 2020 through currently planned measures, and another 2,000 tons by 2030. The Nuclear Regulatory Association (NRA) recommended the additional storage capacity be gained by the use of dry storage.

CRIEPI is conducting studies related to long-term dry storage of spent fuel, including looking at the long-term seal performance of the metal gasket, the aging effects of alluminum alloy used in basket fabrication and the stress corrosion cracking of dry storage canisters, all of which Wataru explained in detail.

Ryoji Asano of Hitachi Zosen Corporation presented an update on spent fuel manufacturing and technology in Japan. Typically, Japan has relied on reprocessing spent fuel to maintain space in reactor spent fuel pools. The Tokai Reprocessing Plant was a pilot plant that operated from 1981 to 2010, during which time 1,140 tons of spent fuel were reprocessed. Japan has also shipped spent fuel to France and the UK; under these contracts, 5,600 tons of LWR spent fuel has been reprocessed. The Rokkasho Reprocessing Plant that's under construction — its completion has been delayed numerous times — will have a capacity to reprocess 800 tons of spent fuel per year. Spent fuel will be transported to a 3,000-ton-capacity storage pool.

For spent fuel storage, the Fukushima Daiichi Nuclear Power Station and the Tokai Unit 2 Power Station have onsite ISFSIs, and an onsite ISFSI with a capacity to store 500 tons of spent fuel is being built at the Hamaoka Nuclear Power Station. A centralized interim storage facility is being built in Mutsu City in the Aomori Prefecture by Tokyo Electric Power Company (TEPCO) and the Japan Atomic Power Company (JAPC). This project began in 2010. Phase 1 will have a capacity to store 3,000 tons of spent fuel, and Phase 2 will add an additional 2,000 tons of capacity.

Consolidated Storage

CISFs are in use in a few countries, such as Finland (wet storage facility), Germany, Sweden and Switzerland. Other countries are now considering or have considered building a CISF, including France, Japan, Spain and the United States. A CISF is widely viewed as a necessary step between at-reactor spent fuel storage and permanent disposal.

In the United States, the private sector is moving forward with plans to obtain NRC authorization to build and operate a CISF, with two applications having been submitted to the NRC for review and approval (one of which has been suspended). In 2016, WCS applied to the NRC for a CISF in West Texas, where WCS already operates a privately run low-level radioactive waste storage facility. In April 2017, WCS requested that the NRC suspend its review of the application pending a sale of the company. As of press time, that application was still suspended.

In March 2017, Holtec International applied to the NRC for its CISF, the HI-STORE. Holtec's facility would be built in eastern New Mexico, very close to the proposed WCS facility. Stefan Anton presented details of the Holtec facility (which the NRC accepted for detailed technical review in late February 2018). If approved, Holtec's CISF will comprise approximately 300 acres within a

1,040-acre site in Lea County, New Mexico, 32 miles east of Carlsbad and 34 miles west of Hobbs. In this initial license application, Holtec is seeking to store up to 8,680 metric tons of uranium (MTU) of commercial spent nuclear fuel, greater-than-Class C (GTCC) waste and a small quantity of spent MOX fuel stored in 500 HI-STORM UMAX storage systems on two storage pads. Holtec is seeking an initial 40-year license term. Holtec anticipates it will later request an amendment to the license that would authorize the storage of an additional 500 canisters for each of 19 subsequent expansion phases to be completed as needed over the course of many years. Holtec envisions that approximately 10,000 spent fuel canisters would be stored at the CIS once all 20 phases are implemented.

The NRC is developing guidance for a storage-transportation-storage interface. **Darrell Dunn of the NRC's Division of Spent Fuel Management (DSFM)** explained the basics of this guidance development. Spent fuel assemblies currently in dry storage canisters at existing ISFSIs licensed under the Code of Federal Regulations' 10 CFR Part 72, which governs the dry storage of spent nuclear fuel, are proposed to be transported under 10 CFR Part 71, which governs the transportation of spent nuclear fuel. They would then be subsequently placed in storage again at a CISF, once again under Part 72 regulations — a so-called 72-71-72 scenario.

