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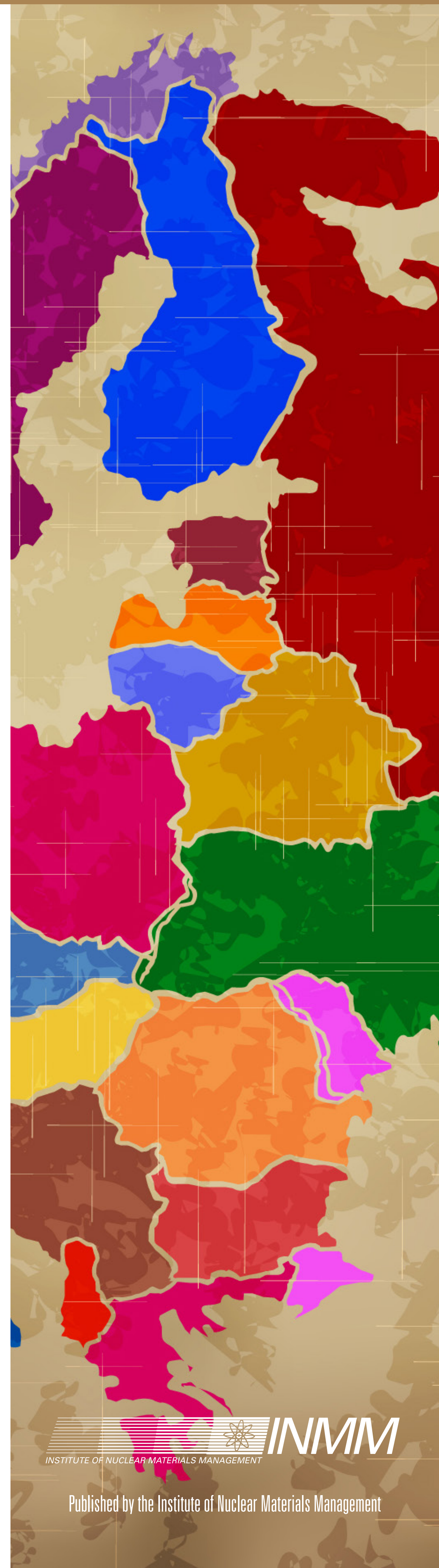

INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT
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JNMM Journal of Nuclear Materials Management

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Mission Statement

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

INMM
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The Journey of INMM

By Corey Hinderstein
INMM President

Everyone from reality dating show contestants to the Chinese philosopher Laozi have spoken of the importance of the "journey." As I begin my term as INMM president, I am compelled to reflect on my journey with the Institute so far, recognizing that I am in the middle and not close to the end.

I joined INMM in 2002, the same year I attended my first annual meeting. When I asked INMM Headquarters to confirm the date, I was surprised. It seems that INMM has been part of my professional life even longer than 14 years. I walk directly in the footsteps of the six men and two women who have served as president during the time I have been active in the Institute, and remain inspired by many others who influenced my decisions each year to renew my membership and advocate for support to attend meetings and workshops. I also regularly twist the arms of friends and colleagues to join if they are not already familiar with the opportunities for professional growth and access to subject matter expertise that come with being part of the INMM community.

But this space is not the right venue for an extended reverie about my personal connection to INMM, if such a venue exists. Immediate Past President Larry Satkowiak wrote in this space in the last issue of *JNMM* about the strategic planning process that the Executive Committee led this year with the valuable input of volunteer leaders and the membership as a whole. Many lessons emerged from that process, and are reflected in the resulting strategic plan, including that the health of INMM depends on the things that I experienced as a younger member in the early 2000s: active and passionate members willing to volunteer their time and energy; substantive output that is technically credible and relevant; and, programs that add value to both experienced and new professionals in the field of nuclear materials management. These characteristics have been central to my initial, and continued, commitment to INMM.

I hope you will continue to talk to colleagues around the world about INMM and how it can be of value to them, as it is to you. Submit an article for this *Journal* and help us sustain the high quality of its content. Talk to a student or young professional at the next workshop or annual meeting and inspire them, as experienced members did me, to return and even become more active at the chapter or international level.

Does it sound like I am asking you to advertise for INMM and do more work to support it? I am. But I will make a commitment too. As U.S. President Teddy Roosevelt said in his 1905 inaugural address, "Much has been given us, and much will rightfully be expected from us. We have duties to others and duties to ourselves; and we can shirk neither." This is true for us in our professional lives, dealing with materials that have greater potential benefits, and capability of harm, than most others. It is also true in our stewardship of a professional community in which we, and our predecessors, have invested so much.

The 57th INMM Annual Meeting

Markku Koskelo
JNMM Technical Editor

As in past years, the first issue of our new editorial year focuses on the INMM Annual Meeting held in this past July in Atlanta, Georgia, USA. The easing of U.S. government travel restriction has had a clear impact on the number of papers presented at the Annual Meeting and the number of attendees at the conference. It is also gratifying to see the continued increase of student participation. See Teressa McKinney's summary of the Annual Meeting for further details.

As has been our tradition for this issue, we have included the transcript of the talks made by our three plenary speakers, Anne Harrington, Deputy Administrator for Defense Nuclear Nonproliferation, National Nuclear Security Administration, Washington, DC, USA, Tero Varjoranta, Deputy Director General and Head of the Department of Safeguards, International Atomic Energy Agency, Vienna, Austria, and Rob Floyd, Director General, Australian Safeguards and Nonproliferation Office, Barton, Australia. Each of the talks offered a summary on how pure technical expertise in our field is not enough and how science, technology, policy, and culture affect our ability to effectively manage nuclear materials.

The article on the plenary speeches is followed by the traditional *JNMM* Roundtable interview of the plenary speakers. The transcript includes the questions posed by the INMM leadership to the plenary speakers and offers additional candid insight from them on the intersection of science, technology, policy, and culture in our field.

Perhaps befitting the increasingly international nature of the INMM, and the large non-U.S. participation in the annual meeting, we have included two very internationally oriented contributed papers in this issue. The first looks at the reasons why several countries in the Middle East are seeking to build civilian nuclear energy capacity despite their very substantial oil reserves. Of particular interest in this paper by Thaqal Alhuzaymi and Ayodeji Babatunde Alajo is the discussion on where the Nonproliferation Treaty (NPT) fits into this process. The second contributed paper includes results from a portion of a larger initiative for using nondestructive measurement techniques on spent nuclear fuel that involves a team comprised of the European Commission, DG Energy, Directorate Nuclear Safeguards; the Swedish Nuclear Fuel and Waste Management Company, Uppsala University, the University of Michigan, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Oak Ridge National Laboratory. The authors of this paper are from Sweden and the United States. Among the goals of this development effort are improving international safeguards by detecting the diversion or replacement of nuclear fuel pins in spent nuclear fuel, as well as several other objectives. See the paper by Peter Jansson et al. for further details.

In the past, this issue has also included the student paper winners from the Annual Meeting. We will publish these papers in a future issue. The student papers are peer reviewed now and peer review takes time and we want to give the students the opportunity to address the comments they receive from the reviewers rather than rushing the papers to publication. See the names of the winning authors and the titles of their papers in Teressa McKinney's summary of the Annual Meeting.

Book Review Editor Mark Maiello provides us a comprehensive review of the book, Nagasaki — Life After Nuclear War, by Susan Southard. If you need additional insight on why the work being done by the members of INMM to manage nuclear materials is so vitally important, read this book. Maiello explains there are a number of other reasons why the book is worth reading.

In his column, Taking the Long View in a Time of Great Uncertainty — Preparing for the Future, Jack Jekowski, columnist and chair of the INMM Strategic Planning Committee, gives us a brief summary of the new strategic plan that the INMM has developed and is in the process of implementing. Clearly, the execution and timing of the strategic initiatives for the INMM as an organization will be impacted by external events, such as what happens in DPRK and Iran, how the continued threat of terrorism impacts us all, and what just happened in the 2016 U.S. presidential election.

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

JNMM *Technical Editor Markku Koskelo can be reached at mkoskelo@aquilagroup.com.*

Report of the 57th INMM Annual Meeting

Atlanta, Georgia USA, July 25–28, 2016

Teressa McKinney
Chair, INMM Technical Program Committee

I hope you had the opportunity to join us at this year's annual meeting that was held at the Marriott Marquis in Atlanta, Georgia, USA, July 25-28, 2016. Despite the reputation of "Hotlanta," the weather proved to be reasonable and staying in a downtown hotel allowed the attendees to venture out in the evenings to explore the city.

Kellen was well represented by its Executive Director Aaron Adair and Administrator Amy Lydic. Although they are somewhat new to the INMM annual meetings, they have proven they are professionals when organizing details behind the scenes. It has been a pleasure working so closely with them both and they are to be commended for the success of the annual meeting. We also have the pleasure of working with Lyn Maddox as conference director and Patricia Sullivan, marketing communications director. Without their hard work behind the scenes we would not have experienced such a special event.

The Executive Committee (EC) met on Saturday before the annual meeting. This typically is our largest EC meeting of the year since most members are also in attendance at the annual meeting and there was indeed a packed meeting room. Sunday was a busy day, too. The extra events included the Containment and Surveillance Working Group, Destructive Assay Users Group, Nondestructive Assay Users Group, Open Source/Geospatial Information (OSGI) Working Group, and ANSI/INMM 5.1 Analytical Chemistry Laboratory Measurement Control Committee. Many thanks to Tom Bonner and the Registration Committee for managing registration the entire week. All the technical divisions met on Sunday afternoon before the President's Reception. The President's Reception provided an opportunity for all participants to meet-and-greet with our vendors and sponsors. We sincerely appreciate all our vendors and sponsors that participated throughout the week. Please reserve your vendor spot early next year. INMM had more requests than anticipated so please keep this in mind next year when making your plans to attend and exhibit.

Monday morning began with INMM award presentations before the opening plenary speakers. The awardees were:

- 2016 INMM Early Career Awards: Katherine Bachner, Adrienne Marie LaFleur, and Shaun Clarke
- 2016 Edway R. Johnson Meritorious Service Award: J. Michael Whitaker
- 2016 Vincent J. DeVito Distinguished Service Award: Jacques Gilbert Baute, Roger Howsley, Paul E. Ebel, and Dennis L. Mangan

Details regarding each of the awards can be found on INMM's website. Please take a few moments to read about the recipients' outstanding accomplishments. Congratulations to all!

The Opening Plenary Speakers, Anne Harrington, Deputy Administrator for Defense Nuclear Nonproliferation, National Nuclear Security Administration, Washington, DC, USA, Tero Varjoranta, Deputy Director General and Head of the Department of Safeguards, International Atomic Energy Agency, Vienna, Austria, and Rob Floyd, Director General, Australian Safeguards and Nonproliferation Office, Barton, Australia, gave an informative and engaging session titled, Connecting Science, Technology, Policy, and Culture for Effective Nuclear Materials Management. Keep providing great suggestions for our INMM Annual Meeting opening plenary speakers. We take all suggestions into consideration. Thanks to Joyce Connery, Steve Mladineo, Larry Satkowiak, Corey Hinderstein, and Jill Cooley for helping to organize this year's plenary session. A transcript of the opening plenary session and the Roundtable discussion with our plenary speakers that followed are published in this issue of *JNMM*.

The technical sessions began immediately following the opening plenary. The full program included 388 oral presentations and thirty posters during sixty-three concurrent sessions that included seven panel discussions. We had more than 713 in attendance from twenty-nine countries. I want to thank the Technical Program Committee for pulling together an exceptional technical program. We received many positive comments throughout the week. Thank you technical division chairs, for your hard work on the technical program:

- Morris Hassler, Facility Operations
- Michael Whitaker, International Safeguards
- Mona Dreicer, Nonproliferation and Arms Control

- Tom Grice, Material Control and Accountability
- Tom Bonner, Nuclear Security and Physical Protection
- Jeff England, Packaging, Transportation, and Disposition

The poster session took place on Tuesday and all who visited the posters were surprised with special treats. We closed the day with the annual Business Meeting and the results of the executive committee elections were announced. The results are Corey Hinderstein, President; Cary Crawford, Vice President; Chris Pickett, Secretary; Bob Curl, Treasurer; and Members-at-Large Kerry Dunn and Willem Janssens. The outgoing Executive Committee Members-at-Large Cary Crawford and Steven Wyrick were recognized as well.

Two Resolutions of Respect were read honoring our late INMM colleagues Gary P. Kodman and Rosemarie N. Martyn. The new INMM Senior Members were announced during the Business Meeting. They are Mona Dreicer, Takahiko Ito, Stephan Richter, and B. Chino Srinivasan. INMM recognized new Fellows of the Institute, Caroline E. Mathews and Walter Kane. Congratulations to you all. The technical program continued on Wednesday and it was another busy day filled with papers and lunch meetings.

Closing Plenary

Thursday technical sessions were conducted throughout the morning and in the afternoon we featured our Closing Plenary Session: Integrated Cyber/Physical Threat Scenario. A team of international experts presented an integrated cyber/physical threat scenario to demonstrate the potential adverse impact on nuclear security (and safety) associated with such an attack. The hypothetical scenario featured an interactive video and demonstration showing hypothetical coordinated attacks on both a competent authority and the operating organization of a nuclear power plant and an interactive discussion of industry-proven prevention and mitigation efforts. A display of a nuclear facility and a similar integrated cyber-physical attack scenario was displayed in the exhibit hall throughout the week of the annual meeting. The closing plenary was very well attended and there were many questions for the team of experts that presented.

A special thank you to Cary Crawford for working with the team of international experts to present this special Closing Plenary Session.

After the closing plenary session, INMM President Larry Satkowiak and Vice President Corey Hinderstein announced the J.D. Williams Student Paper Award winners:

1st Place

Packaging, Transportation and Disposition — Paper #365, *Steady State Thermal Analysis of the Pipe-Overpack Container for Transuranic Waste at Los Alamos National Laboratory,* by Jude Oka, University of New Mexico.

2nd Place

MC&A — Materials Control and Accountability — Paper #392, *Uncertainty Quantification for Quantitative Imaging Holdup Measurements*, by Aaron Bevill, University of Michigan.

1st Place Poster

Poster #463, *Thermal Analysis of Lanthanide Hexafluoroacetylacetone Chelates*, by Shayan Shahbazi, University of Tennessee.

Division Winners

Education and Training — Paper #491, *Developing a Radiological Surveillance Education Exercise at Texas A&M University*, by Manit Shah, Texas A&M.

International Safeguards — Paper #173, *Using Cherenkov Light to Quantify Reactor Kinetics Parameters and Infer Fissile Material Inventory for Nuclear Nonproliferation*, by Thomas Holschuh, Oregon State University.

Nonproliferation and Arms Control — Paper #298, *Economic Sanctions and Selectorate Theory as Applied to Nuclear Proliferation in the DPRK and Iran,* by Alton Lu, the University of Washington.

Nuclear Security and Physical Protection — Paper #309, *Development of a System Dynamics Model for Assessing Nuclear Security Culture Using Survey Data,* by Geonhi Lee, Seoul National University.

Special thanks to Jim André from Pacific Northwest National Laboratory who coordinated this year's Student Paper competition and Glenda Ackerman, from Dade-Moeller and Associates, who helped with the early coordination of papers and communications with the Technical Divisions, as well as the nineteen volunteers who evaluated presentations and posters here, and the many technical "readers/graders" from the Technical Divisions who did the initial paper scoring.

We appreciate you taking the time to provide comments back to us about what you like or dislike about the annual meeting. We do take the time to read each of these and incorporate into the next year's annual meeting as much as possible. I plan to attend the 58th annual meeting at the Renaissance Indian

Wells, Indian Wells, California, July 16-20, 2017. I hope you plan to be there, too. See you then!

