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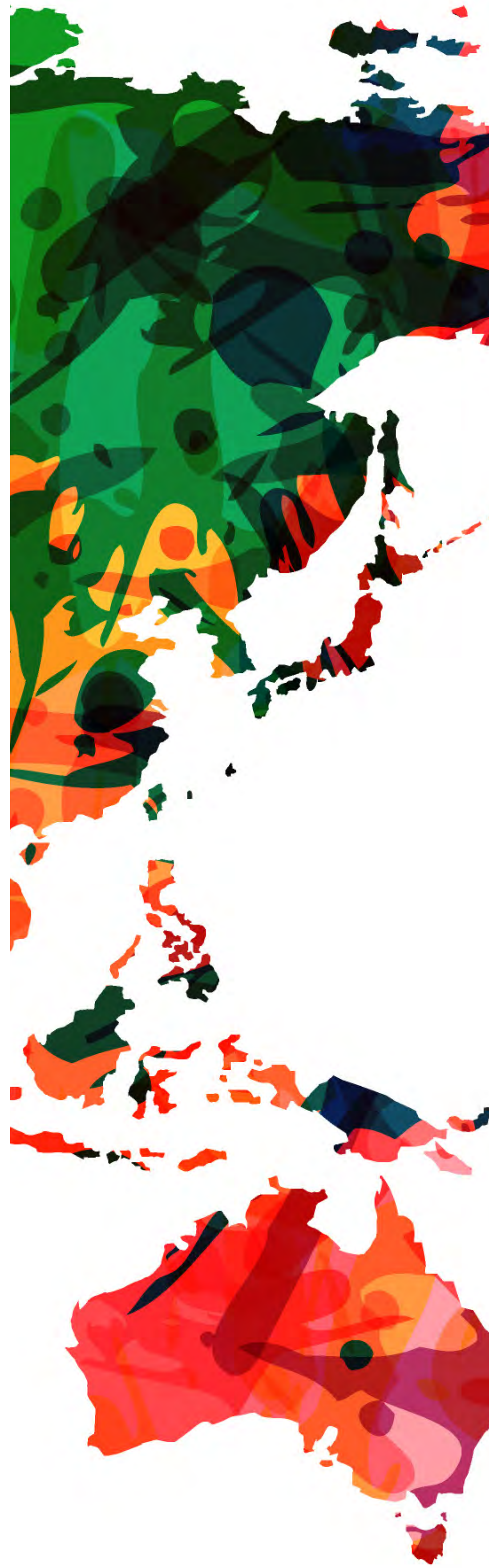

INMM
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Mission Statement

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.

INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Adapted from the July 2017 President's Report to the Membership

By Corey Hinderstein
INMM President

For the international nuclear materials management community, it has been a busy and exciting year. World events effecting our field from developments in North Korea to the Westinghouse bankruptcy to the consequences of Brexit on international safeguards to the reopening of the Waste Isolation Pilot Plant (WIPP) in New Mexico all demonstrate that our professional competencies remain vitally important.

We are now a year into the implementation of our 2017-2020 INMM strategic plan, designed to build on the strong foundation of INMM and prepare us for the future. This first phase of implementation requires a lot of work that may not be visible to the members but will form the backbone of our actions moving forward. This includes data gathering about membership trends, meeting results and sponsor activity. We look forward to turning data into initiatives over the next few months.

We have made some very visible changes, too. At the INMM Annual Meeting, we revealed the new logo for INMM. Soon we will reveal the new-look INMM website, designed to deliver members, sponsors, and other interested parties the information they need in a clear and direct manner — and with fewer clicks! We are not leaving our past behind us, but rather building on it for a stronger future.

Leadership Transitions

As is the nature of a dynamic, volunteer organization, INMM experienced some leadership changes this year. Here are some of the volunteers who are ending their terms or beginning new roles:

- Ken Sanders and Jill Cooley have served as Members-at-Large on the Executive Committee and began their terms October 1, 2015. They will both be rolling off at the end of September 2017 and we thank them for their service.
- Michael Baker and Teri Leffer will join the Executive Committee as Members-at-Large. We congratulate them and look forward to their contributions.
- Congratulations to Steve Wyrick, confirmed this year as the Management Division Oversight Chair.
- Congratulations to Glenn Abramczyk, joining the team as Exhibits and Sponsorship Chair.
- Congratulations to Claudio Gariazzo stepping up to a new role of Chapter Relations Committee Chair.
- Mark Schanfein served as interim Membership Chair, a role previously held by Michelle Romano. We thank them both for their commitment to attracting new members to INMM. James Miller has assumed the position of Membership Chair.
- After announcing his retirement, we thank George Baldwin for serving in the role of Communications Committee Chair for more than seven years. Congratulations to Zoe Gastelum for assuming the role of Communications Committee chair.

The Institute is fortunate to have such dedicated volunteers, people who believe in its mission and are willing to give their time and talents to support the Institute. There are many opportunities to volunteer with INMM, and I encourage all members to look for a way to get involved.

Musings

I remain honored and humbled to serve as the president of INMM. My first Annual Meeting was in 2003, and I was struck by both the technical content and the welcome of the experienced participants, many of whom are still coming to annual meetings. I make it my goal as President to foster both of these sides to the INMM *community* — and to emphasize that concept in our events and other actions. Sometimes we have to make hard decisions, and we will always face challenges. But if we, as a global nuclear materials management community, can rely on the substance of our disciplines and the foundation of our relationships, we can make the world a better, safer and more secure place.

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Markku Koskelo
JNMM *Technical Editor*

Abundant Optimism at the 32nd Annual Spent Fuel Management Seminar

Carlyn Greene
Ux Consulting Company (UxC), Stone Mountain, Georgia USA

In mid-January 2017, about 100 nuclear industry professionals once again met in Washington, DC for the 32nd Annual Spent Fuel Management Seminar, sponsored by the Institute of Nuclear Materials Management (INMM), in partnership with the U.S. Nuclear Infrastructure Council (NIC). Participants and presenters included representatives from Japan, Korea, Spain, Sweden, the U.S. Department of Energy (DOE), U.S. national laboratories, the U.S. Nuclear Regulatory Commission (NRC), the Electric Power Research Institute (EPRI), utilities, cask vendors, consultants, and more. As always, the conference included a number of relevant presentations on a wide variety of topics related to spent fuel management, and this year, the participants focused on the hope that the new Administration and Congress will follow the law and resurrect the Yucca Mountain program. NIC Executive Director David Blee said in his opening remarks 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."

Overview

As always, the conference agenda included a cross-section of policy and political discussions, transportation issues, country-specific spent fuel management programs and progress, technology updates, research and development work, consolidated storage updates, and a concluding session about how spent fuel issues affect decommissioning sites.

The optimistic tone was set by one of the keynote speakers, former NRC Commissioner Jeffrey Merrifield, who is now a partner at Pillsbury Winthrop Shaw Pittman. Merrifield said that the March 2010 statement by then-Secretary of Energy Steven Chu that the Yucca Mountain site was not a workable option "left him speechless," as such a pronouncement "defied logic and sound public policy. This was a political decision," he said, and added that "the creation of the Blue Ribbon Commission (BRC) on America's Nuclear Future was meant to kick the can down the road one more time."

Regarding the U.S. Department of Energy's (DOE) decision to develop a separate repository for defense waste, Merrifield noted that in thirty years the U.S. has not been able to get one repository even licensed, now DOE wants to have two. "President Obama has left us with no clarity and no path forward. The biggest beneficiary of the Obama Administration is the anti-nuclear groups that resist nuclear power," he asserted.

As president, Trump should take the following actions, he said:

- Seek full funding for DOE and the Nuclear Regulatory Commission (NRC) to finish the Yucca Mountain license application;
- Re-establish the Office of Civilian Radioactive Waste Management (OCRWM) that President Obama dissolved;
- Seek appropriate legislation to get land and water rights for the Yucca Mountain repository;
- Support private efforts to license and build consolidated interim storage facilities;
- Support an independent entity to take over licensing, construction, and operation of Yucca Mountain;
- Authorize DOE to act expeditiously on the transportation of spent fuel, especially given the potential near-term operations of storage facilities in Texas and New Mexico;
- Re-visit reprocessing of spent fuel in the U.S.;
- Take an active role to negotiate an appropriate settlement for citizens of Nevada to host the Yucca Mountain repository—President Trump "the dealmaker" should make a deal with Nevada residents.

Merrifield touched on the U.S. relationship with Russia. He criticized the Obama Administration's decision to eliminate the mixed-oxide (MOX) program in the U.S. by eliminating funding for the MOX Fuel Fabrication Facility that is still under construction in South Carolina. Merrifield said he recently visited the site, and he can attest to the fact that the facility is "legitimately 70 percent complete." He would also urge President Trump to complete the facility.

In response to a question about the NRC's ability to resume work on the license application after eight years, Merrifield said that the agency had a "terrific team" who put in a lot of time and effort into reviewing the license application, and he has full confidence that the agency could work through the contentions that had been raised to resolve them.

Dr. Bill Boyle, DOE Director, Office of Spent Fuel & Waste Science and Technology, Office of Nuclear Energy filled in for John Kotek, who left DOE in early January to work for the Nuclear Energy Institute (NEI), discussed DOE's activities that support an integrated waste management system. These activities are essentially the same activities DOE has presented the last several years, which include the following:

- Laying the groundwork for transportation;
- Laying the groundwork for consolidated interim storage;
- High-burnup cask demonstration project with industry;
- Disposal R&D;
- Deep borehole disposal concept;
- Evaluating a separate defense repository;
- Developing a consent-based siting process for waste facilities in the U.S.

Boyle noted that about 32,000 cubic meters of defense waste, and about 75,000 metric tons of heavy metal (MTH) are in storage in the U.S. DOE estimates that about 140,000 MTHM will be in inventory "in the future." Boyle provided additional details about each of DOE's activities. These activities "could change" with a new administration.

When asked about the future of the consent-based siting process in a new administration, Boyle said he wasn't sure what the new administration will do, but noted that the effort is funded within the integrated waste management system (IWMS) activities of the budget, and the House of Representatives provided zero dollars for that work in the Fiscal Year 2017 budget, but did designate $150 million for resumption of Yucca Mountain licensing activities. The Continuing Resolution (CR), which went through April 28, provides $22,500 for IWMS work.

When asked about DOE's preparedness to resume work on Yucca Mountain, Boyle noted that in July the Obama Administration re-affirmed its belief that Yucca Mountain is an unworkable option because of Nevada's opposition to it. To his knowledge, he emphasized, DOE has not worked on a restart plan, but if DOE were directed by Congress, or by the Courts, or in the new Administration, to resume work and were given funding to do so, then DOE would comply.

On Wednesday, a session titled "Spent Fuel Political Landscapes" generated much discussion. David Blee chaired the session, and led off with a list of "Out and In" (shown below).

Eric Knox of AECOM, said there is a "buzz to restart Yucca Mountain and bring back OCRWM [Office of Civilian Radioactive Waste Management]," although he emphasized several times that no one knows if those things will happen. The transition teams will turn in a report with an action plan, and Secretary Perry can accept or reject the reports.

On Capitol Hill, with the retirement of the powerful Harry Reid of Nevada, the hope is that progress will finally be made because Yucca Mountain has bipartisan support among members of both parties, including Lisa Murkowski (R-Alaska) and Patty Murray (D-Wash.). Politicians all over the country want spent fuel moved out of their state.

For its part, industry needs to focus on success and insist on it. "Stop dreaming and start doing," he said – "solve the problem." Knox is tired of hearing about "storage, storage, storage. We store spent fuel safely every day, but the ultimate solution is disposal."