The guidance being developed for the review of a 72-71-72 interface in Part 72 applications must consider the following components:

- Activities involved during initial storage, transportation and subsequent storage.
- Applicable regulatory requirements.
- Important system variations, because a variety of storage designs will be used at the CISFs.
- Testing and nondestructive examination (NDE) to demonstrate an adequate margin of safety.
- Allowable credit for examinations or tests — that is, examinations required by an aging management program (AMP).

Dunn reviewed some of the testing and NDE evaluation methods and described possible 72-71-72 examples, such as a system in which the initial certificate of compliance does or does not credit the canister boundary integrity for transportation.

Contingency planning is important, Dunn emphasized, although only a limited number of canisters are expected to show indications of aging. Even so, an acceptable plan for addressing canisters that show signs of aging is expected to be provided in the CISF application. Procedures and controls to limit occupational exposures and site boundary dose limits, and corrective actions necessary to return to normal operations, are required.

Going forward, the NRC will collect input on the development of guidance for a 72-71-72 interface, incorporate draft guidance into a fall 2018 Storage Standard Review Plan (SRP), then issue the SRP for public comment in spring 2019, followed by issuance in summer 2019 of the final guidance document, which will have addressed the public comments.

Michael McBride of Van Ness Feldman LLP discussed how a CISF could be funded in the United States. In 2002, the U.S. Court of Appeals for the 11th Circuit held that the DOE could not pay for onsite storage using NWF money, but the Court did not preclude the DOE from paying out of the Judgment Fund, which is a permanent, unlimited appropriation by Congress. The Court did not specifically address offsite storage, but the NWPA contemplates the DOE only taking title to spent fuel when that spent fuel is shipped offsite for disposal. The Blue Ribbon Commission (BRC) on America's Nuclear Future concluded in its final report that consolidated interim storage would save billions of dollars over onsite storage; therefore, McBride observed that the public interest would seemingly be served if the DOE would pursue consolidated interim storage to save the taxpayers a substantial amount of money.

The DOE has a legal mechanism for reducing judgments to utilities in the form of confidential settlement agreements with the utilities. McBride believes that DOE attorneys have retained the right to contest a utility's claimed damages if a utility has failed to mitigate its damages. To reduce the judgments, McBride contended, the DOE could notify utilities whose judgments require future payments that it will seek to reduce the judgment if the utility does not enter into contracts with the operator of the CISF at costs less than the onsite storage costs. The DOE and the Department of Justice (DOJ) would have to be convinced that the arrangement is a permissible use of the Judgment Fund, and, presumably, the DOE would enter into discussions with the utilities only if it were satisfied that a CISF is less expensive than onsite storage over the entire storage period, as the BRC concluded.

Timing issues will arise, McBride noted. For decommissioned plants, the cost savings will occur once all the spent fuel is moved offsite, but major facility costs are incurred years earlier. Either the DOE would have to front-end those costs, or long-term financing arrangements would need to be available.

Prerequisites would have to be put in place, such as the availability of transportation modes, most likely by rail. Proponents of moving spent fuel to a CISF must be prepared to address the safety and cost issues associated with transporting the spent fuel twice — once to a storage facility, and then again to a permanent disposal facility.

If storage facility operators do not take title, and the DOE takes the position that it cannot take title to the spent fuel except for disposal, utilities may have to retain title to the spent fuel after it leaves their sites, as long as it is going to a CISF — unless it could be argued that CISF facilitates the eventual disposal. McBride emphasized that careful consideration should be given to how these proposals are put forward, so they are not seen to be threatening ongoing legislative efforts in Congress.

McBride concluding by contending that the DOE could get spent fuel off reactor sites to a CISF using the legal mechanism of the utilities' suits against the DOE for damages by arguing to the Court that, if the utilities are not willing to enter into contracts with the CISF operators for interim storage, then they are not "mitigating their damages," if using a CISF would indeed save a significant amount of money. This approach could allow standard project financing of CISFs, could get spent fuel moving off reactor sites and could begin to fulfill the government's commitments. The caveat is that utilities might have to retain title to the spent fuel.