Keywords

Nuclear nonproliferation, arms control, spent nuclear fuel, International Atomic Energy, IAEA

Opening Plenary Session

Connecting Science, Technology, Policy, and Culture for Effective Nuclear Materials Management

INMM 57th Annual Meeting
July 25, 2016

Larry Satkowiak:
Let me introduce our distinguished opening plenary speakers. I think you'll find the discussion quite interesting.

Anne Harrington was sworn in as the Deputy Administrator for Defense Nuclear Nonproliferation for the National Nuclear Security Administration in October 2010. From 2005 to 2010 Anne was the director of the U.S. National Academy of Sciences Committee on International Security and Arms Control (CISAC). While at CISAC she managed several key studies on nonproliferation, threat reduction, and other nuclear security issues. Prior to that Anne served for fifteen years in the U.S. Department of State where she was Acting Director and Deputy Director of the Office of Proliferation Threat Reduction and a senior U.S. government expert on nonproliferation and cooperative threat reduction. She has dedicated much of her government career to developing policy and implementing programs at preventing proliferation of WMDs and missile expertise in Russia and Eurasia. She also had launched similar efforts in Iraq and Libya.

Tero Varjoranta assumed the post of Deputy Director General and head of the Department of Safeguards on October 1, 2013. Prior to assuming this role he was the Director General of the Radiation and Nuclear Safety Authority, also known as STUK, in Finland. Between 2010 and 2012 Tero served as the Director of the IAEA Department of Nuclear Energy, having previously worked as Division Manager in the International Science and Technology Center in Moscow. He has served as the president of ESARDA and also as president of the European Nuclear Regulators Group.

Rob Floyd was appointed to the position of Director General for the Australian Safeguards and Nonproliferation Office in 2010. He is responsible for Australia's implementation and compliance with the Nuclear Nonproliferation Treaty, the Chemical Weapons Convention, and the Comprehensive Test Ban Treaty as well as being engaged in the further development of safeguards and nonproliferation regimes. He has been appointed by the Director General of the International Atomic Energy Agency as chair of the Standing Advisory Group on Safeguards Implementation, also known as SAGSI. He is co-chair of one of the working groups of the International Partnership for Nuclear Disarmament Verification and was the lead official for Australia at the Nuclear Security Summit in March. He is the past chair of the Asia-Pacific Safeguards Network.

We'll begin the remarks with Anne Harrington. Anne, the floor is yours.

Anne Harrington:
Good morning everyone and welcome. We were given the challenge of looking at connecting science, technology, policy, and culture for effective nuclear materials management. I am going to talk particularly about the challenges of culture, which is something that I have been tracking for years but have been seized with particularly over the last several years as we've taken a look at all of the things that we've done in this area for the last twenty-five years — and thought about how can we do this better? Particularly in a world where nuclear technology is expanding to include countries that have not traditionally had nuclear technology and may not be as accustomed to handling it as we are.

My co-speakers and I never really had a chance to discuss speaking responsibilities. So I raised my hand quickly and said I'll do culture. In many ways if we do not succeed in establishing the right culture, it doesn't matter how exquisitely defined the policies are or how wonderful the science and technology is. The lack of a culture to support those will lead to vulnerabilities and weaknesses. We spend a lot of time talking about culture, but what do we really understand about it and how you create it.

So, I do what I always do when in doubt — go to the dictionary. And I'm not going to run through all of the definitions, but will highlights a number of phrases: Integrated patterns. Customary beliefs. Set of shared attitudes. Values, goals and practices. Values, conventions and social practices. Those are all things that are very important. But what's even more important is figuring out how they fit together.

So, what comes first? I took a look at the three topics as a way to begin. You might argue that maybe policy has to come first. For a variety of reasons a government might decide to have an open or a closed fuel cycle. A country like the United States with significant energy resources might decide that a once-through fuel cycle that avoids separating plutonium is preferable. Other countries, especially those with very limited or no other energy resources might decide that the cost and associated risks of the closed fuel cycle might be worth the resulting energy independence. Similarly, one country might be able to develop significant support among its population for long-term spent fuel storage while another country might not.

That's a fairly significant oversimplification, but the point is that policy can be a very significant driver. On the other hand, having a policy that states you will have a closed fuel cycle isn't very meaningful unless you have the science and technology to support it or can't afford to collaborate with another country to provide that technology. So here you could argue that policymakers have to take into account the state of science and technology and what it realistically can support.

And then there's the issue of culture or, rather, I should say cultures. Thanks to conversations with friends around the world and in collaboration with the UK Department, formerly known as Energy and Climate Change, and the Middle East Scientific Institute for Security, we at NNSA have been delving into what we mean by culture and how do we probe through the various layers of culture that affect how we think, perceive, absorb information, and consequently act. And based on those discussions I would propose that a graphic might better represent these three topics like this.

So the three issues are clearly interlocking but each has its own set of influences. And again, I would argue that in the culture aspect, if the culture isn't working the other two cogs don't move. What we've looked at is how nuclear security culture really is embedded in a constellation of other kinds of culture: you could have a national culture, corporate cultures, linguistic or age cultures, professional levels, and safety culture all of which could have an influence on security culture. So success in the nuclear security realm can depend very heavily on how nuclear security core values and basic principles are translated into the operational context of the beholders' national, geographic, societal frame of mind.

We as practitioners may see nuclear security culture as of paramount importance. Whereas others might argue that a safety culture is more important. What we need to recognize is that what we seek is more than just the national or societal or historical prisms through which others view nuclear security culture. The figures show some of these but I'd like to explore this just a little bit more.

In our interactions we're often tempted to project our own cultures or values onto other situations. Things that sound familiar often have quite different meanings and we need to be aware of that. So I started looking at some examples. Let's start with the squeaky wheel. For us the squeaky wheel gets the oil. You make enough noise and you get attention and you get what you want. Laura Liswood wrote a very good book on diversity called, The Loudest Duck, in which she uses this example.

In Asian cultures you have a different idiom. The loudest duck — gets shot. The beginning of that sounds a bit similar and in the U.S. we often only say the first part of the saying, assuming that the audience will know what we mean: "Well, you know, the squeaky wheel…" We don't necessarily finish the thought because all of us understand what the squeaky wheel leads to, right? It leads to something good. Well, in China it's the loudest duck, but the loudest duck gets shot. Or in Japan, the nail that sticks up gets pounded down. So those kinds of differences in how we perceive things can have a huge impact in how we share experiences and how we try to use our cultural background to develop a solid nuclear security culture.

How does that work? So much depends on these core values of ours. What we're trying to do through our programs anyway is to raise awareness of all personnel of the importance of nuclear security, of the nature and immediacy of threats, and of their personal responsibility whatever their organizational level or position for security. How to improve manager performance both in terms of enhancing security effectiveness and contributing to strong nuclear security culture, and how to establish organizational policy and structures that are the basis of culture and its sustainability. These are all the right goals. But how do we get there?

I want to use this slide as an illustration because we've been talking about it a lot lately: Insider threat mitigation. The goal is how to maintain material security. But in a lot of cultures insider threat as a phrase implies you personally are a threat. In terms of our ability to communicate a concept, if we start off by talking about insider threat we may lose our audience right away.

Sometimes we use "human reliability program" and in some cultures that actually does work better.

But the point is that human reliability training could also communicate in certain cultures that you're not reliable. So now we have to train you because you're not reliable. That's not a good place to start. And what is a good place to start in some cultures is a trustworthiness program. Because I am trustworthy, I will work with you to develop this as a corporate culture and as a way of practicing what we do every day at work.

The identification of that right language from the outset is extremely, extremely important. What we've concluded is that one size does not fit all. Cultural factors can and have been shown to have a huge impact on how a country implements nuclear security and we've already talked a little bit about this. WINS has made huge contributions in this area to try to help the understanding of how we translate into other cultures. One of the things we're exploring, for example, and this has proven so true in recent conversations with international partners, when we do workshops on nuclear security culture, how much time do we spend at the end of the workshop actually talking about how that one individual from a large organization or maybe a handful of individuals from a large organization, will go back home and walk into their job and say, "I've got it. I've got the answer. I've just been to this great workshop and we had this terrific facilitator and we have a plan and here it is." But we don't spend time with that person talking about what they will encounter when they go home. We don't take that half of day or even a full day to help them come up with how do you go home and begin to introduce some of these ideas into your layers of culture? That is something that we're going to work on as an organization. NNSA will work on that concept in a very focused way in the coming months. Because we've been given some very useful guidance and I think that we can make some real progress.

I'm going to skip through this next section really quickly and just want to let you know that this is available. I attended the Gulf Nuclear Energy Infrastructure Institute Capstone Event earlier in the year and three women who are all engineers and inspectors at the UAE regulator, as their final project on security they took a look at the impact of linguistic diversity on security at the Barakka Nuclear Power Plant. It is a fascinating study because they have something like a dozen different nationalities, Chinese, Pakistanis, Turkish, Jordanians, U.S., UK, and Emirati, all working at the plant. That multilinguistic environment will very likely continue through construction into operation. And how do you have a security culture, how do you build a security culture when you have that kind of communication challenge?

Their study is absolutely fascinating. English was chosen as the unifying language. But what they found were these elements of diversity in understanding, pronunciation, and construction. As good engineers, they then went and dug into the data and they developed a survey that they did at the plant. It was very interesting. They apologized for the simplicity of the survey. They said we're not social scientists, that they didn't really know how to put it together. Which in fact was absolutely perfect. If they had been social scientists they probably would have come up with an exquisite survey that would have been so complicated that the people who were taking it probably wouldn't have understood the language. A very simple and direct survey was ideal and revealed that people did not feel confident asking for someone to repeat instructions. They didn't feel confident that they understood instructions. They also compared it to the IAEA guidelines for emergency communication and found four points of failure in being able to meet those guidelines simply because of linguistic differences. So, it's another one of those illustrations of how very complex this issue of cultures is and how much work we have to do to meet some of these problems that they have identified.

This is one of those issues, now that we have a lot of the basics right, we need to really explore how to fine-tune and how to customize and how to make our partners more comfortable with what we're doing and our overall efforts more effective.

So, thank you very much.

Larry Satkowiak:

Thank you, Anne. That was very impressive. I think you're right, culture can have unintended consequences in terms of impacts on nuclear security. Our next speaker is Tero Varjoranta, Deputy Director General and head of the Department of Safeguards at the IAEA.

Tero Varjoranta:

In the next 12 minutes I will explain from the Agency's standpoint what is new in connecting people, technology, processes, and culture, and why it is important in light of our legal safeguards objectives, legal obligations, and resources. For instance, at the IAEA we deal with a spectrum of expected developments and extraordinary events. Being able to respond to them was a key challenge of the last year.

We all agree that deterrence of nuclear weapon proliferation is one of the top security priorities of the international community and that the IAEA makes an indispensable contribution in this regard through the effective implementation of safeguards. Of course, it is our legal obligation to implement safeguards: it is not a matter of choice. Our legal obligations determine our workload.

Furthermore, we are seeing our workload increasing. There are more nuclear power plants, more nuclear material, more spent fuel transfers, more decommissioning, and more overall nuclear fuel cycle activities each year. For example, over the past five years, the amount of nuclear material under safeguards has increased by 22 percent to over 200,000 significant quantities (SQs) (Editor's note: The IAEA defines a significant quantity as the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded.) This amount is rising by an average of 18 SQs every day. However, the IAEA budget rose by only 0.6 percent in real terms during that period.

It is expected that these upward trends will continue. We need to accept that as safeguards verification demands grow, the safeguards budget will not match them. This is what we can reasonably predict. But then there is the more unpredictable part, the aforementioned "extraordinary events." These are major events that usually happen suddenly and to which we have to respond quickly. This is the area I want to focus on today. Such events can have a positive or a negative impact. However, either way they complicate the effective management of safeguards implementation. I will divide these extraordinary events into three types of event.

The first type is diplomatic events. A key example of such an event is safeguards in Iran. The JPA (Joint Plan of Action) and JCPOA (Joint Comprehensive Plan of Action) for Iran were extraordinary diplomatic events. Another possible example would be a diplomatic breakthrough on the Democratic People's Republic of Korea's (DPRK) nuclear program. A diplomatic breakthrough in DPRK would obviously require novel and modified monitoring and verification approaches to be developed and probably implemented at short notice in a very challenging environment.

The second type is security events. A key example of such an event would be a state losing control over part of its territory in which we apply safeguards. This is already happening: the Agency is being required to safeguard nuclear material located within areas in conflict, which disrupts our normal ways of operating.

In light of these three extraordinary events, traditional Agency responses — such as our two-year planning and budget cycle, five year research and development plan, mid-term strategy, long-term strategic plan, etc. — to such extraordinary events are likely to be inadequate and too slow to meet the demands of the moment, where "failure is not an option." In this respect we can take important lessons from the Iran file.

Let me explain the implications of the Iran Case Study. Since January 16, 2016, the Agency has been verifying and monitoring Iran's implementation of its nuclear commitments under the JCPOA. There were a number of features of this experience that required a significant, swift, and innovative Agency response. We had to be agile to succeed while still acting within our legal mandate. I would even say that if we had proceeded strictly by the "book," we wouldn't have been able to deliver a successful outcome. Many of the things we were requested to do under the JPA prior to 2016 and then in 2016 under the JCPOA required us to develop new, robust approaches and ways of operating. This included developing new equipment with little time available for testing prior to deployment. In such cases there were no "baseline" documents to consult, such as the planning and budget cycle and mid-term strategy to guide management direction.

Let me list ten of these new challenges for Iran that we met successfully:

1. **Final assessment of the possible military dimensions to Iran's nuclear program. The Agency** had never carried out anything similar previously.
2. **The JPA and then JCPOA had lots of monitoring and verification requirements. These requirements** were only known in detail to the Agency at the last minute as the Agency was not a party to the negotiations.
3. **Verifying the enrichment levels of UF_6 in real time.** This real-time verification activity required the deployment of a new instrument called the on-line enrichment monitor.
4. **Measuring the production and inventory of heavy water. The Agency had rarely done such activity** previously.
5. **Daily access. The Agency needed to create** requirements for daily access.
6. **Centrifuge R&D and manufacturing, remote monitoring,** etc. The Agency needed new, innovative, and robust solutions.

7. The **funding** issue. It was a challenge for the Agency to put together a realistic budget. At least initially both the JPA and JCPOA had to be funded through extra-budgetary contributions. Even then we had to start doing things before sufficient funding had been secured.
8. The **recruitment** process. Recruitment had to be substantially speeded up from the normal recruitment cycle of one year followed by the usual training period of one year for safeguards inspectors in headquarters and in the field. To provide a swift and agile response, some recent retirees had to be reinstated and retirements postponed. As experienced staff moved into frontline positions supporting JCPOA, we had to backfill their vacant posts with temporary staff as we waited for new recruits to arrive and be trained.
9. **Rules changed in the middle of the game.** New resolutions superseded the previous United Nations Security Council and IAEA Board of Governors resolutions. These new resolutions were not well recognized and understood by all, thus complicating our safeguards implementation.
10. **Reporting to the IAEA Board of Governors.** We faced different and extensive reporting requirements under the JPA and JCPOA.

For the IAEA to meet these challenges we need to better connect people, technology, processes and culture. We need to solve these challenges by improving the two areas of productivity and responsiveness.

If we are to remain effective, we must improve productivity. There are three main ways of improving productivity that we are already implementing in the Agency as key areas of progress.

1. We are exploiting new technologies and modernizing our information technology (IT) system with the Modernization of the Safeguards Information Technology (MOSAIC) project underway. However, there is much room for improvement even as we move forward in IT.
2. We can streamline our internal processes. We have begun an internal audit to see where we can cut out any wasteful activity.
3. We can encourage a number of our member states to improve their cooperation with us.

We must also increase responsiveness to address effectively and in a timely manner respond to rapidly changing extraordinary events.