As for the consent-based siting process, Knox said that it imposes another layer of burden that no other industry has, and it just drives up costs and causes more delays. He is not a fan of consent-based siting, he said. He continued, "The BRC, although it had many good people on it, at the end of the day it was an effort by the Obama Administration to use a lot of good, credible people as a sham to provide cover for the illegal shutdown of Yucca Mountain."

Steve Nesbit of Duke Energy noted that the U.S. has been working on geologic disposal of spent fuel under the NWPA for thirty-four years; DOE has been in partial breach of the Standard Contract for nineteen years; the Executive Branch of the federal government has been willingly violating the law for six years; and payments for disposal of commercial nuclear fuel, including interest, exceed $40 billion.

These failures are a "major impediment to the deployment and operation of nuclear power plants," Nesbit said, adding that U.S. influence in nuclear power and nonproliferation suffers from its failure to act responsibly in managing spent fuel.

In addition to completing work on the Yucca Mountain license application and re-establishing OCRWM, the U.S. NIC's Backend Working Group supports abandoning the idea to establish a separate repository for defense waste. This decision was made with no public comment period, and "no coherent rational" for it, Nesbit said. This decision must be stayed or reversed, at least until the U.S. program has made substantial progress. The Working Group also supports pursuing consolidated storage, management and funding reform, transportation planning and execution, assuring shared value for host communities, and continued research, development, and demonstration.

Lake Barrett, former OCRWM director, emphasized that if President Trump directs DOE to resurrect Yucca Mountain, then the new Secretary of Energy should reach out to repair relationships, particularly with Nevada. Once the license application proceedings are resumed, a fair, open resolution of Nevada's safety concerns will be held before impartial Atomic Safety and Licensing Board (ASLB) judges. Barrett said about 100 more contentions are expected to be raised by Nevada officials, who have been gearing up for the possibility that a new Administration could try to restart the program.

In about three years, an informed national policy decision could be made, and the NWPA could be amended. A more robust, sustainable waste management system should be created—one that incorporates interim storage.

DOE must "immediately and proactively" reach out to Nevada to try to reach a mutually beneficial consultation and cooperation agreement. Whatever issues Nevada wants to bring to the table should be discussed – empowerment, partnership/governance structures, benefits, economics. Any agreements should be incorporated into law, contracts, and/or the license itself to ensure the agreements will be upheld.

Keeping momentum for support of Yucca going on Thursday was Andy Zach of the House Energy and Commerce Committee, which will be chaired by U.S. Congressman Greg Walden (R-Ore.). Noting that the comments he made were his own, Zach said the committee hopes to pick up where the government dropped the ball after the Yucca Mountain license application was submitted in 2008. Because of the federal government's inaction, payouts to utilities out of the taxpayer-funded Judgment Fund has tripled in the last few years, with about $4.5 billion returned to utilities to pay for them to store spent fuel. The projected government liability has increased to $25 billion, which is "artificially low" since it assumes the government will start moving spent fuel in 2021. The Nuclear Waste Fund has increased to $36 billion, and the fund increased by $1.5 billion in 2016 in spite of no new revenue coming in since the Court ordered DOE to discontinue collecting the Nuclear Waste Fee.

Other brief thoughts from Zach:

- Regarding the defense-only repository, Zach noted that the timeline for its opening is still twenty-three years away, with a projected opening in 2040. DOE will have to obtain a license from the NRC to build and operate this repository.
- Interim storage—how does that fit into the big picture to protect taxpayers, as moving spent fuel twice will cost a lot of money. Congress will look at it through the lens of a national priority and how to balance it with other needs.
- Funding reform has been a challenging process, and just because one party controls all three branches of government does not mean that reforming funding for waste management will be easy.

Select Country Highlights

Representatives from a number of countries presented their respective country-level spent fuel management programs. Carlyn Greene of the Ux Consulting Company (UxC) provided a high-level overview of spent fuel management policies worldwide, with a closer look at policies in the United States and specifically, the status of dry storage in the U.S. An overarching concept of spent fuel management is that the entities that generate radioactive waste should provide for its disposal and not leave any undue burden on future generations. To that end, every nation with a policy on final disposal has designated deep geological disposal as its endpoint, but no repository for spent nuclear fuel is currently operating. Progress is being made in Finland, Sweden, and France, while several other countries, such as Canada, Japan, the United Kingdom, and the U.S., have made policy decisions to move forward with developing a repository.

Until spent fuel can be permanently disposed or is reprocessed, the consensus is that spent fuel storage in pools or in dry casks is being safely implemented and managed. Many countries may need to store spent fuel for 100 years or more until a repository is operating, and research is being conducted to ensure the safety of this stored material for long time periods.

Spent fuel can be a polarizing issue, as evidenced by the approach taken by different governments to manage it. In South Australia (SA), the government established a Royal Commission that was charged with studying South Australia's potential involvement in the nuclear fuel cycle. In May 2016, the Commission released a report that stated the storage and disposal of spent fuel in SA could provide substantial economic benefits—a total revenue of more than A$258 billion versus total costs of A$145 billion, equating to revenue of over A$5 billion a year for the first thirty years of operation. After extensive public consultation, a Citizen's Jury of more than 300 randomly selected South Australians delivered a report to Premier Jay Weatherill on November 6. The jury was asked to answer the question, "Under what circumstances, if any, could South Australia pursue the opportunity to store and dispose of nuclear waste from other countries." Two-thirds of the jury did not wish to pursue the opportunity under any circumstances. SA's Premier presented the formal response to Parliament in November 2016 that stated the only way to possibly move forward with such a proposal is with bi-partisan support and a state-wide referendum. A few weeks later, Premier Weatherill presented SA's formal response to the State Parliament, which stated that SA's government would not pursue policy or legislative changes, but would remain open to pursuing the option. Weatherill said the government believes that the only way forward to continue the discussion is through a state-wide referendum and reviving bipartisanship support for the proposal.

In Taiwan, nuclear power in general is viewed negatively, and spent fuel storage facilities are regarded as detrimental to the community. State-owned Taiwan Power Company (Taipower) is facing a severe shortage of spent fuel storage capacity. The Taipei government has repeatedly denied permits to establish dry storage facilities, and as a result, Taipower had to shut down the Kuosheng 1 reactor in November 2016 due to lack of spent fuel storage capacity required to refuel the reactor. Taipower has proposed converting part of the fuel loading pool into an area to store spent fuel, but the Atomic Energy Commission has not approved the plan, which would take a year to implement.

More than fifty countries have spent fuel in storage awaiting reprocessing or disposal, with 80 percent of the world's inventory of spent fuel in storage in the U.S. and Western Europe. About 10,000 metric tons (MT) of spent fuel is discharged annually worldwide, with up to 3,000 MT of that to be reprocessed, so annual spent fuel accumulation totals about 7,000 MT. UxC projects this total to increase, with as much as 15,000 MT discharged in 2030. The World Nuclear Association (WNA) reports that about 240,000 MT of spent fuel is in storage, mostly at reactor sites but some is stored at consolidated storage facilities or at reprocessing facilities.

In a few countries, such as Sweden and Switzerland, consolidated storage facilities, both wet and dry, are operational. Spain is planning a consolidated storage facility; Ukraine is building two interim storage facilities; and two privately-run consolidated storage facilities and one federally-operated facility are planned in the U.S.

Current policies of a few countries were highlighted as follows:

- **Canada—**Spent fuel is stored at reactor sites while Canada pursues a deep geologic repository; about 90,000 spent fuel bundles are produced each year; if all existing reactors operate to the end of their licensed life, then about 4.6 million bundles will need to be placed in the repository.
- **China—**Most spent fuel is stored in pools at the reactor sites although Qinshan also has dry storage; reactors in China will be discharging about 1,100 MT of spent fuel per year by 2020 if it meets its target of 58 GWe of nuclear power by then.
- **Lithuania—**Recently commissioned a dry storage facility at the Ignalina Nuclear Power Plant, which is being decommissioned; the facility has the capacity for 190 casks; all spent fuel should be in storage by the end of 2022.
- **Ukraine—**Policy is to store spent fuel for at least 50 years prior to disposal; most spent fuel is stored at reactor sites but Ukraine is building two interim storage facilities**—**one for spent fuel from the VVER plants and one for the long-term storage of Chernobyl's spent fuel; construction is underway; a dry storage facility has operated at Zaporozhe since 2001.

In UxC's Nuclear Power Outlook (NPO) and Requirements Model reports, the nuclear reactor requirements and spent fuel discharges are estimated. As of mid-2016, UxC estimated that the world's nuclear power programs will discharge a total of nearly 575,000 MT of spent fuel through 2030. Less than 30 percent of that will be reprocessed and the rest placed into storage. 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 2016 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; and the federal government continues to reimburse utilities, using the taxpayer-funded U.S. Department of Justice Judgment Fund, for the cost to store the spent fuel. Studies are ongoing that will confirm the safety of storing spent fuel in dry storage for up to 300 years. One such study is underway by a team led by the Electric Power Research Institute (EPRI) to study the performance of high burnup fuel that has been in storage for very long periods of time to ensure it can be safety transported after storage.

DOE has continued to lay the groundwork for an integrated spent fuel management system that would include a pilot consolidated storage facility that would store spent fuel from permanently shutdown reactor sites where all that remains is the independent spent fuel storage installation (ISFSI). Subsequently, a larger interim storage facility would be built that could accept up to 70,000 MT of spent fuel from any site in the U.S. A deep geological repository is also planned. DOE embarked on a tour of the U.S. in 2016 to obtain public input on how a consent-based process to site these facilities should be designed, and published the results of that solicitation at the end of 2016. A wide variety, often contradictory, of views were submitted. DOE also continued its work on a separate repository for defense waste, and to find a site for a deep borehole disposal field test. These policy positions were announced in 2015.

In the U.S., 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, seventy-eight ISFSIs have been licensed in the U.S., and three new ISFSIs began operations in 2016 (V.C. Summer, Watts Bar, and Clinton). Two new ISFSIs could begin operations in 2017/2018 (South Texas Project and Crystal River). At the end of 2016, UxC reported that 2,471 casks were in service storing more than 102,000 spent fuel assemblies. In 2016, close to 200 casks were loaded, and another 200 casks are expected to be deployed in 2017 at U.S. commercial reactor sites.

To date, seven site-specific ISFSI licenses have been renewed, one renewal (North Anna) is under review at the NRC, and two more renewal applications will be submitted by the end of March 2017 (Trojan and TMI-2, which is at the Idaho National Laboratory). Two Cask Certificates of Compliance (CoCs) are also in various stages of the renewal process, and more will need to be renewed by 2020.

In conclusion, UxC envisions the dry storage market to continue to see steady growth in the U.S. and globally for the next several decades as a result of decommissioning plants, delays in repository programs, and delays in reprocessing plants in countries that are pursuing this approach.

Nigel Mote, Executive Director of the U.S. Nuclear Waste Technical Review Board (NWTRB), also presented an Overview of Spent Fuel Management Programs. His presentation included a summary table of the type of storage (location and wet or dry), if the canisters in which the spent fuel is stored are in bolted or welded casks, and the disposal policy of each country. Mote also noted that research and development is underway to support extended spent fuel storage. He pointed out that the areas of research include the following: facility degradation/aging management; cask/canister drying; bolt and seal performance; fuel assembly/cladding/fuel performance; damaged fuel handling; and computer modeling.

Dr. Anders Sjöland of the Swedish Nuclear Fuel and Waste Management Company (SKB), said that the country's twelve operating reactor units, which generate about 45 percent 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, Forsmarks Kraftgrupp, E.ON, and OKG. 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 (U.S.$6.3 billion).