McBride's presentation offered a good segue for **Gary Lanthrum of NAC International**. Lanthrum discussed cost considerations for CISF funding under existing law. Using available public information, Lanthrum said that the cost for onsite storage at permanently shut-down sites depends on the status of the shutdown. While decommissioning is still active, many common costs are shared between the plant and the DOJ under settlement agreements. Once decommissioning is complete, the full costs revert to the DOJ Judgment Fund. Lanthrum presented a detailed table of estimated annual storage costs (in 2018 dollars) from 2022 to 2050 by shut-down plant site.

Lanthrum pointed out that the NWPA has "explicit restrictions" on establishing a federal monitored retrievable storage facility (such as a CISF) before a repository is operational, but that constraint does not apply to private CISFs funded by investors. He also noted that the courts have held that NWF money cannot be used for building CISFs without legislation that explicitly authorizes this. If a private CISF included disposal processing facilities, that could be allowed under the NWPA with NWF appropriations from Congress. Adding the necessary repackaging facility to move spent fuel from dual-purpose canisters used for storage and transportation into disposal-ready casks that meet the repository requirements for thermal operations, criticality poisoning and corrosion resistance would seem to shorten the overall waste management schedule for disposal.

Lanthrum, who once served as the director of the DOE's former Office of Civilian Radioactive Waste Management (OCRWM), concluded with the following thoughts:

- Annual costs for storage are much higher at shut-down sites than at operating plants.
- The bulk power market has become dominated by inexpensive electricity produced by gas turbines. This is causing many nuclear plants to close long before their operating licenses expire.
- The cost of spent fuel storage is somewhat independent of the amount of fuel stored. This means costs duplicated at multiple storage sites can be undercut by considering the storage capacity.
- The number of shut-down sites now planned creates a significant opportunity for lifecycle cost savings.
- The legal construct of minimizing damages seems to offer a path forward without legislation or DOE action.

Decommissioning

One of the main reasons cited for the premature closure of nuclear plants is the economic and financial challenges these plants pose for the plant owners, particularly those plants located in so-called organized markets. **Eric Knox of AECOM** introduced AECOM's decommissioning expertise and discussed the economic implications of nuclear power plant decommissioning. Knox highlighted several statistics, including the following:

- At the end of 2017, the 441 nuclear power plants worldwide accounted for 11% of the electricity generated.
- About 80% of existing nuclear capacity is in OECD countries, but most of those plants (more than 75%) are more than 25 years old.
- Currently, 68 GWe of new nuclear capacity is under construction, with 21 reactors being built in OECD countries and 46 in non-OECD countries.
- The IAEA estimates that over the next 20 years, more than 200 nuclear plants will be retired or will be primed for decommissioning. To date, 110 commercial reactors have been permanently shut down.
- Reactor retirements will increase in the first half of the 2020s and pick up again in the 2030s.

Ed Davis of the Pegasus Group observed that out of the 99 currently operating plants in the United States, 51 operate in a regulated market and 48 operate in what he called "restructured organized markets." He pointed out that the U.S. nuclear fleet is the oldest in the world, with an average unit age of 36 years — so, absent plant license extensions, nuclear plant closures will increase starting in the late 2020s. Davis said that plants currently operating in these restructured organized markets are collectively losing approximately $3 billion per year. Average wholesale power prices from 2008–2016, he said, have dropped by more than half over the last decade, from about $80 per megawatt hour in January 2006 to less than $40 in July 2016. At the same time, average generating costs have decreased from a peak of $40.25 per MWh in 2012 to $33.93 per MWh in 2016.

Between 2002 and 2016, five nuclear units representing 4,698 MWe of nuclear generation announced retirements. This was 4.7% of the nuclear operating fleet. Since 2016, another eight nuclear units, representing 7,167 MWe of nuclear capacity, or 7.2% of the nuclear fleet, have announced early retirement. In early February 2018, Exelon advanced the planned closure date of its Oyster Creek Nuclear Generating Station by over a year, from the end of 2019 to October 2018, and NextEra reportedly is considering closing the Duane Arnold plant by 2022.