To understand what we are trying to do I must define "culture" as those ideas, beliefs, values and knowledge that constitute the shared basis of our action. Certain challenges lie in the organizational culture. Namely, the IAEA, like many large organizations, has a culture steeped in years of doing things in a particular way. There are certain inherited work practices and internal processes. Some of these are not appropriate to meet the demands of a quickly changing world. We need to avoid a culture in which:

- Precedence overrides improvement,
- Process overrides outcomes, and
- Established practice overrides critical analysis.

In my experience, to properly connect and align organizational culture, people, technology, and processes, the following five areas need to be in order:

1. **Leadership —** Effective leadership is essential. In coping with the unexpected, a clear vision and direction from managers is critical if our staff are to feel sufficiently confident to work out of their comfort zone and adapt to rapidly changing situations.
2. **Finance —** The Agency's financial mechanisms need to be adapted to be able to cope with unexpected events. Even using the extra-budgetary mechanism, however, the Agency may still have to act in advance of having the guaranteed financial resources to fund its actions.
3. **Skills —** We need to expand the skill set of our staff through revised training programs for our inspectors that stretch their capabilities and foster innovative thinking and flexible responses.
4. **Technologies —** IT advances will enable us to respond more quickly and more effectively. For example, new software solutions are capable of searching open source information fifty times faster than can be achieved manually.
5. **Processes —** As I mentioned earlier, we are already looking carefully at how we can streamline our internal processes. A good place to start would be our recruitment processes.

Operating within our legal mandate we must have the agility, innovation, and responsiveness to meet the looming extraordinary challenges. It will require an adaptation in the Agency's organizational culture. This will take time, but we need to sow the necessary seeds. We must learn as much as possible from lessons from the Roadmap for the Clarification of Past and Present Outstanding Issues regarding Iran's Nuclear Program, the JPA, and the JCPOA.

In conclusion, I am very positive about the future of IAEA Safeguards and their continued contribution to global security. The Roadmap, JPA, and JCPOA have demonstrated that the Agency is able to respond effectively and with agility even in response to extraordinary events, where "failure is not option." We do need to learn the lessons from this experience. Success will not come automatically. It will require excellent leadership, effective management, highly qualified staff and the ability to respond effectively, quickly and with agility when the need arises. The world will continue to change and the Safeguards Department will need to change with it to manage the everyday implementation of safeguards. The Agency must strive to be even more agile in its responses to extraordinary fast moving events.

We will also continue to work tirelessly to deter the spread of nuclear weapons — every hour of every day of every year — to verify the peaceful nuclear activities in 182 countries across the globe. Failure is not an option. I am confident, that with your support, we will continue to succeed. Thank you.

Larry Satkowiak:
Thank you, Tero. That was a great set of remarks in terms of sort of explaining the challenges that faces the Agency as we move forward. Next I'd like to turn the floor over to our final speaker, Rob Floyd, Director General of the Australian Safeguards and Nonproliferation Office in Australia.

Rob Floyd:
Firstly, I wish to honor the other keynote speakers. I feel like an imposter on this stage when sharing the podium with two people such as Tero and Anne. When I think of their contributions over the years and over recent years, Tero pays a price of huge pressure as he fulfills his responsibilities and even at a personal cost. Tero, I want you to know we appreciate that. So, thank you. They do it for us.

But the fact that I feel diminished by them is actually the central message of what I want to say today — believe it or not. My essential message as we look at this topic is about the role of the individual. And that each of us has a role to play, even those that feel insignificant or daunted by their peers.

Four weeks after the sirens had died, the security staff that were bustling around everywhere had disappeared, and the black limousines with the tinted glass had whisked away the famous leaders, President Obama and Prime Minister Abe, from the Hiroshima Peace Park, I walked around as a lonely figure. I walked around as one person in the steps that these guys had stepped and I pondered. The issue is that although these famous and responsible people had moved on, these people with great responsibility, what was my responsibility? I was overwhelmed by the devastating effects of one small nuclear weapon. One small nuclear weapon, of only 15 kilotons, less than one-thousandth the size of weapons that have been tested elsewhere.

Looking at the photos and reading the stories of the devastation, out to about 1.6 kilometers of almost complete razing of a city. And 100,000 people died by December 1945. For some this was a powerful demonstration of exquisite application of science. For others it was a decisive military blow that brought a war to an end. For others it was tragedy beyond tragedy with immense human loss, personal loss, human suffering, and devastation. It was a totemic event that we hope would never happen again.

For me I was numb. I couldn't fathom the devastation of all that had gone on there and I wondered about the morality of many things. I was filled with many questions. Questions like what are the appropriate policy settings to limit such events? Should scientists make moral and ethical decisions about the acceptable use of their discoveries and applications? Were there technologies that should never even be developed although conceivable? I was left with many questions. Yet, while feeling small and diminished by the rich and famous and important people that had been there before, I felt strangely motivated — strangely motivated that I too had a part to play. That I too in my small responsibilities in Australia as the head of a regulator had a part to play. That I would do my best, that I would do something for this generation and generations to come.

Colleagues, this is the message: each of us has a part to play. Each of us and each of you in this room has a particular part to play in doing our best for this generation and the generations to come.

In addressing the topic today, I will talk very briefly on science and technology and then move through the issues of policy and culture.

It's an inspiring journey when you look at the journey of discovery of atomic science. It was only late in the 1800s that we started to make some sense of what material was made of and the concept of electrons with the discovery of X-rays, only in the late 1800s. The first workable models of matter, of atomic structures were developed in the early 20th century. The structure of the nucleus was elucidated in the 1930s, and the structure of neutrons and protons in the middle of the 20th century. Quarks — I'm so glad quarks arrived — quarks and other subatomic particles were being theorized and progressively discovered in the 1960s and onwards. High-energy particle accelerators enabled us to learn so much more, even to discover the so-called God particle in 2012. Amazing journey and discovery of science. Amazing indeed.

What I find most amazing about that journey is not that it went deeper, deeper, deeper into smaller, smaller, smaller things — although that's incredible — right? What was more incredible is that it allowed us to look out and see bigger and bigger and bigger things and go further and further back in time so that we could even develop an understanding of dark matter, of the origin of stars and we could even get into the whole area of cosmogony, not cosmology but cosmogony — the study of the origin and structure of the universe. Isn't that incredible? Well, some of you just do this stuff — it's just ordinary for you, isn't it? For some of us, for me as a mere biologist, it's amazing that you could look deeper and deeper into matter and end up answering questions about the origin, the structure of the universe!

Such are the amazing discoveries of science. And yet as science advances it would appear as though the sky is the limit when it comes to our understanding and its applications. Or is it? Or is it? Maybe there is an acceptable space for the application of nuclear science that is smaller than the theoretical or the conceptual space.

Let's take a look at a few examples of technologies arising from nuclear science. Consider nuclear medicine — how amazing. In Australia it's said that every adult in Australia is likely to benefit from nuclear medicine at some point in their life. Every adult! Nuclear medicine in many different forms — whether it's diagnosis or treatment or clarification of issues. So surely there should be no problems with policy and public support for nuclear medicine. In Australia we produce radio-pharmaceuticals using a low-enrichment uranium fueled reactor and we use low-enrichment uranium targets. It was a policy choice for broader nuclear security reasons which in turn affected the choice of options for radio-pharmaceutical production.

But friends, in Australia even through every adult benefits from nuclear medicine at some time, we are struggling to decide on the siting even of a low to intermediate level waste repository. And this is where local culture comes to bear.

If we consider the area of nuclear energy, well, we all know the story there. It's incredible that it's only about 11 percent of global electricity generation that comes from nuclear. So when we look at the technology and the science, we see there is so much potential. But for various reasons, the actualized space is less than the potential space.

Part of the message I want to bring to you is that in some cases the science is the easy bit. But dealing with the culture and the policy can in fact be the hard bit. We have many aspects that civil society are concerned about with nuclear energy, whether it's issues to do with safety or whether it's issues to do with waste management and so it goes on. In my country we do not have any nuclear power reactors. There is still an open debate about such a matter.

A third area of nuclear technology I want to mention is nuclear weapons. This is probably the most contentious of all. Nuclear weapons, one would have to say, do not enjoy global support. Yet they are still critically held to ensure national security. It's clear that all nations that have signed on to the Nuclear Nonproliferation Treaty are saying that we should disarm but it's also clear that our circumstances are not such that this is something that can happen easily or even soon. So we see that the policy and we see that the culture impact upon the use of technology.

The sky is not the limit when it comes to our nuclear technology because policy reflects cultural attitudes. It reflects public acceptability and defines a lesser space for application.

So if we look at policy a little bit more closely and just briefly. In the realm of the application of science and technology there is a need for governments to exercise some control for the greater good, even for the global good. Some think that markets have morality and we should leave economic things to the market. It will come up with a moral outcome. Others might think we should do the same with science and discovery. I think there is a role for governments to work for the greater good and to limit and direct accordingly.

The controls or policies, which are just basically government decisions, may have their effect through legislation or regulation or awareness raising or other means. There are many different ways. In the case of nuclear science, policy helps define the acceptable space of operation — the areas where we can utilize these technologies and how we should do it. Policies define what responsible use looks like for nuclear technology, and they take into account considerations such as environmental factors — carbon emissions, waste management, environmental impact — security, economics, safety, nonproliferation, disarmament.

But as I reflected on my visit to Hiroshima, I considered that scientific discovery in and of itself has no morality — it is we that bear that responsibility. It's back to the individuals and the collection of individuals. We bear that responsibility. If you're a policy officer, then you are directly involved in designing the policies that are for the national or the international good. And to the scientists in the room, policy officers are not your enemies, right? They are not your enemies. It might feel like that from time to time, but they are not. I really encourage you to work on partnering with policy people — so that you would understand their space and they would understand your space.

When I was involved in the science agency, my main engagement with policy officers was to try and get money. And that's not a good basis for partnering for policy development. "I could help you, but you'll have to pay." Even as a government research agency it was still about you're going to have to pay. Sitting on the other side of the fence I see it slightly differently now.

Regulators are the implementers of some of these aspects of national policy. My encouragement to my fellow regulators is to keep reminding yourself and your staff of the big picture of why we actually do what we do. We don't do it just to regulate. There is a purpose. And we need to keep our eye on the big picture. To that end I would encourage regulators particularly, but others also, get your staff to visit Hiroshima. And if you have a problem when you're putting a case up to your boss, just say one of the keynote speakers at the INMM said that I had to go. That's okay with me.

If you're a researcher my message is partner, partner, partner. More commonly we seem to engage in the mode of advocate, advocate, advocate. But actually if we change that mindset I think it could be very helpful. But for all of us, no matter what our role is, get involved. Get involved. It's not for someone else, it's for each of us to contribute in whatever way we can. I had found it absolutely exhilarating really to be involved in the Nuclear Security Summit process as a Sherpa for a country. It was tough, it was wearing, but it was exhilarating when we saw leaders articulate things that we had worked on over the years. And when we saw those incremental changes for the better. It is worthwhile getting involved in these things.

Now let me finish with just some comments on culture. And it's culture at the individual level. Anne has beautifully painted the broad picture about culture but I want to focus more on the individual. And one first observation is that leaders have a particular responsibility when it comes to culture. We all influence and shape culture but for those of you that manage one person or more, you've got a greater responsibility because you shape the culture more than anyone else. Some even say that leadership and culture are two sides of the same coin. Peter Drucker says culture eats structure and strategy for breakfast. And he's absolutely right. Such is the power and importance of culture and its influence, as Anne made clear to us earlier.

So in this presentation we started with the ecstatic mountain tops of nuclear science discovery and cosmogony. We considered powerful applications of nuclear science, acknowledged the essential constraining role of policy. But now we need to consider how we work together. Probably the most important part of the whole journey.

Let me highlight some elements of culture that I consider to be particularly important, and I'm not wishing to be comprehensive on this. I wish to encourage you with regard to these.

I would love to see us develop a culture that focuses on best practice rather than mere compliance. So many look to see "what are my legal requirements and I will fulfill my requirements." Others say "what does best practice look like and how could I do that." You see how different those two cultures are. I was so impressed when I visited the UAE and saw their construction activities for their four nuclear power reactors. I talked to the officials there and got a very strong sense that these guys were aiming for the top and they should be congratulated for that. They're a great model to many of us to aim for best practice.

A culture of cooperation and partnership versus a culture of legalism or competition. This certainly comes to mind when I consider the relationship between states and the IAEA. Some states focus on the legalistic interpretation of treaty agreements and work by that. But cooperation and partnership will take the goal of what we are legally committed to, to a higher level — not just working within implied legalistic limitations.

A culture of greater transparency. I think we're seeing changes on this. We're seeing changes on this through the Nuclear Security Summit process. There was an acknowledgement that we should be providing assurances to other states. Although nuclear security is our national responsibility, there is no reason why we can't actually share assurances with others.

A culture of trust and building bridges of trust. This I think is probably the most important. Yes, verification has an important part but if there aren't bridges of trust it hugely limits the effectiveness of what any of us can do. We need to build bridges of trust. I love the Asia-Pacific Safeguards Network, seeing the trust that has built amongst different nations. I see some members of that group here. Different nations and they're sharing their challenges and being vulnerable. They're sharing what they're not doing well because it's a safe and trusted environment. Then other countries are saying, "Yes, I struggle with that also but we tried this or this worked for us." It only works when there are bridges of trust. And in some national cultures that's even more important.

Stronger bridges of trust with some verification allow for greater effectiveness and efficiency. They also allow us to build a safer and a more responsible framework in which the power of the technologies that we're interested in can be harnessed and can be used for all mankind.

Colleagues, science discovers, technology applies, policy guides or constrains, but culture is the glue that puts it all together. Culture matters and culture is the sum of all of us. That is why you matter. Each of us matters.

So, as I walked around the Peace Park and I pondered what is my responsibility. When the famous had left the park some weeks before having delivered amazing speeches, commitments and challenges, I feel it is now left to us. It's actually left to each of us to ensure that we answer the cries of the spirits of all those who died in Hiroshima and in associated conflicts. That we do better for the sake of the living and those yet to live. Thank you.

Larry Satkowiak:
Rob, thank you. That was terrific. Thank you for tying it all together and pulling it all together.

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Nuclear materials management, nuclear nonproliferation, nuclear safeguards, nuclear safety culture, nuclear safeguards culture, IAEA inspections

JNMM Roundtable

Opening Plenary Speakers

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As it has for two decades, the *Journal of Nuclear Materials Management* hosted a roundtable discussion with the opening plenary speakers at the INMM 57th Annual Meeting. The participants had an opportunity to ask the plenary speakers questions based on their presentations during the opening session.

Markku Koskelo: Welcome to the *JNMM* Roundtable. We appreciate your participation in this annual discussion with the INMM Annual Meeting opening plenary speakers. We will begin the questions with INMM President Larry Satkowiak.

Larry Satkowiak: Thank you. During the panel this morning, Tero mentioned five elements of a successful organization. Leadership, finance, skills, technologies, and processes. And then you talked a little bit about the impacts of the JCPOA on the Agency. Which parts of those five elements were most impactful when it came to addressing the challenges of meeting the requirements of the JCPOA?

Tero Varjoranta: The most impactful and most stressful was the leadership. It was basically in three different ways: what can be done, what can't be done, and what should be done. And then translate the challenge into an opportunity. Once you have people trusting that this is an opportunity — this is not a challenge for which you will be punished if you get it wrong — and you get that open mindset it empowers people. This enables them to become creative, innovative and, above all, agile: because agility was the key thing. And agility is not only what we do, it's also how we do it and when we do it. We have to remember that in this situation we were up against severe time constraints.

With the JPA — and then the JCPOA — these were big, diplomatic, international efforts and my team and I more or less, more or less saw it as a question of war and peace. So we had to succeed. Most of us worked flat out for a year and a half, six days a week — often six and a half days a week. But once things worked out we felt a great sense of achievement.