In 2016, Vattenfall announced its decision to close Ringhals 1 and 2, citing increased taxation on nuclear power as one reason. E.ON has announced that Oskarshamn 1 and 2 will be shut down. A new energy agreement that calls for the gradual abolishment of the special nuclear power tax could mean that Sweden's remaining 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. The Clab facility has the capacity to store 8,000 MT of spent fuel, but SKB has submitted an application to increase this capacity to 11,000 MT, as 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 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 2011. SKB is applying for the following:

- To continue to store spent fuel and reactor core components on an interim basis.
- To construct and operate a facility (Clink) to store spent fuel (for encapsulation) and core components. Clink, an integrated encapsulation and storage facility, would have a capacity of 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 ten currently operating reactors.
- 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
- 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 are expected for fall of 2017. SKB needs five approvals to start construction—from SSM, the Environmental Court, the governments of Östhammar and Oskarshamn, and the final decision will be made by the federal government. SKB hopes the Swedish government will issue a construction permit in 2018, with operations planned for around 2030.

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

Sweden's repository would have a design capacity of 6,000 canisters, which corresponds to 12,000 MT of spent fuel. SKB hopes to begin construction in early 2019. The facility would be operated for sixty years, followed by closure and decommissioning.

Dr. Sjöland addressed the International Atomic Energy Agency (IAEA) safeguards of nuclear materials. He noted that normally an owner of nuclear material declares possession of the material, then the IAEA and other authorities can inspect it for verification. A final geological repository is different, however, because the nuclear material cannot be inspected once it is emplaced in the repository, so the safeguards procedure before the material is emplaced must be strict and measurements of each fuel assembly will be necessary. These measurements will include decay heat, contents of the fuel, radionuclide inventory, burnup, initial enrichment, cooling, and more.

Some important questions that would need to be resolved include how to deal with results that indicate non-compliance; codes used at the time of declaration may be different than codes used now, which could yield different results; mistakes made in the records, and others.

Masumi Wataru, of the Central Research Institute of Electric Power Industry (CRIEPI), discussed the overall spent fuel management policy in Japan. He noted that the government's action plan for spent fuel management included establishing a council between the government and the electric power companies. This council met in November 2015, and subsequently announced their intent to secure additional storage capacity of approximately 6,000 metric tons (MT), to include 4,000 MT by 2020 through "currently planned measures," and another 2,000 MT by 2030. He also noted the Nuclear Regulation Authority's (NRA) recommendation to promote dry storage of spent fuel.

CRIEPI is continuing research on both metal and concrete casks. Research for metal casks includes studying the long-term seal performance of a metal gasket; for a concrete cask, CRIEPI has conducted stress corrosion cracking evaluations, and for both metal and concrete casks CRIEPI has evaluated the aging effects of aluminum alloy for the fuel basket. In the future, Japanese utilities will conduct a demonstration test program for the long-term dry storage of spent fuel.

Ryoji Asano, of Hitachi Zosen Corporation, presented an update of spent fuel manufacturing and technology in Japan. Dr. Asano noted that most of the spent fuel is stored in pools at each power plant, and that most of these pools are nearly full, but the inventory in them has not increased since the March 2011 accident at Fukushima Daiichi because all of Japan's reactors were shut down with just a few restarted.

Dr. Asano showed a picture of the dry casks that are stored inside a building at Tokai Unit 2 and Fukushima Daiichi, where the casks at the Fukushima Daiichi plant are stored horizontally and the casks at Tokai are stored vertically. Hitachi Zosen delivered large metallic casks to Tokai No. 2 beginning around 1990. The casks stored at the Fukushimi Daiichi plant are also metallic casks.

Two spent fuel storage projects are planned for Japan—an ISFSI at Chubu Electric's Hamaoka Nuclear Power Station, and at the Mutsu centralized interim storage facility in Mutsu City.

Although concrete casks are widely used in the U.S., Japan historically has considered concrete casks to have two disadvantages, one of which is the notion that the storage casks should be stored inside a building, since the area needed to store concrete casks is about 1.2 to 1.4 times wider than a building used to store metallic casks. However, the chairman of the NRA recently stated that no building is necessary for cask storage because the casks are designed and fabricated to withstand the more severe transport conditions than are required for storage-only casks.

The second concern with concrete casks is due to the possibility of chlorine-induced stress corrosion cracking (CISCC) affecting the performance of the cask. Dr. Asano said "It is impossible to pursue a project by evading this issue" because the ISFSIs to be built will face the ocean in Japan. However, recent studies on CISCC advances are showing that a CISCC-resistant canister is possible.

Dr. Asano concluded by noting that spent fuel storage should be economical, and that a concrete cask/module system can solve the spent fuel storage issues. Hitachi Zosen (who has owned U.S. cask vendor NAC International since 2013) delivers many concrete cask systems to the U.S., and the company wants to introduce concrete cask systems to the Japanese market.

Lubi Dimitrovski, General Manager, Nuclear Operations at ANSTO, provided an update of spent fuel management in Australia as part of his presentation on the overall nuclear power status on the continent. Australia has no domestic reprocessing facility, but exploration of other options, including disposal

1963	Dounreay	150 FA
1996	Dounreay	114 FA
1998	US SRS	240 FA
1999	COGEMA	308 FA
2001	COGEMA	360 FA
2003	COGEMA	344 FA
2004	COGEMA	276 FA
2006	US SRS	330 FA
2009	US SRS	159 FA
Dec 2015	AREVA	ILW Return

in the U.S. and reprocessing in the United Kingdom, began in the late 1970s. In 1997, the Australian government approved the reprocessing of ANSTO's spent fuel at the La Hague facility in France.

Australia has spent fuel from its High Flux Australian Reactor (HIFAR) research reactor, which was Australia's first nuclear reactor and for fifty years the only multi-purpose research reactor. HIFAR, a 10 MWe reactor, operated from 1958-2007. The reactor was converted to operate on low-enriched uranium (LEU) in 2006 before it was permanently shut down in January 2007. The 20 MWe Open Pool Australian Lightwater (OPAL) research reactor has operated since 2006. It has a compact core consisting of 16 LEU fuel assemblies (19.8 percent enriched), and consumes about 27-30 assemblies per year.

ANSTO has managed nine successful shipments of spent fuel to the UK, France, and the U.S. between 1963-2009. The maritime transport of spent fuel has to be done in an International Nuclear Fuel (INF) INF2 ship, as required by the International Maritime Organization (IMO). It meets mandatory INF code for international shipping of nuclear fuel, plutonium, and high-level radioactive waste packages. The ship has special features that make it more robust.

ANSTO shipments are represented in the table shown above.

The assemblies that were shipped to the U.S. were under the foreign research reactor spent nuclear fuel acceptance program, so no waste was returned to Australia. The reprocessing wastes from spent fuel that was sent to France was all returned to Australia by December 2015, and the reprocessing wastes from spent fuel sent to the UK will all be returned by 2020. The UK enacted substitution for vitrified waste beginning in mid-2014.

The OPAL spent fuel is stored in wet storage at the reactor, which also has a connected service pool. The government has approved funding to reprocess this material overseas, and in 2015, ANSTO entered into an agreement with AREVA for the transportation and reprocessing of OPAL spent fuel. The first shipment to France is scheduled for 2018, with subsequent shipments every six or seven years. The vitrified intermediate-level waste that is a result of reprocessing the spent fuel will be returned to Australia before 2040. The schedule is as follows:

- 236 assemblies (four casks) in 2018
- 186 assemblies (three casks) in 2025
- 186 assemblies (three casks) every six or seven years thereafter.

After 2030, the waste will return as ILW in TN-81 casks.

Australia does not yet have a National Radioactive Waste Management Facility, but more than 100 sites across the continent store LLW and ILW. These sites are not suitable for long-term storage or disposal. The Australian government sought out communities willing to host a facility; six sites were placed on a short list, and in April 2016 the government provisionally selected the community of Barndioota in South Australia.

Under the National Radioactive Waste Management Act of 2012, a landowner may nominate land to host this facility until a final site is decided upon by the Australian Government, and on February 2, 2017, the Australian Government Department of Industry, Innovation and Science announced that the government has received two new voluntary nominations to host a National Radioactive Waste Management Facility in the Kimba region in South Australia. Minister for Resources and Northern Australia Senator Matt Canavan said no decision has been made as to whether the nominations will be accepted. Both new sites will be subject to a comprehensive analysis, and will be rated on measures such as technical suitability, community well-being, health, safety, and the environment.

Two different parcels of land in the Kimba region were nominated and assessed in 2016, but neither progressed. If either of these new sites progress further and are shortlisted to the point of being nominated, then a public comment period of at least sixty days would be undertaken to ensure the area has the broad public support needed to take the nomination to the second phase, which is a detailed technical review and consultation.

The facility will be a near-surface facility for permanent disposal of LLW, and temporary storage of ILW in the TN-81 canister over several decades. The ILW will eventually be permanently disposed in a different special-purpose facility. This future facility will not accept any high-level waste (HLW), even if the government should eventually decide to accept HLW or spent fuel from overseas customers. This facility will only store material that originated in Australia.
http://www.radioactivewaste.gov.au/

Conclusion

Overall, the presentations provided an update of spent fuel management issues and initiatives across the globe, with an emphasis on recommendations and expectations for the new U.S. Administration in the back-end of the fuel cycle. Other presentations that were not summarized above informed participants on issues such as spent fuel security and aging management initiatives; spent fuel technology and projects such as the development of the process for unrestrained stackup of spent fuel into dry storage casks; DOE spent fuel campaign updates, including the spent fuel railcar project; transportation considerations; more details on the high burnup cask demonstration plan; and ongoing work to prepare for bulk shipments of spent fuel. In addition, Waste Control Specialists (WCS) and Holtec International provided details about their plans for privately-run consolidated storage facilities, and the conference concluded with a session that focused on issues related to nuclear power plant decommissioning. The 33rd annual Spent Fuel Seminar will be held in Washington, DC USA on January 23-25, 2018; based on the success of the first thirty-two seminars, this is one conference not to be missed.

Detection of Missing Assemblies and Estimation of the Scattering Densities in a VSC-24 Dry Storage Cask with Cosmic-Ray-Muon-Based Computed Tomography

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Abstract

Highly energetic, cosmic-ray muons can penetrate a dry storage cask and yield information about the material inside it by making use of the physics of multiple Coulomb scattering. Work by others has shown this information may be used for verification of dry storage cask contents after continuity of knowledge has been lost. In our modeling and simulation approach, we use ideal planar radiation detectors to record the trajectories and momentum of both incident and exiting cosmic ray muons; this choice allows us to demonstrate the fundamental limit of the technology for a particular measurement and reconstruction method. In a method analogous to computed tomography with the attenuation coefficient replaced by scattering density, we apply a filtered back projection algorithm in order to reconstruct the geometry in modeled scenarios for a VSC-24 concrete-walled cask. We also report on our attempt to estimate material-specific information. A scenario where one of the middle four spent nuclear fuel assemblies is missing—undetectable with a simple PoCA-based approach—is expected to be detectable with a CT-based approach. Moreover, a trickier scenario where one or more assemblies is replaced by a dummy assembly is put forward. In this case, we expect that this dry storage cask should be found to be not as declared based on our simulation and reconstruction results.