Over the last six years, Davis noted, 37 megawatts of coal-fired generating plants were retired; between 2000 and 2010, about 22 MWe of gas-fired capacity was retired. Over the next five years, though, 79% of retirements are expected to be coal and natural gas retirements, with 49% for coal plants and 30% for gas plants, compared to 15% of nuclear-generating capacity. In the United States, the average age of coal-fired plants is 39 years, compared to 22 years and 36 years for gas-fired and nuclear plants, respectively.

Citing data from the International Energy Agency (IEA), Davis said that over the next 20-plus years, over 150 GWe, or more than 200 nuclear plants, are expected to be retired, to be ready to be retired or to begin decommissioning. To date, more than 150 nuclear plants have been shut down and/or are undergoing decommissioning worldwide, not including test reactors. The top drivers for plant retirements are as follows:

- 75% are units that have achieved their expected economic lifetime.
- 20% are units that have closed or will close prematurely because of a political decision (for example, Germany) or due to regulatory reasons and/or economic difficulties.
- 5% are units that are closed following an accident.

Other factors that lead to plant closures include stringent regulations implemented after the Fukushima Daiichi accident, the rising cost of nuclear plant operation and maintenance (O&M), low electricity demand growth forecasts, low natural gas prices, low wholesale power prices and the falling cost of renewable energy sources combined with subsidies.

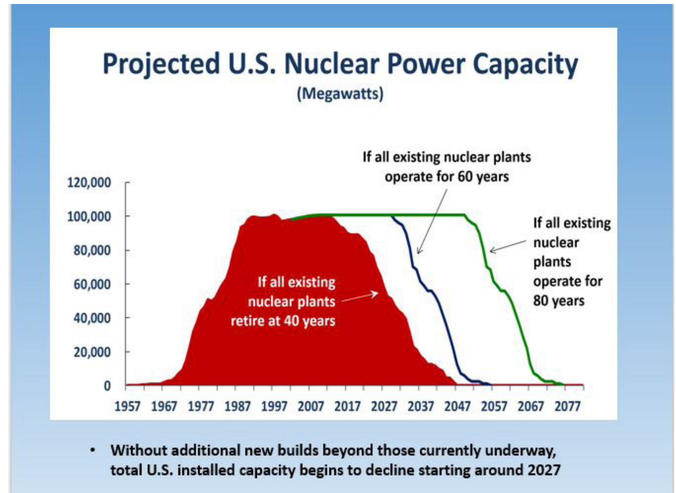

Figure 3. Projected U.S. Nuclear Power Capacity

Most of the retirements worldwide are in the mature markets, with the oldest plants retired first, reflecting the age profile of the country's reactor fleet, particularly in the United States, followed by the EU, Japan and Russia. The rate of retirements will increase in the first half of the 2020s, with reactors built in the 1970s closed, followed by more retirements in the 2030s if subsequent license renewals are not sought and approved. In the United States, 75 reactors have received a 20-year license extension. Without additional reactors being built in the United States, the total installed capacity will begin to decline around 2027 if all existing nuclear plants retire at the end of their 40-year license. If all existing plants were to operate for 60 years, the decline would be delayed until the mid-2030s, and if all existing plants were to operate for 80 years, the beginning of the decline would be delayed until almost 2060 as shown in Figure 3.

Overall, the presentations provided an update of spent fuel management issues and initiatives across the globe. Other presentations that were not summarized above informed participants on issues, such as the use of advanced nuclear technology to close the fuel cycle; the management and disposal of U.S. DOE-owned spent fuel; NRC guidance on aging management requirements for spent fuel storage casks; DOE spent fuel campaign updates, including the spent fuel railcar project; and details from Holtec International about its plans for a privately run consolidated storage facility. The 34th Annual INMM Spent Fuel Management Seminar will be held in Washington, D.C., in January 2019.