Satkowiak: So, in a sense you had to affect a culture change within the Agency in order to drive them down that path.

Varjoranta: Absolutely. As I mentioned in my remarks, organizational culture needs to adjust — in particular in an organization like ours where you have done things in the same way for many years, and then you face something completely new. We are used to a two-year program and budget, five-year R&D plan, six-year medium-term strategy and a long-term strategy for twenty to thirty years. And then suddenly you are in the situation where you need to think and act on your feet. Nowadays, the short-term future is something you can't predict — it can bring something extraordinary.

So it took a cultural shift for people to recognize that without agility we weren't going to get anywhere: the agility was the big difference in this culture.

Personally, I don't think the need for agility is going to disappear and that our future success or failure will depend on it.

Irmgard Niemeyer: I have a question for Anne Harrington and Rob Floyd. Rob, in your keynote you stated that science is the easiest piece. I may tentatively agree but also wanted to note that sometimes policy and culture involved in nuclear materials management create very tricky scientific questions. But assuming that science is the easiest bit, I would be interested in hearing your view on whether science and technology could play a stronger role, being a vehicle, in enhancing the culture of cooperation and partnership, for strengthening the culture of transparency, the culture of trust, so if science and technology could have stronger roles for promoting a common understanding of nuclear materials management culture among as many stakeholders as possible.

Rob Floyd: Thank you, Irmie, for the question. I thought there'd have to be at least some scientists in the room that would want to challenge me on this point. But you did it very gently. I appreciate that.

The cultural issues and the policy issues are inherently multidimensional, which often makes them harder. A lot of science that we do is more unidimensional. And I know from my own history as a research scientist that my sense of significance was built on knowing more and more about less and less. When I went into government I then found that we were facing situations where we had to make major decisions for the country and we were doing it knowing our knowledge was only partial. It was interesting to see that sometimes even with partial knowledge, the policy decision can't wait. It must be decided anyway. So it's a little scary and it's quite challenging as a scientist to work in that space.

Your point about science and technology in terms of enhancing cooperation and building trust, I think is absolutely correct. I've seen that work in many places and I'm sure Anne has got a huge litany of examples that she will be able to draw on from U.S. experience.

The science and technology, in and of itself, is often not a point of political tension between countries. To be able to build understanding via cooperation in a scientific activity is excellent because it builds understanding between countries and between participants, and from that, those bridges of trust that I referred to this morning, begin to build, often start in non-contentious areas and then build up and build up. I've been fascinated by the discussion that's being had here about the JCPOA and the progression of trust over time and the way those relationships worked.

Science and technology I think is an excellent place to be building relationship, understanding, and ultimately trust.

Anne Harrington: Rob's absolutely right. There may be a bigger fan and supporter of science and technology as a bridge, a trust-building mechanism, than me, but I'm not sure. I'd love to meet them if they're out there.

Picking up on the JCPOA and trust. I think that one of the real opportunities in the JCPOA to begin building bridges and constructive transparency is Annex 3. It's very frustrating on the U.S. side that we still have so many sanctions in place for human rights and missiles and everything else that it's very difficult for us to get engaged early. But I'm very happy to see other colleagues in Europe and Japan already thinking about how to move forward in this area.

Somewhat related to that is the area where I spent a great deal of my career, which was developing the International

Science and Technology Centers (ISTC). Originally known as the KGB centers for the three foreign ministers, Kozyrev, Genscher, and Baker (Russian Foreign Minister Andrey Kozyrev, German Foreign Minister Hans-Dietrich Genscher, and U.S. Secretary of State James Baker). Those centers were really dedicated to absorbing the expertise, the excess expertise, the unemployed expertise from the Soviet military programs — the WMD programs and missile programs. And they ran a very good and full cycle and really, I think, contributed a great deal as many people at this meeting contributed to that process as well.

Russia decided a few years ago that it really didn't want to be seen anymore as an assistance recipient and they withdrew. That created a very interesting dialog among the remaining members, which was, are we really ready to close for business or does this platform for international scientific cooperation still have meaning? And they decided that it did. So the agreement for the ISTC was revised. The geographic limitations were dropped. And the focus moved from engaging people who were directly involved in WMD programs to more a platform for focusing on risks of dual-use technology, which are everywhere. And how to channel people with that kind of knowledge into activities that had societal value.

So, new concepts through the science centers could be seismic monitoring for the CTBT (Comprehensive Test Ban Treaty), energy efficiency and sustainability, or any of a lot of new topics that will be managed somewhat differently than the original program, but still taking advantage of the ability to do international science together. We were very excited when the first organization that requested partner status was in fact from the Middle East and the Centers have already been able to engage scientists from Iraq and Afghanistan and elsewhere in some of their work. We see that as being one of those demonstrations of the power of science. It's like music, it's like sports. It has a universal attraction. And I absolutely agree that we need to find more opportunities to do things like this and to find more ways to promote that spirit of transparency. I am not sure how we get that going in North Korea, but it's something that the South Koreans absolutely think about. They've been part of this process from the beginning and as they look at North Korea, they think, "if and when the day comes, we would want to be able to have an engagement program like that where we could have that confidence building and transparency bridge to our colleagues to the north."

Varjoranta: Let me answer it very straight — not yet. It is extremely important to really analyze and learn the lessons from the JPA and JCPOA and take them seriously. You never know when the next surprise comes along. Perhaps it will be a breakthrough on the DPRK. I can assure you that we have a preparedness plan for DPRK. So we are ready within two weeks to send in the first team when the invitation comes from DPRK and our Board approves. But that is the simplest part of the whole story because nobody knows what we're going to find out. And nobody knows how to address what we're going to find out. And there won't be too much time to then start to sort it out. And the DPRK is far more complex in terms of nuclear fuel cycle and in terms of our knowledge than is the case with Iran. And Iran is already complicated enough.

We also have Member State Support Programs, which are necessary for our success. The U.S. support program is particularly important for us but others are too. Somehow we have to get the message through to our supporters as to what agility is all about. We are just at the beginning of understanding. And as I mentioned in my speech, there is lots of talent in the Agency but to succeed and win, you also need luck. So we are very humble in front of the success that we have because there are so many times and there were so many things where things could have gone wrong. But I have to say based on science, technology, and luck, it didn't go wrong. So yes, there are lots and lots of things we have in front of us.

Harrington: So if you play that out to the countries that are involved in supporting the implementation, you get somewhat the same set of issues but one step removed. If you think for example about the export control review procedure that's embedded in the JCPOA, it has time limitations on it. If you don't get it through your approval process and make a determination, then it's assumed that it's okay. So this puts a whole new requirement on an already complicated interagency process of export control coordination in a country like the United States where you've got the Department of Commerce, you've got us, got Department of Defense, Department of State. A lot of players. And now we have a timeline? And arguably the biggest nonproliferation issue that we've dealt with in the past several decades.

It forces agility and flexibility and adaptability all the way down through the implementation system. And so that's also been an interesting thing to observe because six months ago we all thought, great, we're reached Implementation Day, thinking that over the next few months probably a couple of issues would come up but then it's going to smooth out and we'll just be implementing. Well, it hasn't turned out quite like.

There have been perhaps a few more bumps in the road than we might have anticipated to begin with. And all of the agencies in the United States are setting up some sort of more regularized standing group, usually matrixed out of the existing organizations. But it is important that we have something that can be there to support Tero and the IAEA in the ongoing implementation. So it's been very interesting to see how all of this kind of ripples out into the system.

Chris Pickett: My question is primarily for Rob but all are welcome to provide an answer. When I was in the university many years ago I learned that to cause behavioral change in individuals it typically required something called a significant emotional event.

I've also observed in my career that it takes a significant event, sometimes catastrophic event, to cause cultural change in society. Events like 9/11. My question is, how can we affect cultural change in nuclear safeguards and security before we have another significant or potentially catastrophic event?

Floyd: Chris, if I knew the answer to that I would either be very rich or in high demand. In government business, probably just high demand. However, I think your observations are solidly based, whether it's for an individual effecting behavioral change as a result of a significant emotional event or catastrophic events causing national or international change. When I look at this idea through the lens of the Nuclear Security Summit process, and I considering all of the great things that were able to be achieved through that process, I see that much was achieved although much still remains to be done. Many of those advances were actually the decisions of states acting in their own unilateral decision-making realm, in their own sovereignty.

Where there were less outcomes was when major change required all NSS states to agree together. Often it has been said that there isn't the political energy in the system at the moment for states to commit to developing a nuclear security convention or something like that. The sad reflection is that it probably will take some nuclear security catastrophe to empower such a development.

I agree with that analysis that I think by and large that's what it would take for a major change in architecture or something like that in nuclear security. I've thought long and hard about how we could see those sorts of things develop without a catastrophe. Surely we're wise enough that we could anticipate something rather than having to just respond to a catastrophe. I've thought long and hard about it and I'm still not sure how we would do that. So I guess in that particular example my conclusion is that we work with the system we've got whilst there is not the political energy for major change, but at the same time we lift that system to its highest level of performance that we possibly can. I think there's lots of scope there. So rather than being defeated by not having a "convenient" catastrophe, I think there is a lot that we still can do in many areas to affect change. There is also a lot we can do in the cultural and behavioral areas without a catastrophe.

Harrington: I would add that the Nuclear Security Summit series itself has created a cultural change, but it's been incremental. I think if you don't have that major emotional issue you can still accomplish significant shifts in culture. But it takes a lot of work and it takes a lot of commitment.

I keep drawing on these recent discussions of culture, but one of our participants from a very hierarchical society said, well, I agree it has to start at the top, but how do I get to my boss. I don't have a way to get to my boss. So we sat down and started brainstorming about what would have an impact on your boss. He said, "Well, a senior visitor from outside the country or from the IAEA. Somebody who comes from outside our culture who could make the point that this important and that he should worry about it." And I think we have to start probing in those directions and see what increments we can begin to accumulate.

Varjoranta: I also fully agree with both of you. In most cases, it takes a crisis. If we go down into the human level, individual level, that's just how we are hardwired. We just function in a way that we like to do the same old, same old and resist change and it's always difficult to change.

It's always easier to learn from the mistakes of others: but also to learn from good or best practices. Maybe in the safeguards community we haven't had enough small crises: we have had only a few big crises. But if you look at nuclear safety, there are lots of changes that have happened over the years. And nobody wants to go back to the old days. Even they are practicing emergency preparedness drills every year at every facility. These drills are exciting and motivating. So I'm sure that it's something that we can also learn from that. We can start understanding best practices and learn from others' mistakes so we don't make them too.

Felicia Durán: My question is for Anne Harrington, but perhaps the others can address as well. The results of the Genie Study, it seemed to me indicated that some linguistic differences were a key cultural dimension. I think that is true even among speakers of English in the United States. But I was curious as to whether there were any other findings in that study and that for the other speakers, is there anything in your experience that has indicated these types of dimensions that are important to culture.

Harrington: I think one of the really interesting points in the study was the recognition that in a country like the UAE, by definition you're going to have a multicultural society running your nuclear program because you simply do not have enough of your own trained engineers. You probably don't even have a large enough population to draw from. Everybody would have to become an engineer or chemist or somehow contribute to the operation. If they go to a full eight operating reactors, that's a lot of people to run these reactors and to be the safeguards inspectors and the regulator and everything else that would have to happen, let alone start taking care of the spent fuel and everything else that's part of a whole nuclear program.

I think part of what this recognizes is that in some of our newcomer countries, particularly where you have smaller populations and limited technically qualified people, we probably are going to have this sort of situation in a number of other places. And I think they've accurately identified that this can be a security issue. One of the fascinating questions that came out of the discussion that we had at Khalifa University, was, "What happens when the people on the inside who are all speaking in English have to communicate with emergency response on the outside which functions in Arabic. What if the person identifying the security lapse is a Chinese national who speaks English but not too well and no Arabic?"

The authors of the study suggested resolving these challenges by outlining a curriculum, both a basic curriculum and ongoing activities that address the intercultural dimension of security. Including things like an "Emergency Arabic for Dummies" program where you learn key phrases that enable you to communicate to somebody on the outside. Those were the major findings but I thought the implication for future nuclear reactor builds in other countries was very interesting. When we talked about preparation for a nuclear future, you can't just send somebody to an undergraduate nuclear engineering program and expect them to be a qualified operator when they come out of school. This is a long-term professional educational commitment that you have to make if indeed you want to be able to do this by yourself.

Varjoranta: In the Agency definitely it's a big thing. We have ninety-five different nationalities working in the Department of Safeguards with ninety-five different mother tongues. Not only do we have different outlooks on life, we have different understandings of key words and concepts. For example, "safety," "safeguards," and "security" — do not exist in all languages. In my own language there is only one word; in English there are three.

Another example — "effectiveness" and "efficiency." In most languages there is only one word. So how do you translate that? Usually if you do the word by word translation, it doesn't carry the thought. So that's why you have to translate the thought. One of my best early mentors was at that time the only translator of Chinese poetry into Finnish. He always took a lot of time to understand what the poem meant, and only when he understood what the message was, and what the poet was trying to say, did he translate it into Finnish.

Floyd: If I could add, my experience in this space is interacting largely with Southeast Asia, East Asia countries, and networks in that region. I absolutely love working regionally with these countries. Regarding linguistics, the only common language we work with, and struggle with at times, is English. And so we have to work slowly and carefully to make sure things are understood.

But a couple of other aspects that are really important, and they're not just strictly linguistic, have to do with the respecting of hierarchies, and Anne was touching on this before. The respecting of hierarchies may affect what a junior person may say when the senior person is present. Sometimes you could ask the same question to the junior person when the senior person is absent and you may get a completely different answer. We need to understand those kinds of issues of culture of how a hierarchy works. It's an issue of honor and respect. For Australians, who don't tend to be so hierarchical, there is a cultural adaptation that we need to go through to be able to effectively engage.

Another aspect is the whole issue of honor and face. The saving of face clearly is way more important in a number of the countries we work with then it is in my own culture and situation. So if I do not take account of that, I'm in deep trouble.

These elements may affect the modes of engagement and how you gather people together? Do you have seniors in or out? There are certainly ways where hierarchies can aid your communication. There are some messages that can be delivered senior-to-senior that would not be possible for a junior staff member to deliver — even to their own boss. These are some of the nonlinguistic, but really powerful things that I've encountered.

One other I'll just mention is, I said to somebody once, "Your country could take the lead on this. This would be a great thing for your country to take a lead on." The response was, "Lead? Why should I?" That was not a response to say the issue was not important. It was more a cultural response reflecting that we just don't do that sort of thing. That was an important learning for me to realize I wasn't getting pushback on the issue, I was just getting a dissonance of culture. There is a lot of beauty and richness in each national culture, but if you don't spend the time then you don't get to understand it and your effectiveness will be diminished accordingly.

Harrington: One quick add to that. Metrics is something that's very important all of us and we always rely on questionnaires. We finish a workshop and we want input back. A UK colleague of mine and I were together at a meeting recently and one of the recent participants in a workshop that the UK had sponsored went up to my British colleagues and gave her a very constructive critique of the workshop. The observations were detailed and useful. My UK colleague commented to me after the discussion, "That was absolutely fascinating because we got 100 percent excellent back on our critiques. No commentary, nothing." And basically the challenge described by the workshop participant was, "We were your invited guests at the workshop and so it would have been impolite for us to write down what you had done wrong. But I could convey it to you verbally." And so, in that society, it just would not have been appropriate to have been critical, but in our society, we seek critical feedback.

Leslie Fishbone: I was just wondering if there is something in the world of cultural aspects writ large as that might induce North Korea to come back and negotiate.