Introduction

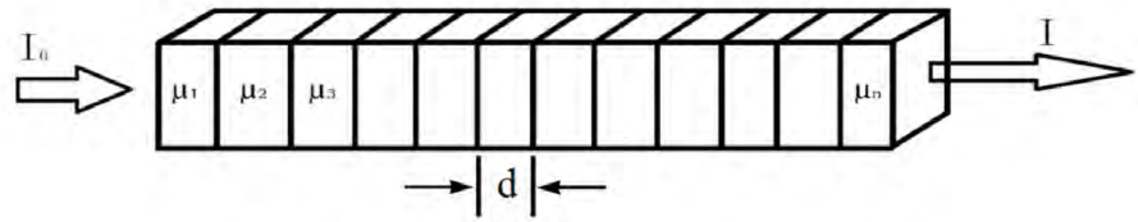
Given the abandonment of commercial reprocessing in the United States[1] and the failure to open a permanent geologic repository for storage of spent nuclear fuel,[2] alternative storage solutions are needed in the interim. Offloading of older, cooler spent fuel into concrete dry storage casks (DSC)[3] that are stored on-site is the expedient solution. Due to nuclear proliferation concerns and the high expense of resealing storage casks, it is pressing to develop a nondestructive monitoring system to verify the contents of a cask once continuity of knowledge has been lost. In this paper, we address imaging a dry storage cask with cosmic ray muons based on a computed tomography technique.[4]

The muon is an elementary particle similar to electron, with a charge of +1e or -1e and a spin of $\frac{1}{2}$, but with a much greater mass (~207 m_e). Muons are created when primary cosmic rays, primarily protons, collide with molecules in the earth's upper atmosphere.[5] These naturally occurring particles are the dominant component of cosmic radiation flux in the atmosphere. The flux is approximately 10,000 muons/m^2/min at sea level, dropping off roughly as $cos^2 0_z$, where 0_z is the zenith angle. The range of muon energies is wide, ranging from about 100 MeV to 10 GeV, with the average value being 3-4 GeV.[6] Both the flux and energy vary with a number of factors, including polar angle, elevation, and the solar cycle. Cosmic ray muons interact with matter in two primary ways: electromagnetic interactions with electrons including ionization and excitation; and multiple Coulomb scattering from nuclei.[7] Compared with ionization and excitation interactions, multiple Coulomb scattering is more sensitive to the atomic number of the material.[8,9]

In mathematics, the Radon transform is the integral transform that takes a function f defined on a plane to a function R_f defined on the (two-dimensional) space of lines in a plane, whose value at a particular line is equal to the line integral of

$$R_f(L) = \int_L f(\boldsymbol{X})|d\boldsymbol{X}| \quad (1)$$

Figure 1. Illustration of a neutral beam crossing a discretized object



The transform was introduced in 1917 by Johann Radon,[10] who also provided a formula for the inverse transform. Radon further included formulas for the transform in three dimensions, in which the integral is taken over planes. Development of computer assisted tomography based on this theorem to see the human body via X-ray images was made by Allan M. Cormack[11] and Godfrey N. Hounsfield,[12] for which both won the Nobel Prize in Physiology or Medicine in 1979.

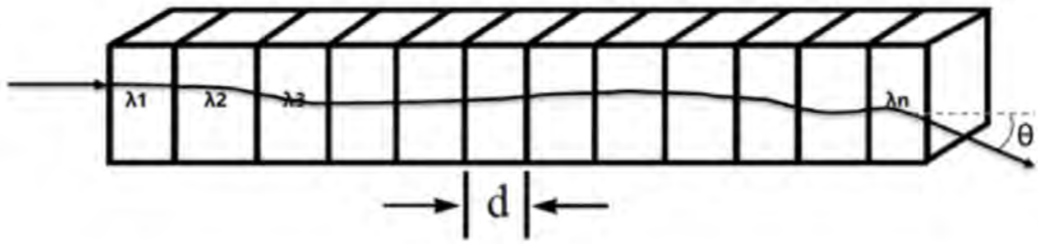
Previous work in using muons to image objects either used a simple Point of Closest Approach (PoCA) method,[13,14] which is fundamentally incapable of resolving the fine structure of an imaged object, or statistical reconstruction,[15] which is extremely computationally expensive. The latest work of imaging a dry storage cask with computed tomography is described in Reference 16; in this work, the authors use only the horizontal directions of the incident muon tracks to determine the position bin where the muon scattering angle is stored. Without measuring the muon momentum, CT reconstruction is carried out with a multigroup model[17,18] to infer the geometrical layout in a DSC. In this work, which does not focus on what can be achieved with specific detector technologies, we assume that the momentum of muons is perfectly measurable using ideal planar detectors. This assumption has been made in other related work, e.g., References 15 and 19. To date, there have been a couple of methods developed to measure muon momentum. A typical spectrometer envisaged for the LHC can achieve 10 percent energy resolution limited for low energy muons[20] and ATLAS detector can yield a relative resolution better than 3 percent over a wide P_T range.[21] Even though indiscriminately deeming naturally existing muons as monoenergetic, with the same method, the reconstructed image is still clear enough to tell whether there is a spent fuel bundle missing in DSC, but material information will be lost. Instead of using a multigroup muon model, we use each muon's momentum which is precisely measured to correct for the influence of polyenergetic muons. Both the horizontal directions of the incident muons and their PoCA points are used to project the scattering angles toward corresponding bins. Next, we apply filtered back projection to the collected information (sinogram) in order to calculate the scattering density of each pixel.

Due to the inaccuracy of the PoCA assumption, it's impossible with that method to identify one missing spent nuclear fuel assembly in a cask, especially the middle one.[14] We examine a different method which has the potential of greatly improved results. In this paper, we focus on difficult cases including a missing middle assembly or the replacement of a middle assembly. Seven different situations are simulated: one of the middle four assemblies missing; the middle four assemblies are replaced by copper assemblies, by lead assemblies or by tungsten assemblies; one of the middle four assemblies is replaced by copper assembly, by a lead assembly and by a tungsten assembly.

2D Muon CT Theory

In transmission-based medical imaging, the incident beam is usually made of x-rays, which, in contrast to muons, are neutrally charged particles. This beam typically undergoes the photoelectric effect, Compton scattering, pair production (if E > 1.022 MeV), or no reaction, as it traverses through a patient or, most generally, an object. The incident beam often has a significant probability of experiencing Compton scattering in an object, which can scatter x-rays at large angles. Thus, the detected beam flux is typically the uncollided beam. As illustrated in *Figure 1*, let I_0 and I be the incident beam and outgoing beam intensities, respectively. The ratio I/I_0 is often used to reconstruct the investigated object using filtered back projection.[22] Of course, the signal obtained from one projection or view is not enough to reconstruct an image. Thus, one typically rotates the radiation source and detectors together, while the object remains fixed, in order to obtain additional information from other views.

Figure 2. Illustration of a muon traversing a discretized object. The magnitude of the scattering angle is exaggerated in the figure for the purpose of illustration.



Referring to Figure 1, the intensity can be described by

$$I = I_0 e^{-d\sum_{i=1}^{n}\mu_i} \quad (2)$$

where d is a selected discretized length in cm and μ_i is the attenuation coefficient of the i^{th} pixel in cm^{-1}. After rearrangement,

$$\ln\left(\frac{I_0}{I}\right) = d\sum_{i=1}^{n}\mu_i \quad (3)$$

In our application of imaging a dry storage cask containing spent nuclear fuel, the incident source is naturally occurring cosmic ray muons. Most muons are transmitted through objects,[23] especially in the case of muons with high momentum (compared with the mean that falls in the range 3-4 GeV). Even though the transmission ratio could be used to reconstruct the inner configuration of a DSC, it is not likely to yield information about the specific materials through which the muon passes.

Ionization leads to energy loss of muons, and multiple Coulomb scattering causes muons to deviate from a straight line path, as illustrated in Figure 2. When many muons traverse an object, many different scattering angles will be registered, following a Gaussian distribution with zero mean value and a standard deviation σ_θ 24 given by

$$\sigma_\theta \cong \frac{15MeV}{\beta cp}\sqrt{\frac{L}{L_{rad}}} \quad (4)$$

where p is the muon's momentum in MeV/c, L is the length of the object, and L_{rad} is the radiation length of the material. For the i^{th} voxel, the variance is given by

$$\sigma_{\theta_i}{}^2 = d\lambda_i \quad (5)$$

where λ_i is the scattering density of the i^{th} pixel. Since the multiple Coulomb scattering in individual pixels can be treated as independent, the variance of the ray signal may be written as

$$\sigma_\theta{}^2 = d\sum_{i=1}^{n}\lambda_i. \quad (6)$$

The scattering density is defined as

$$\lambda(L_{rad}) \equiv \left(\frac{15}{p_0}\right)^2\frac{1}{L_{rad}} \quad (7)$$

where p_0 is the nominal momentum, chosen to be 3 GeV/c in this paper. For more information on these basics, refer to References 7 and 15.

Let the reader note that Equation 3 and Equation 6 have the same form, i.e., the right side of these two equations is a linear integration of a parameter over the particle's path. Although muons are heavy charged particles, their trajectories through objects may be roughly treated as straight lines, even though multiple Coulomb scattering causes deviations. Thus, the scattering density λ may be treated in a similar manner as the attenuation coefficient μ used in the computed tomography image reconstruction process.

Our setup in Geant4 is illustrated in Figure 3, with two pairs of detectors[25] vertically offset (by 100 cm) along the sides of a dry storage cask and a 10 cm separation between each pair of detectors. The detectors, each of dimension 350 cm wide by 150 cm high, are modeled as surfaces with perfect spatial and energy resolution. The simulated cask and associated spent fuel assemblies were configured using the design information of Sierra Nuclear's VSC-24 cask.[26] The "Muon Event Generator" was coupled with the Monte Carlo code Geant4.[27] In our implementation, the cask containing the spent fuel assemblies is fixed in location, while the detectors are allowed to rotate around the cask. In our simulation, we rotated the positions of the detectors at 2° increments to collect data from different views, or ninety times in total.

In our simulation, four detectors register the positions where each muon j crosses. Let those positions be called (X_{1j}, Y_{1j}, Z_{1j}), (X_{2j}, Y_{2j}, Z_{2j}), (X_{3j}, Y_{3j}, Z_{3j}), and (X_{4j}, Y_{4j}, Z_{4j}) for the detectors shown in Figure 3, arranged from left to right. With four interaction points per muon, the absolute incident horizontal direction angles of each muon φ_j can be calculated from

Figure 3. Side (left) and top-down (right) illustrations of the cask and detectors built in Geant4

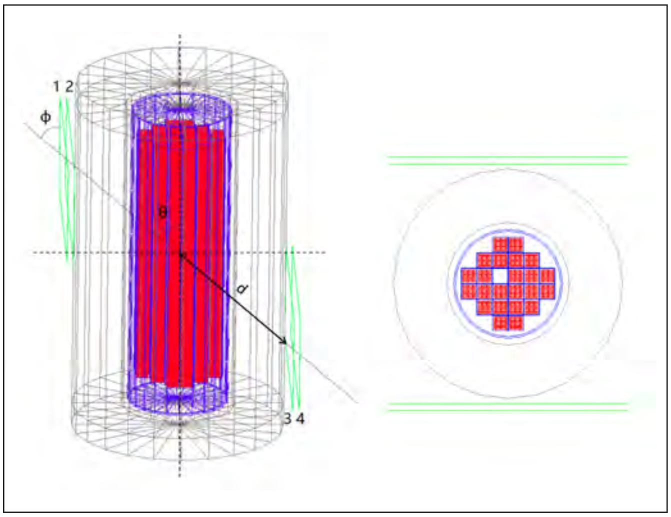
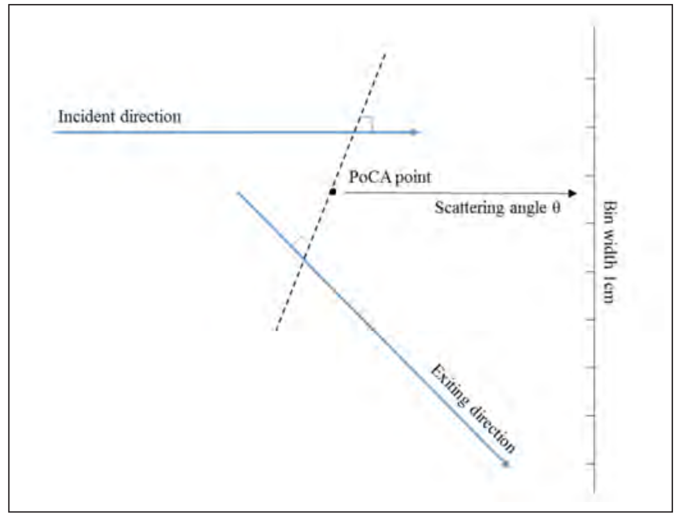