Book Review

Mark L. Maiello, PhD
Book Review Editor

Analytical Methods for Nonproliferation

Edward C. Morse
Hardcover, 250 pages
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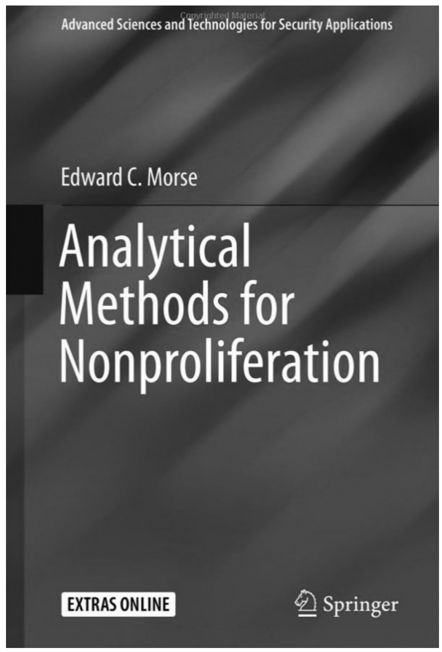
Springer International
Publishing, Switzerland, 2016



I am impressed with the breadth of knowledge that Edward Morse brings to his readers in this text, designed — according to the preface — for advanced undergraduate and graduate students of nuclear engineering. Morse's mathematical, engineering and policy prowess are evident in this concise, detailed effort. In parts, its mathematics may be beyond many readers, and in others, the deep detail about detection systems may also prove too much of an obstacle. But there is no denying the author's talent, which includes the ability to organize and communicate a well-rounded nonproliferation program of study. One assumes that the text will fulfill its classroom mission, but does it translate into a usable book for the non-student? That is the primary question here.

Analytical Methods for Nonproliferation seems more suited for the adept and aspriring nonproliferation specialist. The equations required are not derived step by step but are essentially placed in the reader's lap to absorb. It is evident that this is a text meant to accompany the author's classroom teaching, where the mathematics may be explored in more detail. As a stand-alone text for office use, be warned that the mathematical side of the book is rigorous and that derivations must be completed by the curious, ambitious and well-practiced reader. Even in the chapters covering detection instrumentation, Morse opts for mathematical discussion rather than descriptions of the electronic components. Clearly, he expects mathematical prowess in his students.

The material covered is a logical if somewhat broad mix of nonproliferation issues that nonproliferation specialists will find useful, if not totally attainable. Early chapters cover nuclear detonations, background radiation, detection statistics, forensics and detonation monitoring. The latter portion of the book covers active detection systems for interrogation, advanced detection systems (some made unusable by nuclear arms limitations inspection protocols) and public policy concerning nuclear proliferation. It is a broad palette, but it is sensible. The early chapters provide the foundational material (nuclear explosives, background radiation, detection statistics and the fuel cycle) to allow a discussion of forensics, nuclear testing detection via seismic analysis and radionuclide signatures. Arms control and treaty verification protocols also benefit from this subject-matter progression. The chapters on active interrogation and advanced technologies — areas where higher mathematics are presented — also make contextual sense here, albeit without the fuller understanding that a knowledgeable instructor could provide. The final chapter on public policy may appear a bit out of place for such a technical book, but there is no denying that it is a good, succinct survey of international and domestic nonproliferation governmental agencies and private initiatives. Certainly, these activities are part and parcel of the nonproliferation regime and partially drive the development of the analytical technologies described in the book.

Such a wide spectrum of topics also serves another purpose. It highlights the talents needed to succeed in the field (and in Professor Morse's course). Although career specialization is the norm, the book's contents are contemporary requirements for a working knowledge of the nonproliferation field — and its main objective is the technical, engineering and scientific side of the house. Policy is but an addition here. Materials management, inventory and other IAEA-type protocols are not included to any great depth.

Although the book casts a wide net, the nonproliferation endeavor is indeed wider. As Morse's students specialize, this text will morph from an excellent learning tool into a reliable reference.