Harrington: We had a conversation about that. I don't think that we actually came to any conclusions. But I will look to Tero and Rob to add their wisdom. In particular when I was at the National Academy of Sciences, we did quite an extensive project on North Korea including multiple meetings in the Republic of Korea working with a variety of NGOs and others who at that time were still interacting somewhat with North Korea. I'm not sure there's a cultural connection. This is a strongly politically driven exercise within North Korea where culture is severely constrained and contained and manipulated. You've got a society that probably is not expressing itself the way it might otherwise. I'm not sure if there is anything cultural within the leadership of North Korea that we can connect with. I remember when the deal was struck with Libya to give up its WMD (weapons of mass destruction). At that time Undersecretary of State (John R.) Bolton made a comment in a public meeting that. "Hey, look Libya got a pretty good deal out of this. North Korea, if you were to do the same we could give you a good deal too." Of course that never came to pass and in the end the Libya deal kind of went in its own interesting set of directions.

JCPOA, now there's an interesting model. Iran is allowed to keep many of the capabilities that it had. The one thing that is cut off are all the pathways to a weapon. Well, North Korea already has weapons. So what do you do in that case? What would be the incentive for them to give up their nuclear stockpile?

Fishbone: South Africa is an example.

Harrington: Well, but South Africa had its own set of motivations. Unless North Korea felt it was on the verge of collapse, and that somehow the oppressed citizenry would grab the weapons and use them against the government, I don't quite see how that would work in the North Korean case.

It's a very tricky set of considerations. Because if there is some sort of collapse scenario, South Korea is an NPT

(Nuclear Nonproliferation Treaty) state. They should not have possession of nuclear weapons. I think the Agency would probably be watching that very closely as would we and China and Russia. There are ways to address those issues. I think getting to the North Koreans culturally is going to be a real challenge.

Varjoranta: I agree with you on that. If you look at the past recent times, unpredictability has only increased in the country so it's not really possible to know what the endgame is — what is in the minds of that leader or the leadership. I'm quite optimistic that sooner or later there is going to be some sort of deal with the DPRK. The name of the deal remains to be seen. Perhaps we start with a freeze? Maybe the deal is limited to some facility or facilities. But we expect that whatever the deal might be, the Agency would have to go and see that that deal is fulfilled. And then when we go into the country, we still expect that we will face the same harsh cultural conditions as we did when we were last on the ground.

Floyd: I don't have an answer to what culturally could be used to get DPRK back into negotiations. But I would say three things. One is we need to, as far as we possibly can, look at the situation through their cultural lens and not ours. The second thing is that I think that understanding must be built as much as we can. I want to give a promotional callout here to the Moscow Nuclear Nonproliferation Conference. Anton Khlopkov holds this meeting every couple of years in Moscow. It's a brilliant meeting. Delegates from North Korea attend this meeting and to hear them talk about their situation is a wonderful opportunity to build understanding and to see a little through their lens.

The third thing and final thing, is opportunity often comes rapidly. When you look at a lot of major changes that have occurred in the security landscape around the world, it appears that nothing is happening, and then a major change just happens. It's almost like a step function. Incrementalism for the solution to major world issues is very, very rare I think. The more common phenomenon appears to be an almost step change or phase change. The message out of that is that we need to be ready, we need to be prepared because you never know when we're going to find ourselves on that step change. This goes to Tero's key point, if you listen to Tero often enough you'll hear the A word. Agility. Agility. Agility. And he's seeking to manage and build agility into the safeguards department in the IAEA, which I think for these kinds of reasons is entirely laudable and very wise.

Harrington: Just building on that last point, Rob. The whole reason we reorganized the nuclear nonproliferation function a couple of years ago was exactly this. We concluded that we had to plan on unpredictability. And in order to be flexible and responsive, we had to restructure ourselves along the functional lines that we assessed would have to span far into the future. So material management and minimization, global materials security, nonproliferation arms control, and an R&D function to support all of it. No bumper sticker names, nothing fancy, just function, because you can draw from all of those to create a special unit for North Korea or support JCPOA, which is exactly what we did. And then when you're done with one special task, staff are absorbed back up into their offices and they're ready for the next unpredictable thing. But, yes, it does happen fast.

Koskelo: I would like to thank our panelists. Thank you very much for your answers. And thank all of you for attending and asking your questions. We will see you around a similar table next year.

Keywods

Nuclear materials management, nuclear nonproliferation, nuclear safeguards

Analysis of the Developing States in the MENA Region Seeking Civilian Nuclear Energy, with a Primary Focus on the Kingdom of Saudi Arabia (KSA) and the United Arab Emirates (UAE)

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Abstract

The comprehensive analysis presented here attempts to analyze "newcomer" states in the Middle East and North Africa (MENA), primarily the Kingdom of Saudi Arabia (KSA) and United Arab Emirates (UAE), seeking to implement civilian nuclear energy according to their political and economic situations. By investigating their motivations and funding resources for future nuclear projects, this analysis provides guidance for these states in terms of their nuclear infrastructure and nonproliferation. The overall approach of this analysis relies on the factors for the success of civilian nuclear energy programs identified in experiential studies conducted since the Atoms for Peace speech in 1953. This study also attempts to reduce the gap between developing and developed states by clarifying the major challenges involved in nuclear cooperation and technology transferal.

Since the 1980s, the MENA region has experienced various crises, including the Iraq-Iran War, the Gulf War, terrorist attacks, the Arab Spring, and the Islamic State (IS). However, the two states analyzed here have maintained stable political environments without disturbances to their governmental systems. Moreover, from an economic viewpoint, both states have high revenue from oil and gas production and high oil reserves (more than 20 percent of the world's proven oil reserves). Regarding their motivation for seeking civilian nuclear energy, these states are attempting to address their estimated 8-9 percent annual increase in electricity demand, rapid population growth, and the need for more desalination plants. By implementing nuclear energy programs, these newcomer states will face challenges related to their nuclear strategy, roadmap, infrastructure, and human resources. To address these challenges, the newcomer states will have to secure intense foreign cooperation by signing nuclear agreements with developed states and showing a clear record of compliance with nuclear nonproliferation commitments, such as the Nuclear Nonproliferation Treaty (NPT), the Comprehensive Safeguards Agreements (CSA), and the Additional Protocol (AP), which will raise the transparency of the civilian nuclear program.

Introduction

Rapid population growth and increased electricity demands (for both water desalination and electricity generation) are major energy challenges for governments around the world. Many governments believe that nuclear energy is one of the safest, most reliable, and most cost-effective energy sources that can provide electricity for long periods of time. According to reports by the International Atomic Energy Agency (IAEA),[1] nuclear power demand is expected to increase between a low projection of 17 percent (if the current market remains and few changes in resources and technology occur) and a high projection of 94 percent (if the rate of electricity demand and economies continue to grow) of the world's current total nuclear power capacity by 2030. Thus, many states are seeking to implement civilian nuclear energy programs. Experiential studies conducted since the Atoms for Peace speech in 1953 indicate that the essential factors that determine the success of such programs are as follows: 1) nuclear nonproliferation commitments (Nuclear Nonproliferation Treaty [NPT], Comprehensive Safeguards Agreements [CSA], and the Additional Protocol [AP]), 2) the political situation, and 3) the economic situation (motivations, resources, and gross domestic product [GDP]).[2]

The goal of this paper is to analyze the "newcomer" developing states in the Middle East and North Africa (MENA), primarily the Kingdom of Saudi Arabia (KSA) and United Arab Emirates (UAE), seeking civilian nuclear energy. Additionally, an overview of both states from a nuclear nonproliferation and infrastructure perspective that satisfies the essential requirements for the successful development of civilian nuclear energy is provided. This study attempts to bridge the gap between newcomers and developed states, which can be achieved by clarifying a number of the major and initial difficulties that affect both types of states in the process of cooperation and technology transfer. The presented analysis will investigate the political and economic environments of both states. Politically, this study will analyze the stability of the governmental system as a strong indication of the entire political framework of the targeted state. This study will investigate economic motivations and resources from an energy perspective as well as consider a general GDP-based perspective.

Background

Studies on the development of civilian nuclear power that focus on similar objectives are rare, although two studies by Jewell (2011) were found in literature.[3,4] These studies performed analyses of the motivations and capacities for deploying civilian nuclear energy in fifty-two aspirant states and then in five North Africa states. The evaluations included financial and institutional capacities as well as technical requirements for the electricity grid. The institutional capacity was measured by the World Bank Political Stability Index (PSI) and the World Bank Government Effectiveness Indicator (GEI). The financial capacity was measured by GDP and GDP/capita. Although the use of PSI and GEI are logical and reasonable when evaluating institutional capacities, both indicators are subject to debate. For example, although Pakistan, India, Argentina, Brazil, and Russia have operational nuclear power plants (NPPs), these countries present low PSI or GEI; therefore, these states have overcome the PSI and GEI indicators, met all of the technical requirements, and managed the financial difficulties. The results of the second study showed that Libya and Tunisia had the top two PSI among North Africa states: however, both of these governmental systems have been toppled and the countries are unstable.[5,6] The PSI and GEI were founded on different international efforts, covering a wide range of sources. However, these indicators were highly influenced by Western and European cultures, which are different from the cultures of MENA states.

Historical observations have indicated that under certain circumstances, such as a lack of capability or capacity, strong motivations could make up for the required capabilities or capacities. Therefore, a thorough investigation will not be conducted in this study with regard to the technical requirements, which will eventually be addressed through cooperation with developed states as well as the IAEA.[7,8] In this study, a common ground was defined for evaluating a political situation in which a logical and reasonable indicator reflects the reality of the government systems. Although this indicator may be controversial, it is unique because it is based on logic and reality. The indicator is based on the results of previous crises that the government systems in the MENA region, particularly KSA and UAE, have experienced. These results will be further detailed in the political situation section.

Table 1. Date of NPT Signature or deposit for the states in the MENA region

NPT Agreement			
States	**Signature or Deposit Date**	**States**	**Signature or Deposit Date**
KSA	3 October 1988	Syria *	1 July 1968
UAE	26 September 1995	Lebanon	1 July 1968
Kuwait	15-22 August 1968	Egypt	1 July 1968
Oman	23 January 1997	Libya *	July 1968
Qatar	1989	Algeria	12 January 1995
Bahrain	3 November 1988	Tunis	1 July 1968
Iraq *	1 July 1968	Morocco	1 July 1968
Jordan	10 July 1968		

* Non-compliance status
Source: United Nations Office for Disarmament Affair (UNODA)
Note (light blue): KSA and UAE are the primary focus of this study.

Role of the NPT

The NPT is a very important commitment and considered one of the primary concerns of the international community with regard to nuclear energy. This treaty defines the privileges, responsibilities, and obligations for the 191 state parties and ninety-three signatory states involved.[9,10] The three pillars of the NPT are the promotion of nuclear arms control and disarmament, the prevention of nuclear weapon development, and the encouragement of peaceful cooperation.[10,11] However, the NPT is one of the major factors in the successful development of civilian nuclear energy.[2] Table 1 shows the date of the NPT signature or deposit of ratification for the states in the MENA Region.[9] As parties to the NPT, all MENA states have signed the NPT or deposited their instruments of ratification.

Note that most of MENA states were early signatories to the NPT; in addition, Syria, Iraq, and Libya are currently in non-compliance status.[12-14] The KSA and UAE are two of the later signatories to the NPT. Both states apparently understand that any perception of non-compliance with the NPT may breed distrust from the international community, which will generally affect their future nuclear activities. By maintaining compliance with the obligations and commitments of the NPT agreement, the chances of international cooperation will be much higher, particularly if the political and economic situations in both states help support the need for a civilian nuclear energy program.

Political Situation

Political situation is measured based on the government's stability. An indicator of governmental stability is a combination of logic and the historical conditions, and such indicators for MENA countries are developed by tracing the major changes in the government system according to the various crises in the region. Major changes in the government system have been defined as changes in the entire presidential office, monarchy, or government cabinet. This study used major changes in the governmental system as a strong indicator of the government's stability.

Since September 1980, five major crises have been identified in the MENA region: the Iraq-Iran War, the Gulf War, terrorist attacks,[15] the Arab Spring,[16] and the Islamic State (IS).[17] Three of these crises, the Iraq-Iran War, the Gulf War, and the Islamic State, have not had a significant impact on the government stability of the MENA states that remain in compliance with the NPT. However, terrorist attacks have impacted government stability in Lebanon,[18,19] whereas the Arab Spring impacted the government stability in Egypt, Yemen, and Tunisia.[16] Over the short term, the political environment in certain states in the MENA region will prevent developed states from cooperating towards the development of civilian nuclear energy programs. However, the governmental stability of both the KSA and UAE have not been impacted by these crises. Thus, regional crises should not necessarily preclude the successful implementation of nuclear power technology within the safeguards prescribed by the IAEA. For example, in 2015, Egypt and Russia signed a memorandum of understanding regarding the construction of NPPs.[20] Therefore, these activities are possible if the stability of the government is strengthened post-crisis.

Economic Situation

Motivation for Seeking Civilian Nuclear Energy

The largest countries among the Gulf States in terms of their economies are using approximately one third of their daily production of oil and gas to produce electricity.[21] The estimated increases in the population growth, energy demands, and renewable water requirements per capita by 2030 are shown in Table 2. The increase in electricity demand is estimated to be approximately 8-9 percent per year for KSA and UAE,[22,23] and this increase will be caused by population growth and industrialization. Both states rely on water desalination plants because of the lack of surface and ground water. In the near future, population growth will drive the need for increased desalination plant capacity, which will require greater amounts of electricity. The current solution is to continue building additional plants to burn more oil and gas to meet the demand regardless of the mandates of the climate conference in Paris in 2015, which will place additional pressure on both governments with regard to energy resources.

Table 2. Future population, energy demand, and renewable water in the Gulf States

Gulf States	Population (Million) A		Energy Demand B (Terawatt/Hours)		Renewable Water Per Capita C (Cubic Meters)	
	2015	2030*	2015	2030*	2015	2030*
KSA	28.8	38.8	101.0	317.0	83.0	66.0
UAE	9.3	12.5	99.5	315.0	28.9	23.0
Kuwait	3.4	4.5	66.4	138.0	5.7	5.0
Oman	3.6	4.8	13.9	28.9	836.6	350.0
Qatar	2.2	2.9	18.7	38.9	37.0	29.0
Bahrain	1.3	1.8	14.0	29.0	135.6	109.0

A. Source: World Bank Data, which include recent (2015) population estimates and an approximately 2 percent annual population growth rate.

B, C. Compiled from Report on the Workshop: Nuclear Dangers Nuclear Realities[21] and updated with recent data. The energy demand is increasing by 8-9 percent for the KSA and UAE and by ~5 percent for the remaining Gulf States. The estimated decreasing percentage of renewable water is ~ (-2 percent) for all Gulf States except Kuwait and Qatar, which is ~ (-1 percent).

* Indicates projected value

Note (light blue): KSA and UAE are the primary focus of this study.

Table 2 shows that KSA will face the largest increase in energy demand and population among the Gulf States, with UAE in second place. Both states are motivated to seek civilian nuclear energy because of 1) the expected growth in population, 2) the yearly increases in demand for electricity, and 3) the need for more desalination plants. To this end, discussions on the implementation of civilian nuclear energy were announced by both governments.[21-23] The UAE has started the construction of four pressurized water reactors,[22] whereas, KSA has merely announced the creation of King Abdullah City for Atomic and Renewable Energy (KACARE), which remains in the planning, study, and evaluation stages.[23] These two civilian nuclear energy programs are collectively estimated to cost more than $100 billion, rendering them among the largest nuclear programs of the century,[22,23] with KSA's program costing $80 billion and UAE's program costing $20 billion. Apparently the huge budgets for these programs raises concerns as to whether the states will be able to fund these long-term investments.