Figure 4. Illustration of a top-down view of incident and exiting trajectories, PoCA point, and the third detector plane showing the bin in which the scattering angle is stored



Equation 8, which is used to resort all registered muons into quasi-parallel ray data sets during data processing.[28]

$$\varphi_j = angle((x_{2j} - x_{1j}), 1i * (y_{2j} - y_{1j})), \qquad (8)$$

The scattering angles can be calculated using

$$\theta_j = acos(\frac{(x_{2j}-x_{1j}, y_{2j}-y_{1j})\cdot(x_{4j}-x_{3j}, y_{4j}-y_{3j})}{|(x_{2j}-x_{1j}, y_{2j}-y_{1j})|\cdot|(x_{4j}-x_{3j}, y_{4j}-y_{3j})|}). \qquad (9)$$

Using each muon's momentum to correct for the influence of polyenergetic muons and the recorded path length to correct for the influence of different trajectories,[15] the normalized scattering angle of a muon becomes

$$\theta_j' = \frac{p_j}{p_0}\sqrt{\frac{D}{L_j}}\theta_j \qquad (10)$$

where P_0 is the nominal momentum, D is the vertical distance between detectors 2 and 3 (see Figure 3), and L_j is the distance between *(X_{2j}, Y_{2j}, Z_{2j}) and (X_{3j}, Y_{3j}, Z_{3j}).*

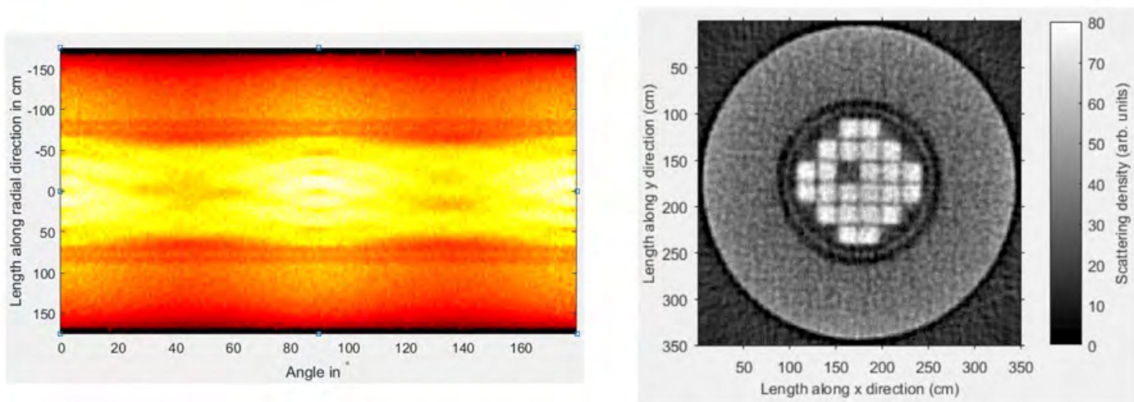
Next, the registered incident muon spectrum is divided into one-degree-wide azimuthal bins according to their incident horizontal direction angles φ, which separates the incident muons into 180 quasi-parallel groups. For muons in each angular group, we project the muon scattering angles, according to each muon's incident horizontal direction and POCA point,[29] to the plane that contains detector 3, as shown in Figure 4. Next, we divide this plane into 1 cm wide vertical bins along the horizontal direction and calculate the root mean square (RMS) of the muon scattering angles in each of these vertical bins to form a column of the sinogram. This differs from the method presented in Reference 16, which only used the horizontal directions of the incident muon tracks to determine the position bin where the muon scattering angle is stored. Due to the fact that muon trajectory in an imaged object is not straight and the PoCA point roughly represents where the deflection of the muon is, we expect that projecting the scattering angle into the bin hit by the line passing by the PoCA point and along the incident horizontal direction (see Figure 4) should be more accurate.

Muon CT Reconstruction Result Analysis

For one of the middle four assemblies missing scenario, 7.1×106 muons are used for reconstruction, which is equivalent to 18.7 hours of exposure. For details of this calculation, refer to our calculation of muon collection time at the end of this paper. The root mean square of the scattering angles in each azimuthal bin is used to form the sinogram shown at left in Figure 5. Filtered back projection was used to reconstruct the image pictured at right in Figure 5, showing the estimated scattering density in each pixel.

Looking at the reconstructed image in Figure 5, it is evident that the middle fuel assembly is missing, which matches the configuration built in Geant4, as shown in Figure 3. The estimated scattering density for the spent nuclear fuel assembly is 68.0±2.7 arb. units, and the estimated value for the empty slot is 17.2±2.1 arb. units, which are separated by roughly 18.3 σ.

Figure 5. Sinogram (left) and reconstructed computed tomography image (right) of a dry storage cask with 1 fuel assembly missing (as in Figure 3)



In order to be able to handle more challenging scenarios where one or more spent nuclear fuel assemblies from the center of cask are removed and replaced with dummy material in order to appear identical, we put forward some possible scenarios: (1) the middle four spent nuclear fuel assemblies are replaced by copper assemblies, or by lead assemblies, or by tungsten assemblies, or (2) one of the middle four spent nuclear fuel assemblies is replaced by a copper assembly, or by a lead assembly, or by a tungsten assembly.

In a case where the middle four spent nuclear assemblies are replaced, 7.5×10^6 muons are used for reconstruction. The corresponding Geant4 model and reconstructed images are shown in Figure 6.

The estimated scattering densities of Fe (the main constituent of the canister), Cu, Pb, W and U (main constituent of spent nuclear fuel), are 25.8±2.1, 29.9±2.9, 45.7±2.4, 58.4±3.2 and 67.7±2.9 arb. units. In comparison, the known scattering densities (at muon momentum of 3 GeV/c) of these five materials are 14.2 (Fe), 17.4 (Cu), 71.3 (W), 44.5 (Pb), and 78.9 (U) mrad2/cm. The relationship between known scattering densities and our estimated scattering densities is shown in Figure 7. A monotonically increasing relation between estimated and known scattering densities is expected. Yet, there is clearly some source of systematic error inherent to our estimation method that prevents us from estimating scattering density in an absolute sense. Even so, our results with an ideal detector system suggest there is potential to use muon imaging to find these scenarios to be "not as declared." Given the observed relationship, there is also potential to be able to identify the dummy material with some fidelity.

Furthermore, we aimed to understand the expected lower detection limit[30] by replacing only one of the middle four spent nuclear fuel assemblies with either a copper, lead, or tungsten assembly. For these scenarios, 10^7 muons were used for reconstruction. The Geant4 model and reconstructed images are shown in Figure 8. The estimated scattering densities of Fe (the main constituent of the canister), Cu, Pb, W and U assemblies (the main constituent of spent nuclear fuel), are 25.1±2.0, 33.6 ±2.3, 47.4±2.1, 61.4±2.2 and 68.0±2.4 arb. units. Again, the known scattering densities of these 5 materials are 14.2 (Fe), 17.4 (Cu), 71.3 (W), 44.5 (Pb), and 78.9 (U) mrad2/cm, so we are not currently able to determine the true scattering density values with our estimation method. Although we expect it to be more difficult to tell that there is one central assembly replaced by a dummy assembly than it is to tell that there are four replaced central assemblies, especially in the case of W, the statistical difference may be used to support the assertion that the spent nuclear fuel assembly is "not as declared." Also, it could be noticed that the estimated scattering density of the same materials in Figure 8 are bigger than that in Figure 6. This is due to the influence of surrounding materials and the inaccuracy of PoCA assumption. The more amount of high Z material surrounding a lower Z material, the latter is more likely to be overestimated. Because some of scattering points of surrounding high Z material fall in the region of low Z material.

Figure 6. Geant4 model (upper left) and reconstructed images of a VSC-24 cask with the middle four spent fuel assemblies replaced by Cu (upper right), Pb (lower left) or W assemblies (lower right)

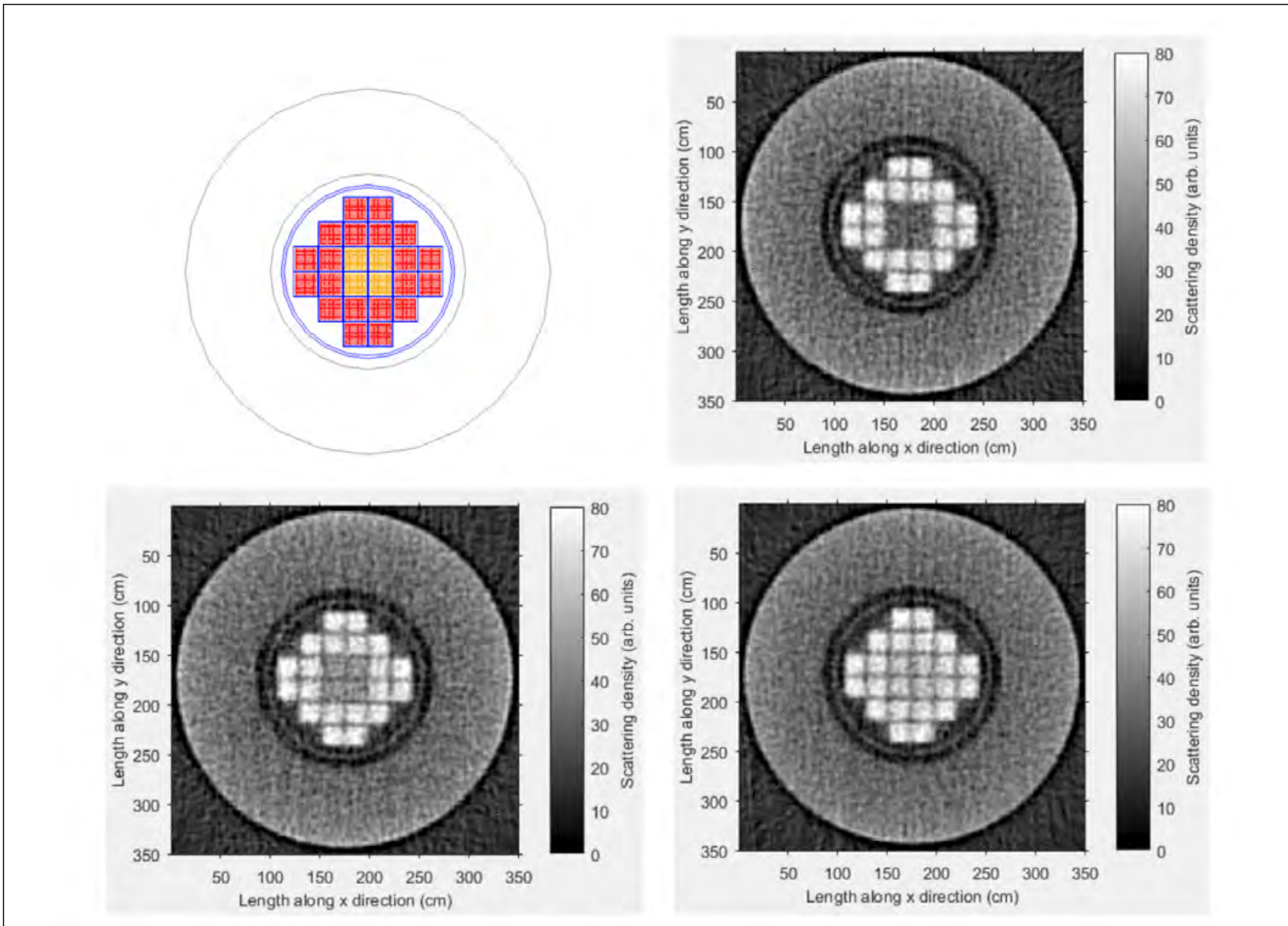


Figure 7. Comparison between known values and estimated values of scattering density for the scenarios shown in Figure 6 and Figure 8