A quick survey of the book reveals the following:

- The chapter on background radiation is done well. With an eye toward detection, there is an opening on the self-shielded disk, half-space and optical thickness that will require some mathematical skill to fully comprehend, but the chapter then settles nicely into an informative read that includes primordial radiation, cosmogenic radiation, Compton scatter and man-made radiation. The accompanying illustrations and tables are more than adequate, and those describing the main primordial naturally occurring decay series and gamma spectra are particularly well done.
- The detection statistics chapter is very involved. Some background in the material will be of help here to the reader (this reviewer was out of his element when the discussion of confusion matrices reared up). It was tough going through Bayesian statistics and pulse shape discrimination but, as I implied above, with the correct professor at the helm to guide students through these choppy waters, success is highly assured.
- The Nuclear Fuel Cycle chapter discusses centrifuges, along with laser isotope separation. The chapter is a brief, to-the-point overview of the cycle.
- There is good coverage of seismic, infrasonic and hydroacoustic detection of nuclear detonations. Again, though it's somewhat mathematically challenging, there is enough discussion to provide a decent understanding by a casual reader about the various physical signatures required for detection and analysis.
- The discussion of Active Interrogation measurements (highly mathematical) includes a mention of dose estimation and cancer risk, a nice touch that accounts for an issue often mentioned in connection with human exposure when vehicles are scanned.
- Advanced Detection Technologies is another nice touch, because it covers new scintillation materials and semiconductor materials, along with alternatives for neutron detection.
- A separate chapter on methods to verify arms control and treaty compliance discusses three plutonium aging methods, along with neutron imaging and neutrino counting. Of note is the author's awareness that some of these methods reveal much more than is needed for verification — for example, components or data that might be considered military secrets. Thus, the methods will not necessarily be universally applied, or will perhaps need negotiations before being accepted.
- Two appendices are included that cover the nuclear Nonproliferation Treaty and the Atomic Energy Act. A four-page glossary and an index finish the book. As a bonus, one can download text-specific material from the publisher at extras.springer.com.

This text will not appeal to everyone. Nonproliferation scientists and engineers will likely applaud its mathematical rigor. Others, such as policymakers with no interest in the physics behind nonproliferation efforts (such as verification), will no doubt steer clear. It's a classroom book first and foremost, and a reference for those skilled enough to use it. It is a well-planned, broad-scope survey of the major topics in the nonproliferation field, with an interrogation and treaty verification perspective. As I mentioned, it does not cover management and inventory of nuclear materials. It is, however, a tribute to its author, who went to great pains to create a customized text for his lecture course. His skills and knowledge are indeed worthy of the university classroom. Based on the content of the book alone, those who can attend his lectures are fortunate.

Taking the Long View in a Time of Great Uncertainty

Perhaps Not in My Lifetime

Jack Jekowski
Industry News Editor and Chair of the Strategic Planning Committee

"So today, I state clearly and with conviction America's commitment to seek the peace and security of a world without nuclear weapons. I'm not naive. This goal will not be reached quickly — perhaps not in my lifetime. It will take patience and persistence. But now we, too, must ignore the voices who tell us that the world cannot change. We have to insist, 'Yes, we can.'"

— PRESIDENT BARACK OBAMA • APRIL 5, 2009

By any measure, President Obama's 2009 speech in Prague, Czech Republic — in which he suggested that a future without nuclear weapons was possible — represented a historic turning point for the world, and contributed to his being awarded the 2009 Nobel Peace Prize. Obama's efforts during the next seven years included biannual Nuclear Security Summits, the elevation of diplomacy in the U.S. National Security Strategy, the negotiation of the New START Treaty to reduce Russian and U.S. nuclear stockpiles, the Iran Deal (Joint Comprehensive Plan of Action [JCPOA]) and chairing the U.N. Security Council. These efforts demonstrated a resolve to move that vision forward and create a new international order.[1]

Modernizing the U.S. Nuclear Stockpile

Amid that promise of a different future world, however, the Obama Administration also moved forward with plans to modernize the aging U.S. nuclear stockpile, reflecting a position taken during that historic speech in Prague and in subsequent policy documents:

"Make no mistake: As long as these weapons exist, the United States will maintain a safe, secure and effective arsenal to deter any adversary, and guarantee that defense to our allies ..."