Funding Resources for Civilian Nuclear Energy

In this section, a general overview of the economies of KSA and UAE, which will include oil, natural gas, and GDP, is provided to gain an understanding of both economies. The Gulf region is an area rich in oil, which is among the purest oil worldwide. Additionally, both states have tremendous natural gas production capacities and reserves. These Gulf State governments financially rely on their production and reserves of oil and natural gas. According to the Organization of Petroleum Exporting Countries (OPEC), in which the KSA has a leading role,[24,25] both states are leading countries in oil production. Table 3 presents data on the oil and gas reserves and production for both states.

Table 3. Oil and gas data for the KSA and UAE

Oil and Gas Data	KSA	UAE
Crude oil reserves (million barrels)	265,789	97,800
Natural gas reserves (billion cubic meters)	8,317	6.091
Crude oil production (thousand barrels/day)	9,637	2,797
Natural gas production (million cubic meters)	100,030	54,600
Value of petroleum exports (million dollars)	321,723	126,307

Source: Organization of Petroleum Exporting Countries (OPEC), KSA and UAE Facts and Figures[24,25]

Both states have sizable reserves and a substantial production capacity for gas and oil, which will maintain a stable economic status for several years. Several billion dollars of oil in the form of petroleum exports are added as revenue per day to the budgets of both states. According to the U.S. Central Intelligence Agency (CIA), the KSA is an oil-based economy with a GDP of $927.8 billion and a GDP/capita of $31,200 (2013 estimate), which ranks the KSA first among the Gulf States from a GDP perspective,[26,27] whereas the UAE has an estimated GDP of $269.8 billion and a GDP/capita of $29,900 (2013 estimate), which ranks the UAE second.[26,28] The aforementioned, indicate that both states are wealthy and present a low risk of insufficient funding for the long-term investment of a civilian nuclear energy program.

Status of Newcomer States Seeking Civilian Nuclear Energy

United Arab Emirates (UAE)

UAE's Nuclear Program Specifications

The UAE was the first state in the Gulf region to construct nuclear reactors. As shown in Table 4, the four reactors are named Barakah 1, Barakah 2, Barakah 3, and Barakah 4.[22] Each of these reactors is an Advance Power Reactor APR1400, which is a light water reactor (LWR) that can produce 1,400 megawatts of electricity (MWe). The construction of the four reactors began in July 2012, May 2013, September 2014, and September 2015, and they are scheduled to be complete and operational by 2017, 2018, 2019, and 2020 respectively. The total capacity of the first phase of the UAE's civilian nuclear energy program will be 5,600 (MWe); a second phase has not been announced.

Table 4. UAE's nuclear power reactors

Reactor's Name and Type	Electricity Production (megawatts)	Construction Date	Expected Date of Operation
Barakah 1, APR-1400	1400	July 2012	2017
Barakah 2, APR-1400	1400	May 2013	2018
Barakah 3, APR-1400	1400	Sep 2014	2019
Barakah 4, APR-1400	1400	Sep 2015	2020

Source: World Nuclear Association (2014), *Nuclear Power in United Arab Emirates*.[22]

The four units will be supplied by a consortium that is led by the Korea Electric Power Company (KEPCO) and includes Samsung, Westinghouse, Hyundai Engineering & Construction, Doosan Heavy Industries, and KEPCO Subsidiaries.[22] In addition, a domestic waste repository is an option for the UAE's nuclear program for medium- and low-level waste, and a portion of the waste fuel will be sent to France for reprocessing or to another country with a reprocessing plant. Studies on a domestic geological repository are being conducted with a Swedish company.[22]

UAE's Nuclear Program Strategy and Policy

The UAE government adopted a new model of approaching civilian nuclear energy that non-nuclear weapon states have explored since the Atoms for Peace speech in 1953. This model attempts to ensure the confidence and support of the international community for the peaceful development of UAE's civilian nuclear program.[29] The UAE has shown the international community that it is only interested in peaceful uses of nuclear energy by adopting such models and signing various nonproliferation agreements as shown in Table 5. The UAE's actions aligns with policies in the developed states for transferring civilian nuclear technology as well as with the high standard for nuclear nonproliferation that the international community aims to maintain.

Table 5. UAE's nonproliferation activities

Agreement's Name	Date of Signature or Ratification
Nuclear Nonproliferation Treaty (NPT)	1995
Comprehensive Safeguards Agreements (CSA)	2003
Additional Protocol (AP)	2009
123 Agreement with the USA	2009

The above nonproliferation activities are limited; the list does not include all conventions.

By signing the 123 Agreement, the UAE pledged to import its nuclear fuel and forgo domestic fabrication, enrichment, and reprocessing plants. To this end, the UAE signed various long-term contracts to import nuclear fuel from international firms at a fixed price.[22] The UAE also announced that these reactors would be operated through a joint venture with a foreign firm, with 60 percent ownership by the UAE government and 40 percent by the foreign firm for a period of 60 years.[22] Subsequently, the UAE's civilian nuclear program will rely on the international market for its nuclear fuel.

The other nonproliferation steps considered by the UAE include the selection of LWR and the lack of reprocessing plants in the UAE's territory. Developed states considered this approach to be an effective method for impeding the misuse of nuclear technology. Under normal operations, LWR does not produce high percentages of sensitive nuclear materials such as plutonium (^{239}Pu), in comparison to other types of reactors, such as the fast breeder reactor (FBR).[30] LWRs have another proliferation-resistance feature: when refueling, the entire power plant must shut down, which enables easy monitoring of the NPPs by the IAEA.

Kingdom of Saudi Arabia (KSA)

The KSA realized the need for nuclear technology in 1988 with the creation of the Atomic Energy Research Institute (AERI) in Riyadh.[31,32] The AERI was the first nuclear institute in the Gulf region, and although it was established as a research base, the institute is now involved in many other activities. Initially, the AERI was responsible for researching nuclear technology related to aspects such as agriculture, industry and health. The initial responsibilities of the AERI included the representation of the KSA in the IAEA as well as the creation of the regulatory framework for nuclear energy in the KSA.[33] The new city (KACARE) announced by the King in April 2010 is intended to expand the responsibilities of the AERI. KACARE will be responsible for the KSA's civilian nuclear energy program and projects involving other renewable energy resources, including solar and wind energy projects. KACARE will serve as KSA's representative to the IAEA. Since the inception of KACARE, the importance of achieving cooperation and agreement between KSA and other leading organizations has been acknowledged for the development of KACARE's strategies, roadmaps and plans for civilian nuclear technology and other renewable energy resources.

KSA's Nuclear Program Agreements and Cooperation

KACARE has sought cooperation with many of the developed states, and its achievements in terms of cooperation, which were determined according to newspaper reports and KACARE's website, include agreements with the following: 1) Areva, France; 2) Investigación Aplicada (INVAP), Argentina; 3) Korea Atomic Energy Research Institute (KAERI), South Korea; 4) China Nuclear Engineering Corporation (CNEC), China; 5) Finnish Radiation and Nuclear Safety Authority (STUK), Finland; 6) Rosatom State Nuclear Energy Corporation, Russia; and 6) Hungary.[23] Prior to these cooperation agreements, the KSA had made several nonproliferation agreements, which are listed in Table 6. The KSA signed the NPT in 1988, the CSA in 2009, and the Small Quantities Protocol (SQP) in 2005; thus far, an AP has not been signed (without an AP, the IAEA cannot provide credible assurance of the absence of undeclared nuclear material and activities). The KSA signed a memorandum of understanding for nuclear energy with the United States in 2008, and the Taqnia Company (a Saudi company) set up a joint venture called "Invania" with INVAP (an Argentinian company) in 2015 to develop nuclear technology for the KSA by focusing on small reactors, such as CAREM.[23] The KSA has also engaged in various negotiations regarding nuclear energy technologies with countries such as the United States, Japan, the Czech Republic, and Britain; however, agreements have not been announced.

Table 6. KSA's nonproliferation activities

Agreement's Name	Date of Signature or Ratification
Nuclear Nonproliferation Treaty (NPT)	1988
Small Quantities Protocol (SQP)	2005
Comprehensive Safeguards Agreements (CSA)	2009
Additional Protocol (AP) *	-

* KSA has not yet signed the Additional Protocol (AP).

The above nonproliferation activities are limited; the list does not include all conventions.

KSA's Proposed Nuclear Capacity

KACARE announced that the initial capacity of the KSA's nuclear program would be 17-18 gigawatt-electric (GWe), which should be achieved by 2032.[23] However, this estimate is merely the initial plan, and it is subject to change. In January 2015, KSA officials announced that the targeted nuclear capacity will more likely be achieved by 2040.[23] KACARE plans to construct approximately sixteen reactors by 2032. If this initial plan is followed, the first two reactors will be operating by approximately 2022, and two reactors will subsequently be added each year until the completion of the sixteen reactors.[34,35]

KSA's Proposed Nuclear Reactor Types

The type of nuclear reactor to be used by KSA's nuclear program has not been officially announced, although information has been provided to newspapers and communicated via interviews with the president and the vice president of KACARE. The first reactor type considered by KACARE is the European Power Reactor (EPR), which is capable of producing up to 1,650 MWe. The EPR is a third-generation pressurized water reactor.[36] Other reactor types that have been considered are the AP1000, SMART, and CAREM. The AP1000, which was designed by Westinghouse Company (a U.S. company), is a third-generation-plus pressurized water reactor that is capable of producing between 1000 MWe and approximately 1200 MWe. SMART is a pressurized water reactor designed by KAERI, and it can generate up to 100 MWe, and CAREM is a small pressurized water reactor designed by INVAP (an Argentinean company), and it can generate approximately 25 MWe, which renders this type suitable for use as a research reactor (see Table 7). The choice of LWRs for the KSA's nuclear energy program is a smart option because of its proliferation-resistance features and reduced capacity to produce sensitive nuclear material.

Table 7. The proposed nuclear reactor types in KSA

Reactor Name	Reactor Type	Electricity Production (MWe)
EPR	Pressurized water reactor	Up to 1,650 MWe
AP1000	Pressurized water reactor	Up to 1,200 MWe
SMART	Pressurized water reactor	Up to 100 MWe
CAREM	Pressurized water reactor	Up to 25 MWe

KSA's Proposed Nuclear Fuel Cycle

The president of KACARE has mentioned that KSA wants to be an independent producer of nuclear energy, which implies its involvement in the major stages of the nuclear fuel cycle, including enrichment and fabrication. The KSA has not proposed plans to build a reprocessing plant; however, the sharing of such sensitive technology is limited because of the danger of using the separation technology to obtain "unirradiated direct use material," which could be repurposed for military use. No official announcement or indicators regarding KSA's proposed nuclear fuel cycle have been presented. Therefore, KSA's nuclear fuel cycle may involve one of the following scenarios: 1) the KSA may obtain nuclear fuel from outside sources, which is similar to UAE's nuclear fuel cycle; or 2) the KSA may build fabrication and enrichment plants. The first scenario would save time and increase the transparency of the KSA's proposed nuclear program, whereas the second scenario would include mining, milling, enrichment, and fuel fabrication. If the KSA selects this path, then the Additional Protocol (AP) will have to be signed to provide for higher transparency and enable the IAEA to provide credible assurance of the absence of undeclared nuclear materials and activities. If KSA is going to follow its initial nuclear plan (with its first reactors running by 2022), then nuclear fuel will have to be imported because building and operating fuel plants and manufacturing fuel represent long-term investments. However, implementing these plans will require more time than building the reactor itself. Therefore, a combination of both the first and second scenario is likely.

Different Scenarios for Implementing Civilian Nuclear Energy

The implementation of civilian nuclear energy will initially require the use of highly developed approaches and strategies along with focused cooperation with developed states. From a nuclear technology perspective, developed states are those with advanced capabilities in reactor design and construction (R-D&C) as well as reactor operation and maintenance (R-O&M). Developed states are governed by strict rules regarding the transfer of civilian nuclear energy technology to newcomer states because of the high standard of nuclear nonproliferation that the international community attempts to maintain. Table 8 describes the common scenarios based on current strategies and government agreements for implementing civilian nuclear technology that have been observed since the Atoms for Peace speech in 1953.

Each scenario (see Table 8) involves foreign and local contributions. The advantage of the first scenario is that the country can implement a NPP in a short time to meet its increased electricity demands, although at a limited capability. The disadvantages of the first scenario are that the state will not be able to design or construct its own reactor and it will slowly gain experience in reactor operation and maintenance over the short and medium term (ten to twenty years). In the second scenario, the state will gain reasonable experience in reactor operation and maintenance early in the process and will gain capabilities for implementing most stages involved in reactor design and for performing full operations and maintenance. In the third scenario, the state will be able to contribute to reactor design and construction from the beginning of the implementation process, and with time, the state will be able to design, construct, operate, and maintain its own reactors. The second and third scenarios are viable options for states with an INFCIRC/153-type safeguard agreement as long as an AP is enforced.

Nuclear Proliferation Concerns

Nuclear proliferation is an important global concern that led to the creation of the IAEA in 1957.[37] The initial mission of the IAEA was to control and promote peaceful nuclear technology via the development of the necessary legal frameworks, regulations and legislation.[37] The global concern later resulted also in the NPT and Safeguards Agreements (CSA) to be concluded

Table 8. Different scenarios for implementing civilian nuclear energy

Time	First Scenario A		Second Scenario B		Third Scenario C	
	Foreign Contribution	Local Contribution	Foreign Contribution	Local Contribution	Foreign Contribution	Local Contribution
Short Term (7-10 years) and Involvement Percentage percent	R-D&C 100 percent R-O&M >90 percent	R-D&C 0 percent R-O&M <10 percent	R-D&C 100 percent R-O&M 70-90 percent	R-D&C 0 percent R-O&M 10-30 percent	R-D&C 60-75 percent R-O&M <70 percent	R-D&C 25-40 percent R-O&M >30 percent
Medium Term (10-20 years) and Involvement Percentage percent	R-O&M 70-90 percent	R-O&M ~10-30 percent	R-D&C >70 percent R-O&M <30 percent	R-D&C <30 percent R-O&M >70 percent	R-D&C ~30 percent R-O&M <5 percent	R-D&C ~70 percent R-O&M >95 percent
Long Term (more than 20 years) and Involvement Percentage percent	R-O&M 30-70 percent	R-O&M 30-70 percent	R-D&C <10 percent Special Supplies and Consultant <5 percent	R-D&C >90 percent R-O&M >95 percent	Special Supplies and Consultant <5 percent	R-D&C >95 percent R-O&M >95 percent
Comments: Depends on the states' strategies and legal agreements.	1- State will find it difficult to contribute to R-D&C. 2- State can provide limited contributions to R-O&M.		1- State will find it easy to contribute to R-D&C and may face challenges (in the short-to-medium term) in conducting its own R-D&C. 2- State can fully contribute to R-O&M.		1- State can provide a greater contribution to R-D&C and will be able to conduct its own R-D&C. 2- State can fully contribute to R-O&M.	