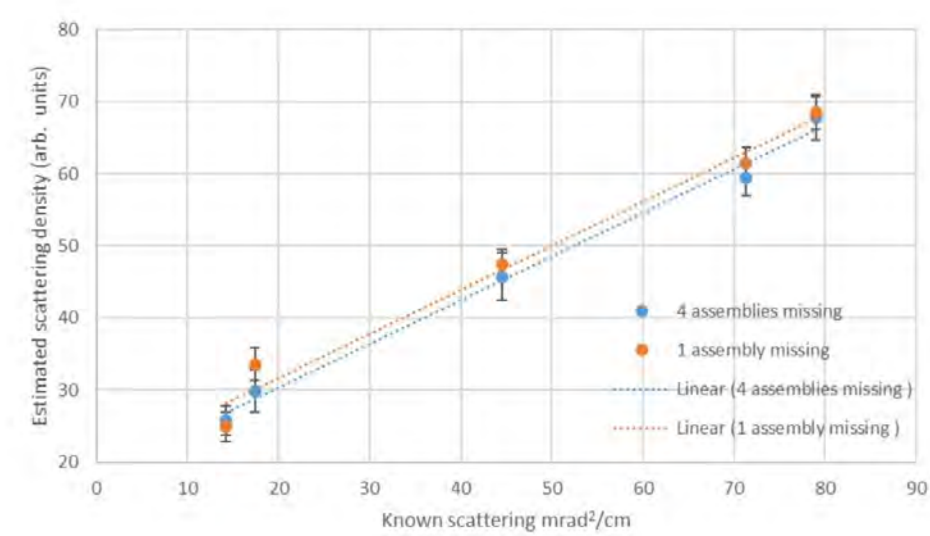
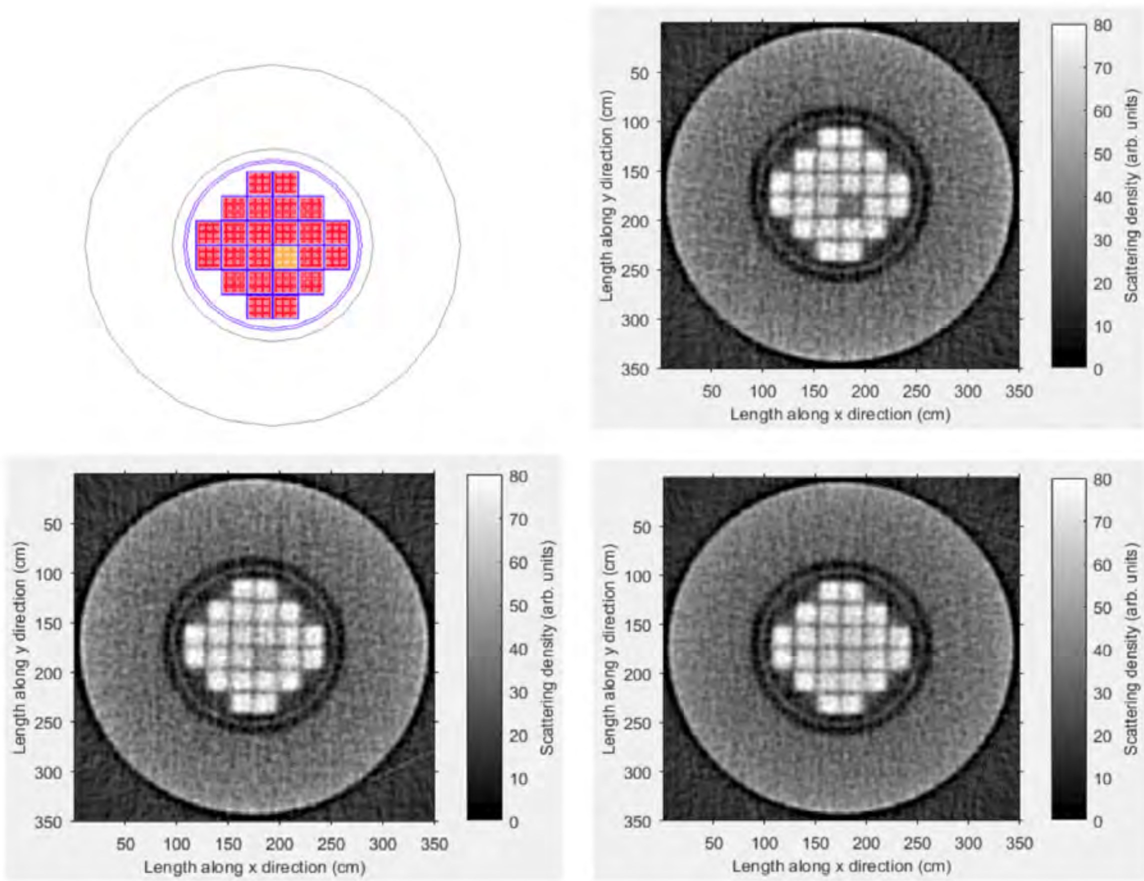


Figure 8. Geant4 model (upper left) and reconstructed images of a VSC-24 when one of middle assemblies is replaced by a Cu (upper right), Pb (lower left) or W (lower right) assembly



Calculation of Muon Collection Time

In the configuration shown in Figure 3, both the zenith angle and detector angle Φ are 54.5 degree and distance *d* is equal to 215.1 cm. When there is no simulated cask present between these two pairs of detectors, the muon flux rate registered by these detectors is 1.3×10^4 muons per minute. For the detailed steps used to calculate the flux rate, refer to Reference 30. About 2 GeV of energy will be lost by any muon that crosses our fully loaded dry storage cask.[31] Muons with initial momentum smaller than 2 GeV/c, accounting for about 30 percent of the total flux, tend to stop in the cask.[32] Thus, the expected time needed to register 7.1×10^6 muons in our four detectors with the dry storage cask present is found to be 18.7 hours.

Conclusions and Future Work

In this paper, we describe how a computed tomography algorithm can be applied to image a VSC-24 dry storage cask using scattering angle as input information, instead of traditional transmission data, to yield geometry and estimate material information. Our calculation represents the limit of what is possible for the configuration described. Cosmic ray muons passing through the cask were observed by two pairs of ideal detectors vertically offset along the sides of the cask. When one of the middle four assemblies is removed, the reconstructed image is expected to clearly show the empty slot. We also showed that when the middle four assemblies were replaced by copper or lead or tungsten assemblies, a significant discrepancy is expected. Furthermore, when one of the middle four assemblies is replaced by a copper or lead or tungsten assembly, the estimated scattering densities are expected to be found to be "not as declared," because the dummy assemblies are expected to be separated from the surrounding spent nuclear assemblies by at least 3 standard deviations when 107 muons are used. Since our method estimates the scattering density of any reconstructed pixel (see the relationship between estimated scattering densities and known scattering density presented in Figure 7), we also expect to be able to estimate the composition of the dummy material (see Figure 8).

Keywords: Cosmic ray muon, dry storage cask, scattering density, computed tomography, VSC-24

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Book Review

By Mark L. Maiello, PhD
Book Review Editor

The Case for U.S. Nuclear Weapons in the 21st Century

Brad Roberts

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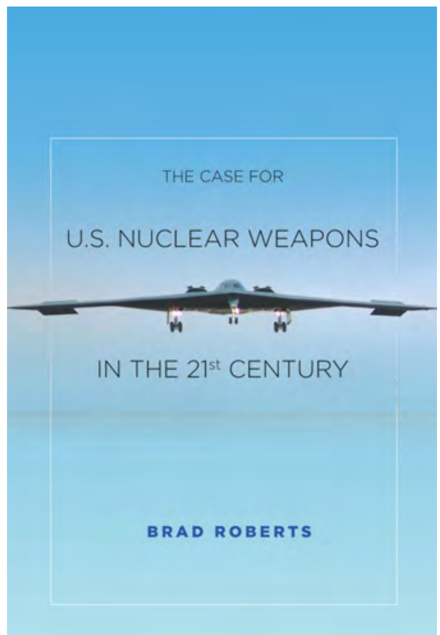

Roberts, director of the Center for Global Security Research at Lawrence Livermore National Laboratory and an Obama administration deputy assistant secretary for nuclear defense policy, has produced a factually based, highly readable counterargument to the nuclear free advocacy of recent years. Rather than attack the race-to-zero argument head on, the author presents a cool, level-headed analysis based on recent-past and expected world conditions affecting the deterrence posture of the United States. He wastes no time with a historical nuclear weapon narrative but instead begins with a concise discussion of U.S. nuclear policy evolution administration by administration beginning with the George H.W. Bush presidency. From there, current U.S. adversaries are analyzed with separate chapters devoted to isolationist North Korea, authoritarian China, and Russia under Putin's anti-democratic regime. The book's timing could not have been better coinciding with the rise of a populist, domestically focused, U.S. presidency, an expansionist China, and an aggressive Russian state utilizing cyber-attacks in repeated attempts to fracture the Western international coalition.

The author's pragmatic approach is both edifying and sobering. The analysis features dealing with Putin's Russia echoing the daily warnings one hears on CNN or MSNBC about Russian interference in U.S. politics but with a perspective that includes the other side's calculus of their tactical situation. "Humiliation," "encirclement," and "threatened" are words rarely heard from the American side when discussing Russia's motivations for their cyber-attack and misinformation campaigns targeting the 2016 American election. But make no mistake; the author brings this clarity for the sole reason of arguing for the maintenance of a strong nuclear posture—not to excuse Russia for its expansionist moves and covert attacks on western democracies. Roberts provides eye-opening detail about the current global alignment of nations and an international perspective minus—by its copyright date—the ascendancy of Trump. But I daresay factoring in the current administration's maneuvers, the author by virtue of his diligence and hard work, appears prescient.

Grounded in the real-world experience of service in the Obama administration, Roberts explains how the optimistic "U.S.-Russian reset" of 2009 was derailed by the ascendancy of Putin in 2013. Putin's view that NATO's intervention in Libya exceeded the organization's mandate and was therefore a signal of U.S. intentions to push its hegemony forward while maintaining the international order to its liking, was key to breaking down relations between Washington and Moscow. As a result, Russia embarked on a mission to increase its prowess by annexing territory (the Crimea and eastern Ukraine), and working covertly through espionage and cyber-warfare to decouple the U.S. from its European allies and themselves from each other, thus weakening the alliance and the international regime so favorable to supporting the American agenda. Roberts' insight into these matters is the reader's gain. He uses his access to Obama administration materials to open a door for the reader that permits—as an example of the fine structure provided—Putin's own words to be read. In speeches to the Duma in which the motivations of the Russian president's anti-Americanism are articulated, Roberts clarifies the Russian standpoint of world order: America and the West, unopposed by another superpower, have forsworn diplomacy for the rule of the gun. Putin's evidence is the American foray into the Middle East, particularly Syria and Iraq, that through the Russian authoritarian's eyes, have made the world less safe (so much for America winning the Cold War).