This modernization effort initially included life-extension programs (LEPs) for the U.S. nuclear weapons inventory, and then, subsequently, a plan to update the three legs of the U.S. nuclear triad, as well as command and control systems and the wrap-around infrastructure of the National Nuclear Security Administration's (NNSA) Nuclear Security Enterprise (NSE). Some have argued that the United States does not need all "legs" of the nuclear triad,[2] nor the development of a new long-range cruise missile.[3] Nonetheless, plans to modernize the U.S. stockpile over the next 30 years continue, now estimated by the U.S. General Accounting Office (GAO) to cost $1.2 trillion over the next 30 years. The recent CBO report, "Approaches for Managing the Costs of U.S. Nuclear Forces, 2017 to 2046,"[4] suggests alternative scenarios that would save more than $100 billion. However, some have questioned the CBO's scenarios with respect to the overall value of a fully modernized nuclear deterrent that would result from this proposed investment, while others suggest that spending less could actually make the United States safer.[5]

This column is intended to serve as a forum to present and discuss current strategic issues impacting the Institute of Nuclear Materials Management in the furtherance of its mission. The views expressed by the author are not necessarily endorsed by the Institute, but are intended to stimulate and encourage JNMM readers to actively participate in strategic discussions. Please provide your thoughts and ideas to the Institute's leadership on these and other issues of importance. With your feedback, we hope to create an environment of open dialogue, addressing the critical uncertainties that lie ahead for the world, and to identify possible paths to the future based on those uncertainties that can be influenced by the Institute. Jack Jekowski can be contacted at jpjekowski@aol.com.

The elements of this modernization effort and their costs, as identified in the CBO report, include the following:

- Allocating $772 billion for the operation, sustainment and modernization of strategic nuclear delivery systems and weapons — the long-range aircraft, missiles and submarines that launch nuclear weapons; the nuclear weapons they carry; and the nuclear reactors that power the submarines.
- Allocating $25 billion for the operation, sustainment and modernization of tactical nuclear delivery systems — the aircraft capable of delivering nuclear weapons over shorter ranges — and the weapons they carry.
- Allocating $445 billion for the complex of laboratories and production facilities that support nuclear weapons activities and the command, control, communications and early-warning systems that enable the safe and secure operation of nuclear forces

Specific high-visibility elements of the modernization effort include the following:

- A new ballistic missile submarine (SSBN), designated the Columbia class.
- A new silo-based intercontinental ballistic missile (ICBM) and refurbished silos and other supporting infrastructure for ICBMs through the Ground-Based Strategic Deterrent program.
- A new long-range stealthy bomber, designated the B-21 Raider.
- Refurbishment of the current-generation D5 submarine-launched ballistic missile (SLBM).
- A new SLBM to eventually replace the D5.
- A new air-launched nuclear cruise missile, the Long-Range Standoff (LRSO) weapon.
- A life-extension program (LEP) for the B61 nuclear bomb that would combine several different varieties of that bomb into a single type, the B61-12 (already underway).
- A LEP for the B61-12 bomb when it reaches the end of its service life, referred to as the Next B61.
- LEPs for the SSBN-related W76 and W88 warheads.
- A LEP to refurbish the W80 warhead that would be used on the LRSO.
- A series of LEPs that would produce three interoperable warheads (called IW-1 through IW-3), each of which would be compatible with both ICBMs and SLBMs.

Note that all four of the other Nuclear Weapons States (NWSs) are similarly investing in modernization and upgrades to their nuclear stockpiles, and that the cost of modernization in the grand scheme of the overall U.S. budget represents a fraction of a percent of the total U.S. budget for that same time frame.[6]

A New Administration's Perspective

With the election of Donald Trump, the position of the United States on nuclear deterrence appears to be changing significantly. Recently codified in a new Nuclear Posture Review (NPR)[7] and reflected in the early positions taken by the President in public comments and tweets, and by members of his Cabinet in Congressional testimony[8] in multiple policy areas, the groundwork for dramatically changing the approach of the Obama Administration has been established. These include:

Suggesting that the U.S. needs to not

only modernize its nuclear strategic deterrent, but perhaps expand the deterrent to Cold War levels.