A, Adoption of UAE's civilian nuclear model
B, Adoption of China's civilian nuclear model
C, Adoption of South Korea's civilian nuclear model

by non-nuclear-weapon states with the IAEA, which were followed by the AP in 1997.[38-40] The CSA is an agreement that attempts to implement a verification method for assuring that states comply with their obligations at all nuclear facilities within their territory and for preventing diversions of nuclear material from peaceful purposes to military uses.[38,39]

The AP was adopted by the IAEA in 1997 after the commencement of the clandestine Iraqi nuclear weapon program. The AP is an additional agreement for strengthening and improving the CSA by stipulating that states provide additional information on their nuclear programs and clarification as needed to support IAEA inspectors and allow access to their nuclear facilities as well as any location specified by the IAEA.[40]

Sensitive Nuclear Plants and Materials

An NPP is not considered to be sufficient for proliferation; however, the fuel cycle process is considered the primary parameter for proliferation.[31,38] The most important processes in the fuel cycle are enrichment, fuel fabrication and reprocessing plants, and the knowledge required to separate isotopes, enhance specific isotope concentrations, and convert compounds from one phase to another may be employed for military purposes. These plants are central to the proliferation concerns of developed states. The nuclear materials that cause the greatest proliferation concerns are: Pu, ^{233}U and highly enriched uranium (HEU) (^{235}U 20 percent) when applied for direct use; and thorium and U (^{235}U <20 percent) when applied for indirect use.[38] However, the special nuclear materials ^{239}Pu, ^{233}U and HEU ^{235}U have received special attention[31,38] because these nuclear materials (see Table 9) are associated with a quantity that is sufficient to produce a single nuclear bomb.[38]

Table 9. Significant quantities for sensitive nuclear materials

Material	Significant Quantity
Direct Use Material	
Plutonium	8 kg
U-233	8 kg
U-235 in HEU	25 kg of contained U-235
Indirect Use Material	
U-235 in LEU	75 kg of contained U-235, 10 t of natural uranium or 20 t of depleted uranium.
Thorium	20 t

Source: *IAEA Safeguards Glossary 2001 Edition, International Nuclear Verification Series No. 3.*

Double Standard Argument

All of the developed states have formed their own procedures for cooperation when transferring peaceful nuclear technology using official government agreements. One of the best examples of a highly evaluated agreement is the 123 Agreement used by the United States. This agreement entails thorough evaluations of sensitive nuclear materials, equipment, and facilities by isolating sensitive nuclear plants, such as fuel fabrication, enrichment and reprocessing plants.[41] The disadvantages of the 123 Agreement include the variations observed in the agreement from state to state, which could reflect a double standard. The U.S.-UAE 123 Agreement clearly stated that the UAE must forgo the right to implement fuel fabrication, enrichment and reprocessing plants, which was also stated in President Obama's letter to Congress in the context of the U.S.-UAE 123 Agreement.[41] The following statements will provide additional details on the U.S.-UAE 123 Agreement:

> **First:**
> *"The United States and the UAE are entering into it in the context of a stated intention by the UAE to rely on existing international markets for nuclear fuel services as an alternative to the pursuit of enrichment and reprocessing. Article 7 will transform this UAE policy into a legally binding obligation from the UAE to the United States upon entry into force of the Agreement."*
>
> **Second:**
> *"In view of these and other nonproliferation features, the Agreement has the potential to serve as a model for other countries in the region that wish to pursue responsible nuclear energy development."*
>
> **Third:**
> *"Confirmation by the United States that the fields of cooperation, terms, and conditions accorded by the United States to the UAE shall be no less favorable in scope and effect than those that the United States may accord to any other non-nuclear-weapon State in the Middle East in a peaceful nuclear cooperation agreement."*

Obviously, the United States, as represented by the Obama administration, has a special model for the MENA region, which is reflected in the new 123 Agreement with the UAE signed in 2009. However, the United States confirmed that other states in the Middle East region will not receive any favorable arrangements in terms of cooperation, conditions, and context in 123 Agreements. In other words, the United States is not willing to share enrichment and fuel fabrication knowledge to any interested nation in the Middle East.[41] However, the U.S.-Vietnam 123 Agreement signed in 2014 did not clearly state that Vietnam must forgo the right to implement these sensitive plants.[42] Thus, the newcomer states in the MENA region must carefully evaluate the available international nuclear cooperation agreements to determine the most suitable agreement for their nuclear program.

Conclusions

This paper attempts to analyze the newcomer states to the MENA region seeking civilian nuclear energy, primarily the KSA and UAE, by investigating their political and economic situations, including their motivations and funding resources. Moreover, this study attempts to clarify a number of the major and initial difficulties that would be faced by both states. Because of the rapid increases in population growth and the increasing needs for desalination plants and demands for electricity, both states have begun to evaluate and implement nuclear energy. Both states are politically and economically stable, which are validated by: 1) the governmental systems maintaining stability throughout the history of crises in the MENA region and 2) the states maintaining economic stability through the high daily revenue resulting from oil and gas production, huge oil reserves and high GDP and GDP/capita.

Newcomer states that seek to implement civilian nuclear energy programs can achieve this objective within a reasonable time frame with the cooperation and support of developed states, which can be secured by official government agreements. The international community takes all activities involving nuclear technology seriously to prevent the proliferation of nuclear technology. Thus, newcomer states must demonstrate that they will use nuclear technology peacefully and convince the international community of their benign intent by following the established high standard of nonproliferation and adopting well-developed approaches, strategies and policies for their civilian nuclear program. For newcomer states, LWRs are the preferred type of reactor because of the following: 1) the production of large quantities of sensitive nuclear materials are not encouraged, 2) the production of sensitive materials can be easily controlled, and 3) the proliferation-resistance features facilitate simple inspections by IAEA inspectors.

Regarding the fuel cycle, developed states prefer newcomer states to import nuclear fuel to eliminate the risk of newcomer states obtaining fuel fabrication and enrichment technology. A double standard is arguably imposed with respect to the fuel cycle for nuclear programs, which is reflected in certain international nuclear agreements, such as the U.S.-UAE 123 Agreement and the U.S.-Vietnam 123 Agreement. The standard imposed in these agreements varies from state to state depending on the political relations and situations between the newcomer states and developed states. The establishment of fabrication, enrichment, and reprocessing plants is associated with the potential use of sensitive nuclear materials and the knowledge required for nuclear military applications. All leading states in the nuclear field are obligated to limit the sharing of their knowledge on sensitive nuclear materials and plants because such knowledge may lead to nuclear military applications unless the materials are subject to IAEA safeguards. Thus, after the general approach and strategy for implementing a civilian nuclear energy program is established, the best standard for the specific newcomer state must be determined.

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Keywords

Nuclear energy, energy policy, nuclear nonproliferation, nuclear materials, nuclear safeguards, IAEA inspections

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Axial and Azimuthal Gamma Scanning of Nuclear Fuel – Implications for Spent Fuel Characterization

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Abstract

A project to research the application of non-destructive assay (NDA) to spent fuel assemblies is underway among a team comprised of the European Commission, DG Energy, Directorate Nuclear Safeguards; the Swedish Nuclear Fuel and Waste Management Company, Uppsala University, the University of Michigan, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Oak Ridge National Laboratory that collaboratively are advancing some of the goals of the Next Generation Safeguards Initiative's Spent Fuel (NGSI-SF) Project. The NGSI–SF team is working to achieve the following technical goals more easily and efficiently using nondestructive assay measurements of spent fuel assemblies in order to improve both international safeguards and repository safety: (1) verify the initial enrichment, burnup, and cooling time of facility declaration, (2) detect the diversion or replacement of pins, (3) estimate the plutonium mass, (4) estimate the decay heat, and (5) determine the reactivity of spent fuel assemblies. The measured neutron, gamma-ray, and heat signatures from spent fuel assemblies, as well as simulations, will be combined in advancement of the technical goals.

This current study focuses primarily on the application of time-stamped list mode data acquisition applied in the context of a fixed collimator that allowed a thin axial portion of the fuel to be observed as the fuel assembly moved vertically past the collimator. Measurements were performed at the Central Interim Storage Facility for Spent Nuclear Fuel (which is abbreviated using the Swedish acronym: Clab) in Sweden, in 2013 and 2014. In total, fifty spent nuclear fuel assemblies were measured in detail, twenty-five boiling water reactors and twenty-five pressurized water reactor assemblies.

In this context, time-stamped list mode data acquisition have not previously been used for gamma-ray spectroscopy measurements of used nuclear fuel measurements. We compare it to the more typical fixed-axial location pulse height analysis approach. The flexibility of analyzing data from time-stamped list mode measurements enables research into questions of how beneficial axially resolved information is for each of the varied research goals; in particular the current research is an initial step toward comparing the benefit of several fixed axial measurements vs. scanning an entire assembly.

Introduction

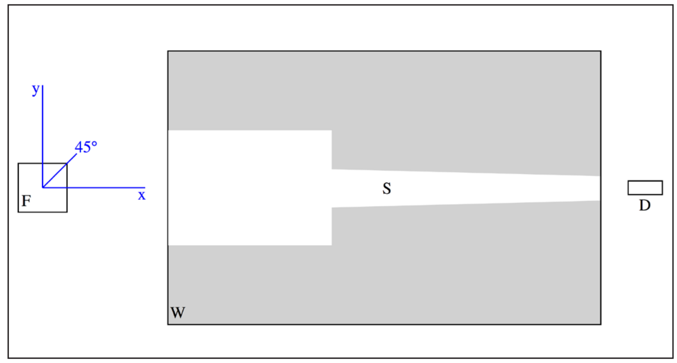
A project to research the application of non-destructive assay (NDA) to spent fuel assemblies is underway at the Central Interim Storage Facility for Spent Nuclear Fuel (for which the Swedish acronym is Clab) in Oskarshamn, Sweden. The project is a collaboration among the European Commission, DG Energy, Directorate Nuclear Safeguards (Euratom), the Swedish Nuclear Fuel and Waste Management Company (SKB), Uppsala University, the University of Michigan, and several U.S. national laboratories (Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Oak Ridge National Laboratory) participating in the Next Generation Safeguards Initiative Spent Fuel (NGSI-SF) Project.[1,2,3]

The technical goals of this team include: (1) verifying that a given assembly is the assembly that the facility has declared to the International Atomic Energy Agency (IAEA) or other regulators; this involves verifying the initial enrichment, burnup, and cooling time of each assembly; (2) verifying that the integrity of a spent fuel assembly is maintained by developing the capability to detect the diversion or replacement of pins; (3) quantifying the plutonium mass in individual assembly; this may be of interest to regulators in the context of input accountability for pyroprocessing plants; (4) rapidly estimating the heat content in each individual assembly to satisfy domestic regulations; and (5) measuring the reactivity of each assembly in order to assure all potential fuel configurations are safe in terms of heat and criticality.

Given the operational difficulty of measuring the spectrally resolved gamma intensity along the axial length of a fuel assembly at most facilities and given that static measurements made at one axial location have generally proven satisfactory for those interested in such measurements in the past, a detailed study of the benefit of measuring from multiple axial locations, or of scanning the full axial length of the assembly, is lacking. This research absence has motivated the current research path at Clab. How much axial and azimuthal information is needed is anticipated to vary depending upon which of the five research goals is of interest. For example, it is anticipated that assembly average heat and assembly average Pu mass estimation will benefit from "assembly average" axial profile information given that the quantity of interest is inherently an assembly average; yet exactly how to measure the axial information, scanning vs. a number of static detectors, is not clear. With respect to reactivity estimation, the motivation is criticality safety; for this technical need, the greatest interest will be that region with the greatest residual multiplication, which is most often the extremes of the assembly. For assembly identification, it is likely that one axial location will suffice; while for verifying that pins are not missing, one axial location may also suffice but a few locations may increase confidence. The research presented here is an initial step toward answering these questions by studying the axial variation in the spectral resolved passive gamma signal from fifty spent fuel assemblies (twenty-five boiling water reactors [BWR] and twenty-five pressurized water reactor [PWR] assemblies). Future research will combine the spectrally resolved data with signatures from additional NDA instruments for the purpose of quantifying how well an integrated system can meet the five research goals identified above.

The passive gamma measurements reported here are a subset of passive gamma measurements performed by our collaborative research team, which includes SKB, the U.S. Department of Energy (DOE), and Euratom. Measurements made while the fuel was stationary used data acquisition hardware set to pulse height analysis (PHA) mode, thus producing photon intensity vs. energy spectra. These were performed within this collaboration as reported in References 4, 5, 6, and 7. In this paper we report on measurements performed using time-stamped list mode data acquisition made while the fuel assembly was moving in front of the collimator.

Figure 1. A sketch of the experimental situation at Clab, seen from above. The detector (D) is located about 2.5 meters from the centre of the fuel assembly (F). The collimator slit (S) is conical in the horizontal plane. In the vertical plane, the slit have constant opening width of 5.0 mm. The width of the wall (W) is 190 cm. The rotation angle is defined as positive from the x-asis towards the y-axis with 45 degrees indicated in the sketch.



Measurements

At Clab, the equipment for the axial scanning of nuclear fuel assemblies is installed in the pool. The gamma scanning equipment, which is independent from the crane generally used for fuel movement, also has the capability to rotate the fuel around its axis, thus enabling azimuthal scanning. About 2.5 meters spanned the distance between the fuel assembly centre and a high-purity germanium detector. The detector, model GX4018 from Canberra Inc., had a relative efficiency of 40 percent and an energy resolution (FWHM) of 1.8 keV at 1332 keV. The digital signal analyzer Lynx from Canberra Inc. was used to collect time-stamped list mode data using custom made software. A horizontal collimator slit was used, see Figure 1. The slit exposed the entire horizontal extent and about 15 mm vertical extent of the fuel assembly. More details on the gamma scanning equipment can be found in References 4 and 8.

Normally, the fuel is scanned axially with a gamma-ray detection system pointing toward a corner of the assembly and the fuel is rotated between scans. During one axial scan, the fuel assembly was visible from the detector during about 200 seconds, see Figure 2. This was the procedure followed for the majority of the measurements reported here. Also in this work, measurements were performed during the rotation of two fuel

Table 1. Parameters of the measured fuel assemblies are listed. Cooling time is determined with the time of measurement. The use of the terms "Fuel Type 1," "Fuel Type 2," etc., indicate if the fuel was made by the same or different commercial vendors. IE is the initial enrichment of 235U in the fuel, before reactor operation.

Fuel id	Fuel type	Burnup [GWd/tU]	IE [percent]	Loading date	Discharge date	Cooling time [y]
BWR1	10x10 BWR Fuel Type 1	46.4	3.1	1999-10-28	2006-08-29	8.26
BWR2	10x10 BWR Fuel Type 2	43.8	3.2	1999-06-09	2004-08-17	10.3
BWR3	10x10 BWR Fuel Type 2	44.4	3.4	1996-08-18	2002-08-12	12.3
BWR4	10x10 BWR Fuel Type 2	41.9	3.4	1996-08-18	2002-08-12	12.3
BWR5	10x10 BWR Fuel Type 1	42.0	3.1	1999-10-28	2006-08-29	8.26
BWR6	8x8 BWR Fuel Type 1	38.1	2.7	1978-08-05	1985-09-12	29.2
BWR7	10x10 BWR Fuel Type 2	41.2	3.1	1999-06-09	2004-08-17	10.3
BWR8	10x10 BWR Fuel Type 3	39.8	3.2	2001-08-29	2005-05-19	9.54
BWR9	10x10 BWR Fuel Type 1	40.4	3.1	2001-08-29	2007-09-07	7.24
BWR10	10x10 BWR Fuel Type 1	39.5	3.1	2001-08-29	2006-08-29	8.26
BWR11	8x8 BWR Fuel Type 1	31.5	2.1	1980-11-08	1992-08-22	22.3
BWR12	10x10 BWR Fuel Type 4	33.5	3.0	1997-06-24	2005-06-10	9.48
BWR13	10x10 BWR Fuel Type 4	36.8	3.0	1997-06-24	2005-06-10	9.48
BWR14	8x8 BWR Fuel Type 1	30.5	2.6	1978-08-05	1985-09-12	29.2
BWR15	8x8 BWR Fuel Type 1	29.4	2.1	1980-11-05	1989-08-25	25.3
BWR16	8x8 BWR Fuel Type 1	26.8	2.1	1980-11-05	1987-06-11	27.5
BWR17	8x8 BWR Fuel Type 1	32.7	2.3	1975-03-01	1986-07-15	28.4
BWR18	8x8 BWR Fuel Type 1	21.5	2.1	1980-11-14	1992-08-22	22.3
BWR19	8x8 BWR Fuel Type 1	30.8	2.6	1984-10-17	1989-06-10	25.5
BWR20	10x10 BWR Fuel Type 4	26.4	3.0	1998-08-02	2005-06-10	9.48
BWR21	8x8 BWR Fuel Type 1	27.7	2.3	1975-03-01	1987-07-01	27.4
BWR22	10x10 BWR Fuel Type 4	20.4	3.0	2001-07-14	2005-06-10	9.48
BWR23	10x10 BWR Fuel Type 4	16.0	3.0	1999-05-24	2005-06-10	9.48
BWR24	8x8 BWR Fuel Type 2	13.3	1.3	1984-10-17	1987-07-10	27.4
BWR25	8x8 BWR Fuel Type 2	9.13	1.3	1984-10-17	1987-07-10	27.4

assemblies in order to estimate the azimuthal variation of the measured gamma-ray intensity as a function of angle.