Roberts explains what Russia will do to even the score. Fearful of NATO moves to garner membership closer to Russia's borders and equally appalled by internal insurrection possibly instigated by NATO or American efforts, Putin and the Russian military hierarchy may have concluded that the West is already fractured regarding its response to a limited nuclear threat and may have adopted a posture that includes the western alliance backing down in the face of potential escalation. No one can be quite sure what is addressed behind the doors of the Kremlin so Roberts has culled the work of many domestic and foreign analysts to provide the following developments that will resonate with anyone following recent cable news programming: Russia is complimenting its nuclear capabilities with cyber and space commands; the Russian military believes that cyberwarfare may lead to capitulation by the enemy; and perhaps most disturbing and foretelling of all is the following analysis that sums up Putin's aims: he cannot obtain destruction of the hated United States without committing national suicide so he seeks maximum extension of Russian influence, the destruction of NATO, and the discrediting and humiliation of the U.S. as guarantor of Western security. We now have proof of this doctrine as western democracies battle Russia to protect their election systems. And no greater proof was observed than by Russia's interference in America's sovereignty that resulted in a current presidential administration that was/is publically anti-NATO, publically pro-Putin and currently fraught with such ineptitude, it is now regarded as a security threat to the West. Our nation's dire situation aside for the moment, need we look further to illustrate the insightful nature of Robert's work?

Nuclear weapon policy issues receive equally profound treatment. Chapters 6 and 7 discuss extended deterrence in Europe and Asia respectively. Extended deterrence—the nuclear umbrella of protection that has been a centerpiece of U.S. defensive policy for decades, is both a declarative and technical strategy. The plan must be backed by the capability to provide a nuclear response. As such, it has become a much debated topic in the context of U.S. nuclear weapon reduction (Obama administration) and a plan to lessen reliance on nuclear weapons (Clinton and Bush administrations). The concerns of U.S. allies lie with the narrowing of the nuclear umbrella. Roberts discusses extended deterrence in the context of the evolving security environment of Europe and the discussions within NATO concerning "nuclear sharing" (the deployment of U.S. nuclear weapons and nuclear capable aircraft under the command of the U.S. on the soil of select member nations). This policy originated in the 1950s and though reaffirmed in 1999, nuclear weapon reductions in Europe continued to the point where they were reduced to 97 percent of their peak. The Obama administration answered the question about removing the last 3 percent of the weapons by engaging its NATO partners to develop a new strategic concept outlined in Chapter 6 (spoiler alert: nuclear weapons do not disappear). Roberts does not provide a one sided argument. The critics of the new strategic concept are given voice particularly regarding the use of mixed nuclear and conventional weapons to achieve credible defense (the exact recipe for that mix was not formulated in the strategy).

Readers will find the subsequent discussions detailed but eminently readable. Roberts explains the developing strategies within NATO in light of Putin's annexation of the Crimea and continued interference in the Ukraine. What NATO needs he emphasizes, is a clear understanding on where all the escalation thresholds are with regard to Russia. Given the current administration's reluctance to acknowledge Russian involvement in the 2016 U.S. election cyber-influence campaign – a threshold determined by U.S. intelligence to have been crossed, breached and violated - all readers should take heed of this chapter and its guidance.

In the Pacific, deterrence policy is dominated by the actions of North Korea and its steadfast, reactionary path towards nuclear weapon and international ballistic missile development. Recent developments have to an extent outstripped this chapter (number 7) but by no means are the discussions irrelevant. While acknowledging that extended deterrence is as important in the Pacific as it is in Europe, Roberts points out significant differences in this region: China's maintenance of a positive relationship with the U.S., China's acknowledgement that its economy is tied to the U.S., China's military build-up and assertiveness in the region and Japan's and/or South Korea's potential development of strike forces of their own. The latter undermine deterrence and would likely be met with reactions harmful to both nations. Another difference: unlike Russia which has used military and cyber means to destabilize the allegiance between European nations, China has not.

One of the hallmarks of this book is its comprehensive view—a view that takes it beyond nuclear weapons. This is apparent in chapter 7 where the discussion includes the role of regional conventional weapons such as missile and interceptor defenses. As an example, Roberts points out that while Japan must consider the mix of defensive systems it needs against North Korea, it must also now consider designing such defense against a more influential and posturing China. This broader analysis is done elsewhere in the book giving the reader perspective on the role of nuclear weapons in the context of current geopolitical and military landscapes.

The earlier chapters (2 and 3) cast a wide net as well. Here, Roberts sets the table for the remainder of the book exploring what North Korean leaders are possibly thinking is their end-point, their theory (or theories) of nuclear victory. This is followed by a characterization of the U.S. response to regional challengers like China, North Korea and Russia. His "blue theory of victory" is suggested as a means to manage escalation and de-escalation with a nuclear armed state in both peacetime and war. As mentioned, Roberts recommends a continued use of nuclear weapons adapted to the changing threat landscape. Nuclear weapons make the risks of global leadership bearable for the U.S. Other nations are not prepared to join in a weapons rollback and therefore a unilateral reduction by the U.S. is at the very least, unwise. In his epilogue, Roberts dispels the untruth that the way nuclear weapons are thought of in the U.S. is anachronistic—a holdover perception of the Cold War era. This he claims is the thinking of advocacy groups seeking nuclear reductions or zero attainment; thinking, from his analysis, that is simply incorrect.

There are few downsides to this book. The inclusion of non-nuclear strategy and tactics is sometimes hard to follow for the uninitiated but its exclusion would only diminish the analysis. There are no tables, figures or photographs but no component of the book truly calls out for any of that. The terminology is understandable throughout. The acronyms utilized are rather commonplace and in any case, are defined in the text. More than forty pages of reference notes and a sixteen-page index fulfill scholarly research needs. It is a well- constructed and comprehensible analysis. *The Case for U.S. Nuclear Weapons* is a fine read even for those with convictions planted on the other side who advocate for their dissolution. It may very well happen one day, but in Roberts view, that day is not today.

Taking the Long View in a Time of Great Uncertainty

All Things Nuclear

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

It seems that the term "nuclear" is present almost daily in one media story or another, whether it relates to the growing concern that the world is closer to a nuclear exchange;[1] or that North Korea has made another advancement in their quest for a nuclear weapons capability;[2] or that Russia has violated the Intermediate Nuclear Forces (INF) Treaty;[3] or that all of the Nuclear Weapons States (NWS) are modernizing their nuclear stockpiles and delivery systems;[4] or that the nuclear power industry continues to be in turmoil;[5] or that the U.S. Senate will change its rules and exercise the "nuclear option" to use a simple majority to achieve its ends.[6]

Indeed, the term "nuclear" is being used almost haphazardly these days by nation states and others, desensitizing the population to that term, and raising the specter that there is a "new generational" perspective being created that does not recognize the destructive power of nuclear weapons, (nor the potential global benefits of nuclear energy). Most importantly, the casual use of the terminology diminishes the respect and awe that "all things nuclear" should have for impacting the future of human existence. Organizations such as the United Nations Institute for Disarmament Research[7] are working to change this perspective, and, for example have recently released a seminal research report examining the impact of the use of nuclear weapons and risks associated with various scenarios.[8] Nevertheless, all of the world's nuclear weapons-possessing states are "modernizing" their nuclear stockpiles and delivery systems, lending credibility to the concerns that use of nuclear weapons in a military conflict is becoming more probable.

This is the new world in which we must operate, however, and the challenge to the *Institute of Nuclear Materials Management*: how can we bring the extraordinary science, technology, and policy knowledge among our membership together to not only better prepare the Institute to engage in such a world, but to hopefully be able to steer a course to the future that is more promising than what it appears to be headed toward right now.

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 identify the 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.*

Current "Things Nuclear" That are Shaping Our World

International

- **Continuing tensions between the West and Russia.** The Trump Administration has indicated that it will attempt to work with Russia on the many issues that are creating international concerns. However, continuing tensions over the annexation of Crimea, incursions into the Ukraine, violations of the Intermediate Nuclear Forces Treaty with the deployment of new Russian missile systems, and the role of Russia in the Syrian conflict create barriers to the possibility of improving relations. These tensions continue to impact the previous Lab-to-Lab and other scientific and technical interchanges that were the hallmark of the post-Cold War relationships that benefited the Institute's interactions with Russia as well.
- **Escalation of tensions and territorial claims in the East and South China Sea.** The long-standing territorial conflict between China and Japan, as well as other Southeast Asia nations, over islands and sovereignty in the East and South China Sea continues, as tensions have escalated and are now influencing national defense policy in Japan and other states.[9] The Trump Administration's outreach to Taiwan initially upset the long-standing "One-Chi-

na" policy position between the U.S. and China, however, recent diplomatic discussions with respect to the evolving situation in North Korea seems to have alleviated some of these initial disagreements.

- **Iran.** The international community continues to have hope that the negotiated Joint Comprehensive Plan of Action (JCPOA) with Iran will be successful in deterring further development of technologies and Uranium enrichment that could lead to nuclear weapons. Unfortunately, the rhetoric emerging from the Trump Administration continues to threaten that agreement, although other parties to the agreement have expressed strong support for the continued implementation of the JCPOA. This rhetoric reached a crescendo during the president's recent trip to Riyadh, Saudi Arabia, where both he and King Salman identified Iran as a terrorist-supporting state, and the president called for the isolation of Iran and eventual regime change.[10]

  Recent missile tests by Iran have also created additional concern not only with the current U.S. Administration but also within the U.N. National Security Council.
- **North Korea (DPRK).** Rhetoric by North Korea continues to escalate tensions with the new U.S. administration. It is unclear what path the new administration will take, although recent administration statements point to a diplomatic-economic strategy backed by military presence.[11]
- **Nuclear Renaissance.** Although some countries have decided to forgo nuclear power as a result of the Fukushima accident of 2011 (such as Germany and Switzerland),[12] nuclear power construction in and by China, Russia, and India is moving rapidly ahead, including in the Arab states. Technological struggles by Japan at the Fukushima site, however, continue to influence global opinions on the safety and cost of nuclear power, although Japan is slowly moving forward with restarting their closed nuclear plants under a new government regulatory environment, but with mixed support among the general population.[13] Further complicating this situation was the recent Chapter 11 filing for bankruptcy by Westinghouse Electric Company, a wholly-owned subsidiary of Toshiba Corporation.[14] Although potentially only impacting the construction of new AP1000 nuclear reactors in Georgia and South Carolina, Westinghouse has operations in Asia, Europe, the Middle East, and Africa and two AP1000 power plants are in the final stages of completion at the Sanmen and Haiyang sites in China.
- **India-Pakistan Relations.** Tensions between these two nuclear armed nation states rise and fall as both nations continue to strengthen and modernize their strategic weapons systems.
- **Cyber Threat.** The growing threat posed by both state and non-state hackers to infiltrate even the most secure networks has created an alarming vision of the future. This is in the face of the growing reliance of critical infrastructure on remote communications, including those that are associated with nuclear facilities.
- **Nuclear Modernization.** Growing international tensions and security uncertainties continue to drive modernization efforts of all the major nuclear weapons-possessing states, particularly as aging infrastructure, weapons, and delivery systems bring into question their ability to meet deterrent needs. Despite efforts to reduce nuclear stockpiles and the associated danger, these modernization programs, including those of the U.S., might become a harbinger of a new multi-country Cold War.
- **U.S.-European Relations.** The withdrawal of the United Kingdom from the European Union adds a further unknown to the development of Western economic and security collaborations, including issues surrounding its own nuclear weapons deterrent.[15] President Trump's visit to Europe in May has added further tensions, leading to calls in Europe for increasing self-dependency.
- **Long-Term Spent Fuel Storage.** Progress continues internationally with the construction of long-term geological repositories.[16] Many countries will be watching the implementation of these sites to determine the impact this important step in the overall nuclear cycle has both fiscally and politically.