Stating, regarding the JCPOA, that the lifting of sanctions imposed is not "appropriate and proportionate" relative to Iranian measures to draw down its nuclear program, which threw the decision back to Congress to determine the future path of the agreement. Citing continued testing of ballistic missiles and aggressive policies in the Middle East, including support of Syrian President Bashar al-Assad's government and groups such as Hamas and Hezbollah — which the United States considers to be terrorist organizations — the Administration is looking either to renegotiate the Iran Deal or to terminate it, with the first step requiring Congress to recommend actions by mid-December.

Engaging in rhetoric that has heretofore been unheard of at the presidential level, including saying that North Korea, as a result of their continued pursuit of nuclear weapons and ICBMs to deliver them, would be met with "fire and fury like the world has never seen."[9]

So dramatic have these policy changes been that the Senate Committee on Foreign Relations called for a special hearing on November 14, 2017 (the first time in decades) to discuss the presidential authority to use nuclear weapons.[10] This has correspondingly raised concern on a global basis.[11]

History will tell the story of whether this new approach to global security works, but for now, the words of President Obama in 2009 — "perhaps not in my lifetime" — ring loudly.

Endnotes

1. See the inaugural "Taking the Long View" column for an early timeline of the Obama Administration's activities to achieve the Prague vision (JNMM, vol. 39, no. 1, pp. 39–41). Also see JNMM, vol. 41, pp. 111–113, for a discussion of how the National Security Strategy was redefined to recognize the importance of diplomacy.
2. See "Nuclear strategists call for bold move — scrap ICBM arsenal," www.reuters.com/article/us-usa-nuclear-icbm-specialreport/special-report-nuclear-strategists-call-for-bold-move-scrap-icbm-arsenal-idUSKBN1DM1D2
3. See "Cancel the long-range standoff missile," www.brookings.edu/blog/order-from-chaos/2017/06/28/cancel-the-long-range-standoff-missile/
4. See "Trump plans for nuclear arsenal require $1.2 trillion, Congressional review states," www.nytimes.com/2017/10/31/us/politics/trump-nuclear-weapons-arsenal-congressional-budget.html, and the Congressional Budget Office Report "Approaches for managing the costs of U.S. nuclear forces, 2017 to 2046," www.cbo.gov/system/files/115th-congress-2017-2018/reports/53211-nuclearforces.pdf
5. See "Spending less on nuclear weapons could actually make us safer," www.washingtonpost.com/opinions/spending-less-on-nuclear-weapons-could-actually-make-us-safer/2017/11/16/396ef0c6-ca56-11e7-aa96-54417592cf72_story.html?utm_campaign=EBB%20 11.17.17&utm_medium=email&utm_source=Sailthru&utm_term=.67cc19e6b17f
6. See "US nuclear modernization is not only affordable, but necessary," http://thehill.com/opinion/national-security/358574-us-nuclear-modernization-is-not-only-affordable-but-necessary
7. See www.whitehouse.gov/the-press-office/2017/01/27/presidential-memorandum-rebuilding-us-armed-forces for the Executive Order initiating the NPR, and www.defense.gov/News/SpecialReports/2018NuclearPostureReview.aspx for the report and related materials
8. See https://armedservices.house.gov/legislation/hearings/fiscal-year-2018-priorities-nuclear-forces-and-atomic-energy-defense-activities
9. See www.nytimes.com/2017/08/08/world/asia/north-korea-un-sanctions-nuclear-missile-united-nations.html
10. See www.foreign.senate.gov/hearings/authority-to-order-the-use-of-nuclear-weapons-111417 for an archived video of this hearing. Also see "Trump and the nuclear button," www.washingtonpost.com/opinions/trump-and-the-nuclear-button/2017/11/25/85bb50b2-cafd-11e7-8321-481fd63f174d_story.html?utm_term=.d1226020aa26 , and "Trump's loose talk on nuclear weapons suddenly becomes very real," www.washingtonpost.com/news/the-fix/wp/2017/10/11/trumps-loose-rhetoric-on-nuclear-weapons-has-become-a-very-real-concern/?utm_term=.adebf7954b18
11. See "Whose finger is on the button? Nuclear launch authority in the United States and other nations (2017)," www.ucsusa.org/nuclear-weapons/us-nuclear-weapons-policy/sole-authority#.Wh5LTbWWyUk

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