U.S.

- **New U.S. Administration.** The potential impact of new U.S. policy as a result of the election of President Trump has been addressed in recent "Taking the Long View" columns.[17] As the world nervously awaits the "next surprise" or change in national policy, it behooves the Institute to closely monitor this changing environment particularly as it pertains to the technical and policy issues associated with the JCPOA; North Korean nuclear ambitions; geologic storage of spent fuel and high-level defense waste; nuclear power; and the nuclear weapons modernization efforts.

- **U.S. Budget Deficit.** The economic malaise that has impacted the global community is reflected in the growing U.S. budget deficit, which is approaching $20 trillion.[18] The economic uncertainties that continue to be exacerbated by global conflicts and the uncertain future of the European Union, add a difficult unknown to the stability not only of the U.S. economy but the world as well.

U.S. Nuclear Security Enterprise

- **WIPP Radiation Incident.** As the WIPP site moves back to operational capability, three years after the accidental release of contamination resulting from a breached storage container, there is a growing optimism that the nation's efforts to permanently dispose of legacy waste are on track, including efforts by the new Administration to restart the work associated with the re-opening of the Yucca Mountain project.
- **Future of the Enterprise.** The future of the Nuclear Security Enterprise is yet to be determined, as National Nuclear Security Administration (NNSA) Administrator Klotz has remained in his position for the Interim. President Trump's nomination for Secretary of Energy, former Texas Governor Rick Perry, has recently expressed support for the U.S. national laboratories and the modernization of the stockpile, as well as for WIPP and other programs. The Implementation Plan recently issued by NNSA in response to Congressional language in the FY2016 National Defense Authorization Act (NDAA)[19] demonstrates that a major change in governance and relationships is about to occur within the Enterprise, as the results of two Congressionally-mandated studies of the Enterprise and the DOE system of national laboratories[20] have created a new wave of recommendations to resolve issues that have grown more significant in the past three decades.

The New 2017-2019 INMM Strategic Planning Initiative and "All Things Nuclear"

In many previous columns we have examined the "externalities" that influence the world that the INMM and its members work in, and speculated upon events that might move the world into very different futures. As the Institute has worked on its new Strategic Plan[21] for the past year, the Executive Committee (EC) has recognized the growing interdependency between the highly technical work that some of our members do in the nuclear disciplines, and the equally important work that some of our other members are engaged in with respect to policy, diplomacy, and international agreements. Under this strategic Goal to create a stronger link between our technical and policy disciplines, the EC established a high-priority objective to "***Identify emerging global security priorities to inform INMM activities***." We certainly have no lack of subjects from which to choose as suggested above – but what are the highest global security priorities that are facing our professions and Institute? And, in this rapidly changing world, what are the issues that may take generational commitments to solve?

To address this question, the INMM Executive Committee (EC) has made a commitment to host a ***Global Security Summit*** during the 2018 INMM Annual Meeting that would engage both technical and policy experts, as well as Institute membership, to synthesize current data, and develop the top priorities for the Institute to address in subsequent years. These would become focus areas for special sessions during the Annual Meetings and serve as a basis to identify potential topics and speakers for plenary sessions.

During the 2017 Annual Meeting in Indian Wells, the Strategic Planning Committee will work with members of the EC, including the Technical Division Chairs to further develop the structure and context for such a Summit.

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Endnotes

1. See the Bulletin of Atomic Scientists "Doomsday Clock" announcement (http://thebulletin.org/sites/default/files/Final%202017%20Clock%20Statement.pdf) which moved the hands this year to two-and-a-half minutes before midnight, citing, among other factors: *"The United States and Russia—which together possess more than 90 percent of the world's nuclear weapons—remained at odds in a variety of theaters, from Syria to Ukraine to the borders of NATO; both countries continued wide-ranging modernizations of their nuclear forces, and serious arms control negotiations were nowhere to be seen. North Korea conducted its fourth and fifth underground nuclear tests and gave every indication it would continue to develop nuclear weapons delivery capabilities. Threats of nuclear warfare hung in the background as Pakistan and India faced each other warily across the Line of Control in Kashmir after militants attacked two Indian army bases."*
2. See http://www.nbcnews.com/news/north-korea/north-korea-new-missile-can-carry-heavy-nuclear-warhead-n759406, "*North Korea: New Missile Can Carry 'Heavy Nuclear Warhea*d".
3. See https://www.armscontrol.org/pressroom/2017-02/russia-must-immediately-resolve-inf-treaty-non-compliance-issue, "*Russia Must Immediately Resolve INF Treaty Noncompliance Issue".*
4. See https://www.armscontrol.org/factsheets/USNuclearModernization, "*U.S. Nuclear Modernization Program*"; https://www.sipri.org/media/press-release/2016/global-nuclear-weapons-downsizing-modernizing, "*Global Nuclear Weapons: Downsizing, but Modernizing*"; and https://www.sipri.org/sites/default/files/FS%201606%20WNF_Embargo_Final%20A.pdf, "*Trends in World Nuclear Forces*".
5. See https://www.nytimes.com/2017/03/29/business/westinghouse-toshiba-nuclear-bankruptcy.html?_r=0, "*Westinghouse Files for Bankruptcy, in Blow to Nuclear Power",* for an article on the Westinghouse declaration of bankruptcy, which calls into question the potential success of the U.S. effort to begin re-establishing a nuclear power capability in Georgia and South Carolina.
6. See https://www.nytimes.com/2017/04/06/us/politics/neil-gorsuch-supreme-court-senate.html, "*Senate Republicans Deploy 'Nuclear Option' to Clear Path for Gorsuch".*
7. http://www.unidir.org/
8. See http://www.unidir.org/files/publications/pdfs/understanding-nuclear-weapon-risks-en-676.pdf, "*Understanding Nuclear Weapons Risks*".
9. See http://www.cnn.com/2017/02/07/asia/east-china-sea-senkaku-diaoyu-islands-explainer/, "*East China Sea: How an Uninhabited Island Chain Splits Japan and China*", and http://www.southchinasea.org/
10. See https://www.theatlantic.com/international/archive/2017/05/trump-saudi-speech-islam/527535/, "*Trump's Speech on Iran, Annotated*".
11. See: https://www.washingtonpost.com/world/tillerson-says-all-options-are-on-the-table-when-it-comes-to-north-korea/2017/03/17/e6b3e64e-0a83-11e7-bd19-fd3afa0f7e2a_story.html?utm_term=.d3aa103fb9f6 "*Tillerson says: 'All Options are on the Table' When it Comes to North Korea*".
12. See https://en.wikipedia.org/wiki/Nuclear_power_phase-out, "*Nuclear Power Phase-out*".
13. See http://www.abc.net.au/news/2017-01-05/the-future-of-nuclear-energy-in-japan-after-fukushima/8162686, *"The future of nuclear energy in Japan, nearly six years after the 2011 Fukushima disaster".*
14. See https://www.forbes.com/sites/jamesconca/2017/03/31/westinghouse-bankruptcy-shakes-the-nuclear-world/#5339ed802688, "*Westinghouse Bankruptcy Shakes the Nuclear World*".
15. See: http://truepublica.org.uk/united-kingdom/will-britain-handing-nuclear-deterrent-part-brexit-deal-eu/ *"Will Britain Be Handing Over Its Nuclear Deterrent As Part Of The Brexit Deal with the EU?"*
16. See http://www.nature.com/news/why-finland-now-leads-the-world-in-nuclear-waste-storage-1.18903, "*Why Finland now leads the world in nuclear waste storage*"; http://www.skb.com/our-operations/clab/, which describes Sweden's interim storage effort; and http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/storage-and-disposal-of-radioactive-wastes.aspx, for a longer

article describing all of the issues and nuances associated with long-term storage.

17. See JNMM Vol. 45 No.2, "*Taking the Long View in a Time of Great Uncertainty: That Will Never Happen – the Power of Scenario Planning*", pp. 36-40; and JNMM Vol. 45 No.3, "*Taking the Long View in a Time of Great Uncertainty: Winds of Change*", pp. 35-37
18. See: http://www.usdebtclock.org/
19. See: https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/governance_report_dec._2016_1.pdf
20. See: http://cdn.knoxblogs.com/atomiccity/wp-content/uploads/sites/11/2014/12/Governance.pdf?_ga=1.83182294.1320535883.1415285934, for the Agustine-Mies Report; and https://energy.gov/lab-commission/downloads/final-report-commission-review-effectiveness-national-energy-laboratories for the Glauthier-Cohon report (the "CRENEL" report).
21. See JNMM Vol. 45, No.1, "Taking *the Long View in a Time of Great Uncertainty: Preparing for the Future*", pp. 51-53.

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Designation: ____________________ *Job Title: ____________________
(e.g. Jr., III, PhD, MSc, etc.) (e.g. Engineer, Scientist, etc. If currently a student, indicate "Student")

❑ Yes, I have been an INMM Member before now. (If held under a different name previously, please indicate here): ____________

*Institution: ____________________

*Street Address: ____________________

*City: ____________________ *State/Province/Prefecture: ____________________

*ZIP/Postal Code: ____________________ *Country: ____________________

*Phone: ____________________ Fax: ____________________ *Email: ____________________

❑ *Please exclude my info from the Online Member Directory made available to INMM Members at inmm.org.*

* Membership

❑ Student $30 **
❑ Regular $75

Sustaining Members

❑ Bronze $500
❑ Silver $750
❑ Gold $1,000
❑ Platinum $2,500
❑ Diamond $5,000

Memorial Education & Outreach Fund

❑ I wish to make a contribution to the INMM Memorial Education and Outreach Fund. TOTAL $____________

** Required for Student Memberships only, provide the contact information of a faculty advisor to verify your full-time student status.

Name: ____________________

Phone: ____________________

E-mail: ____________________

*Type of Organization

❑ Academia (Faculty/Staff)
❑ Commercial Utility
❑ Equipment Manufacturer
❑ Government or International Agency
❑ Nuclear Material Processing
❑ Academia (Undergraduate/Graduate Student)
❑ Consultant/Research
❑ Government Contractor
❑ Military
❑ Other

*Fields/Subjects of Expertise: ____________________

*Job Description: ____________________
(i.e. "Student" or a brief explanation of your professional responsibilities as related to your current job title.)

*Total Number of Years Work Experience in the field: ____________________

*Please Number Your Top Three Areas of Interest (1-3):

0 ANSI Standards
0 Facility Operations
0 International Safeguards
0 Material Control & Accountability
0 Nonproliferation & Arms Control
0 Nuclear Security & Physical Protection
0 Packaging, Transportation & Disposition

Membership in Other Societies: ____________________
(e.g., ESARDA, WINS, ANS, etc.)

Honors/Honorary Societies: ____________________

Other Experience or Training: ____________________

*Indicate School

*Indicate Degree & Major: ____________________

*Indicate Date Degree Obtained/Anticipated: ____________

College or University: ____________________

Graduate School: ____________________

Post-Graduate School: ____________________


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