The majority of the measurements reported in References 4, 5, 6, and 7 were performed at one axial location of the fuel assembly with a goal of measuring the count rates of the major peaks of ^{134}Cs, ^{137}Cs, and ^{154}Eu as these are the primary isotopes anticipated to be useful for the ten- to about sixty-year cooling time anticipated for the loading process of the Swedish repository.

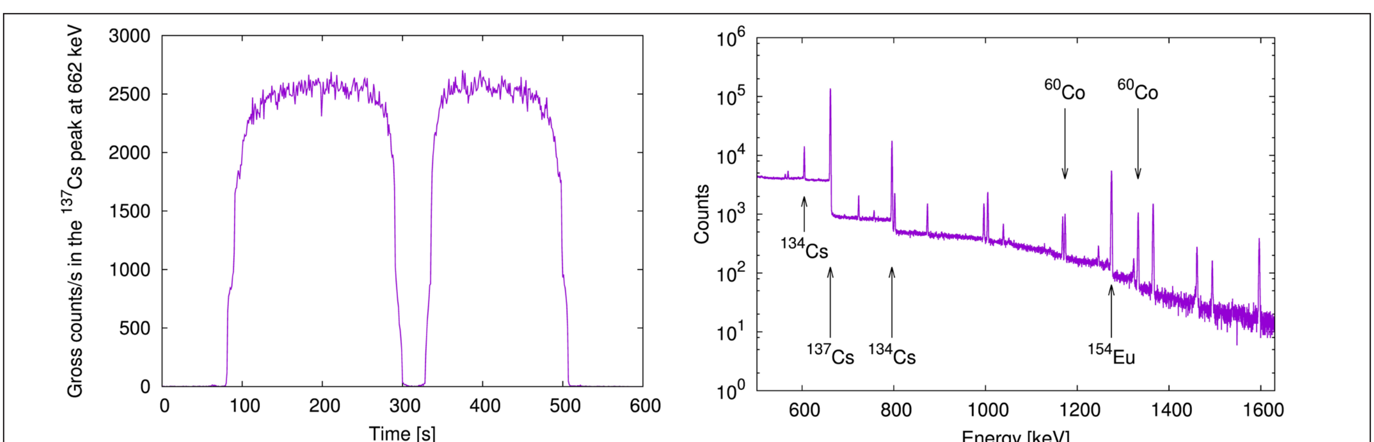
For the measurements presented in this work, detector events were measured in time-stamped list mode using the Lynx data acquisition system from Canberra Inc. The time-stamped list mode saves the pulse height of each detected voltage pulse event as well as the associated real-time stamp of the event, allowing for studies of gamma-ray intensities as a function of time of the fuel assembly measurement.

The parameters of the fuel assemblies measured for this paper are summarized in Table 1. For each gamma-ray energy spectrum measured, the gross and net peak area counts in peaks from ^{134}Cs (796 keV), ^{137}Cs (662 keV), and ^{154}Eu (1274 keV) were evaluated. All peak counts were time-corrected for decay and scaled to an arbitrary selected reference point in time (2014-01-01 00:00 UTC) in order to compensate for the (albeit small) time differences between different measurements of the same fuel assembly, i.e., different corners.

Table 1. (cont.) Parameters of the measured fuel assemblies are listed. Cooling time is determined with the time of measurement. The use of the terms "Fuel Type 1," "Fuel Type 2," etc., indicate if the fuel was made by the same or different commercial vendors. IE is the initial enrichment of 235U in the fuel, before reactor operation.

Fuel id	Fuel type	Burnup [GWd/tU]	IE [percent]	Loading date	Discharge date	Cooling time [y]
PWR1	15x15 PWR Fuel Type 1	52.6	4.0	2005-05-04	2009-05-28	5.36
PWR2	15x15 PWR Fuel Type 1	49.6	4.0	2005-05-04	2009-05-29	5.36
PWR3	17x17 PWR Fuel Type 1	48.2	3.7	1996-07-06	2000-06-21	14.3
PWR4	17x17 PWR Fuel Type 2	46.9	4.0	2004-09-26	2008-06-04	6.35
PWR5	17x17 PWR Fuel Type 2	46.9	4.0	2004-09-26	2008-06-02	6.36
PWR6	17x17 PWR Fuel Type 3	45.7	3.6	1993-07-08	1999-06-23	15.3
PWR7	17x17 PWR Fuel Type 4	44.5	4.0	2003-09-05	2007-06-27	7.29
PWR8	17x17 PWR Fuel Type 5	44.4	3.3	1984-08-20	1988-09-11	26.1
PWR9	15x15 PWR Fuel Type 2	45.8	3.7	2003-06-15	2007-08-01	7.19
PWR10	17x17 PWR Fuel Type 1	43.5	3.7	1994-07-01	1998-06-17	16.3
PWR11	17x17 PWR Fuel Type 1	43.2	3.6	1994-07-01	2000-06-21	14.3
PWR12	17x17 PWR Fuel Type 5	43.0	3.3	1984-08-20	1988-09-11	26.1
PWR13	15x15 PWR Fuel Type 3	40.9	3.2	1982-07-25	1987-04-25	27.5
PWR14	17x17 PWR Fuel Type 1	40.7	3.6	1993-07-08	1997-06-24	17.3
PWR15	17x17 PWR Fuel Type 5	40.5	2.8	1982-04-17	1987-08-27	27.1
PWR16	17x17 PWR Fuel Type 1	40.4	3.6	1993-06-23	1996-06-21	18.3
PWR17	17x17 PWR Fuel Type 1	40.3	3.7	1994-09-22	1999-09-01	15.1
PWR18	17x17 PWR Fuel Type 1	39.8	3.5	1989-07-09	1995-06-09	19.3
PWR19	15x15 PWR Fuel Type 3	35.0	3.2	1980-05-17	1985-05-01	29.4
PWR20	17x17 PWR Fuel Type 5	34.0	3.1	1980-07-04	1986-06-18	28.3
PWR21	17x17 PWR Fuel Type 5	34.0	3.1	1980-07-04	1986-06-18	28.3
PWR22	17x17 PWR Fuel Type 5	31.2	2.8	1982-04-18	1986-08-10	28.2
PWR23	17x17 PWR Fuel Type 1	28.5	3.6	1993-07-07	1996-06-21	18.3
PWR24	17x17 PWR Fuel Type 5	23.2	2.1	1980-07-02	1995-06-09	19.3
PWR25	17x17 PWR Fuel Type 5	19.6	2.1	1980-07-03	1984-05-24	30.4

Figure 2. In the left pane, an example of a measured axial gross count intensity of the ^{137}Cs peak at 662 keV is illustrated. The energy spectrum composed of all counts acquired during the time of that axial profile is illustrated in the right pane. The data illustrated here came from the 45 degree corner measurement of BWR1.



Axial Scan Measurement Procedure

Each axial scan started with the fuel assembly located below the collimator, the entire assembly then moved upwards past the collimator, stopped, and then moved downward for a second complete axial scan of the assembly. The upward motion was slower than the downward motion, about 1.7 cm/s and 2.1 cm/s respectively. All axial profiles are therefore composed of two parts, the first one, the left part or left waveform, corresponding to the upwards motion and the second part, a right part or right waveform, corresponding to the downwards motion with the left part being wider than the right part. The left side of Figure 2 shows an example of a measured axial profile that illustrates the total intensity of the 662 keV line from ^{137}Cs as a function of time; while, the right side of Figure 2 shows an example of the energy spectrum collected during the time interval when the entire assembly scanned up and down in front of the collimator. Data for all the list mode measurements is planned to be presented in Reference 9. Typically, the assembly was stationary for a few seconds between the up and down motion. In general, four axial scans were measured for each assembly; in each case the assembly was turned such that a different corner was closest to, or pointed at, the detector.

Azimuthal Scan Measurement Procedure

Two azimuthal scans were measured and used to evaluate the variation of gamma-ray intensity as the assembly turned through 360 degrees.

One 10x10 BWR (id BWR4) and one 17x17 PWR(id PWR6) fuel assembly were measured at a stationary axial level with a constant angular (azimuthal) rate of rotation. The parameters of the measured fuel assemblies are shown in Table 1. The resulting azimuthal intensity profiles for ^{137}Cs are shown in Figure 3.

Analysis of Measured Data

Axial Variation of Measured Intensity

Frequently, those measuring passive gamma radiation from an assembly want to estimate a global property of the assembly, such as the assembly average burnup. Yet, due to the practical situation of measuring photons from an assembly, the researcher may find it practical to only measure a limited number of narrow axial sections. Hence, the researcher has the additional step of extrapolating from the localized passive gamma measurements that collect photons from a small axial fraction of the assembly to the whole assembly; in some cases such axial measurements are lacking altogether so rough estimates are used. The list mode data acquired for this study from all corners of the assembly can be used for assessing the uncertainty introduced by such estimates.

A comparison was made between the list mode data acquired as the assembly scanned up and down and the measurements performed for a fixed location on the burn plateau located 36 percent of the distance down from the top of the assembly. This latter measurement was made with a multichannel analyzer (MCA) set in pulse height analysis mode using a different MCA as reported in Reference 4. Note in both measurement cases the count rates measured from each of the measured corners was averaged. The list mode data was restructured into a pulse height energy spectrum before the net peak counts was calculated, including a linear background subtraction, for every scan time interval studied in this paper. Figure 4 shows this comparison between average ^{137}Cs peak

Figure 3. The azimuthal intensity profiles of the gross 137Cs peak count rate versus time for BWR4 (left) and PWR6 (right) are illustrated

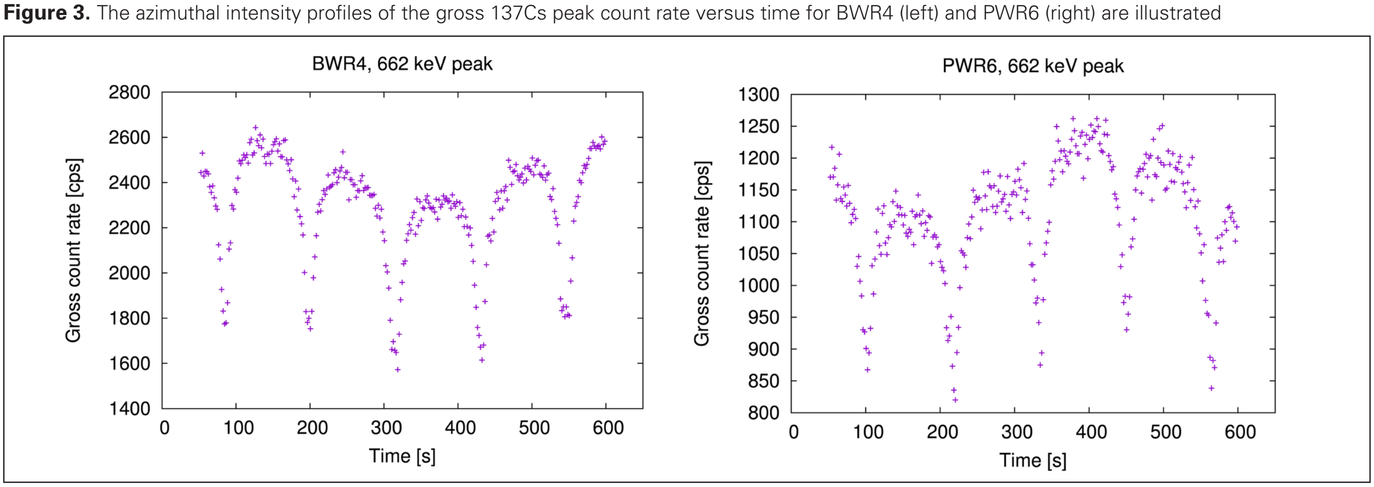


Figure 4. The average dead time corrected count rate of the 137Cs peak for the list mode measurements over the entire axial scan versus the PHA-mode measurements for a fixed axial location on the burnup plateau is illustrated

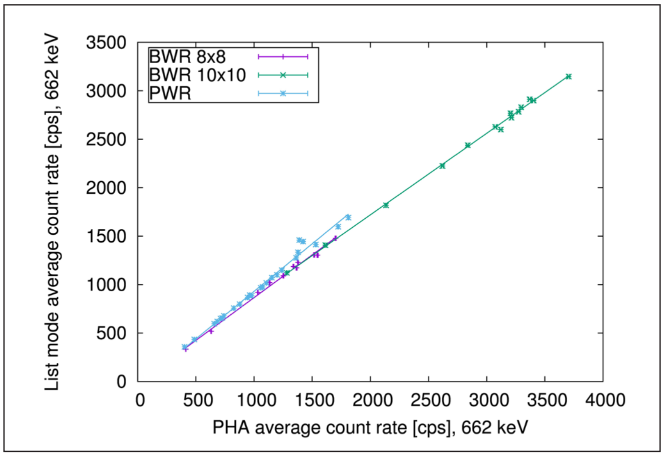
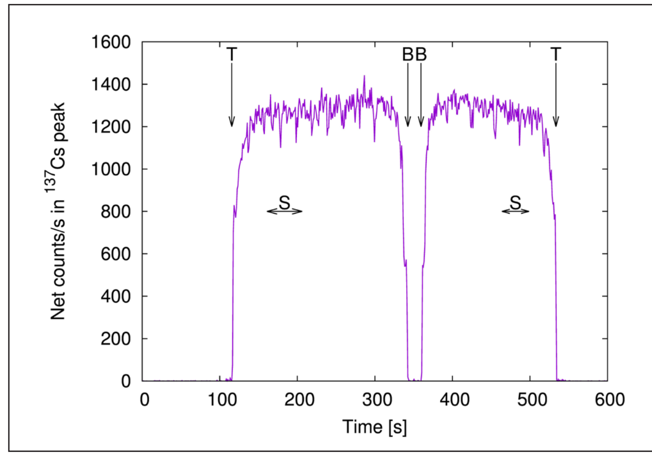


Figure 5. An example of a segment of an axial intensity profile is defined in this illustration. The segment, noted by S, is defined in this case as starting at 60 percent from the bottom and ending at 80 percent from the bottom of the axial profile. The top of the 137Cs axial profile is noted by a T and the bottom by a B. The profiles have two parts corresponding to the upwards followed by the downwards motion of the fuel assembly in front of the collimator. The data used for this Figure is from the axial scan of the 315 degree corner of PWR1. Several dips can be seen in the profile that are caused by attenuation in grid spacers.



count rate from the list mode measurements versus the corresponding PHA-mode measurements, indicating that the two measurement systems produce comparable data. Additionally, we observe that the linear fit to the PWR assemblies have a slightly larger slope than the fit for the BWR assemblies indicating that the assembly average count rate and the count rate measured from a narrow section of the burnup plateau are slightly closer in value with PWR assemblies than with BWRs. This is consistent with the flatter burnup plateaus that are generally observed with PWR assemblies relative to BWRs. It is worth commenting on the two PWRs with PHA count rates just below 1500 cps that are significantly above the PWR linear fit. These two assemblies are the only two assemblies of a particular fuel type for which we have reason to suspect possible grid spacer interference with the PHA measurement. As can be seen in Figure 5, such interference reduces the net count rate by about 15 percent.

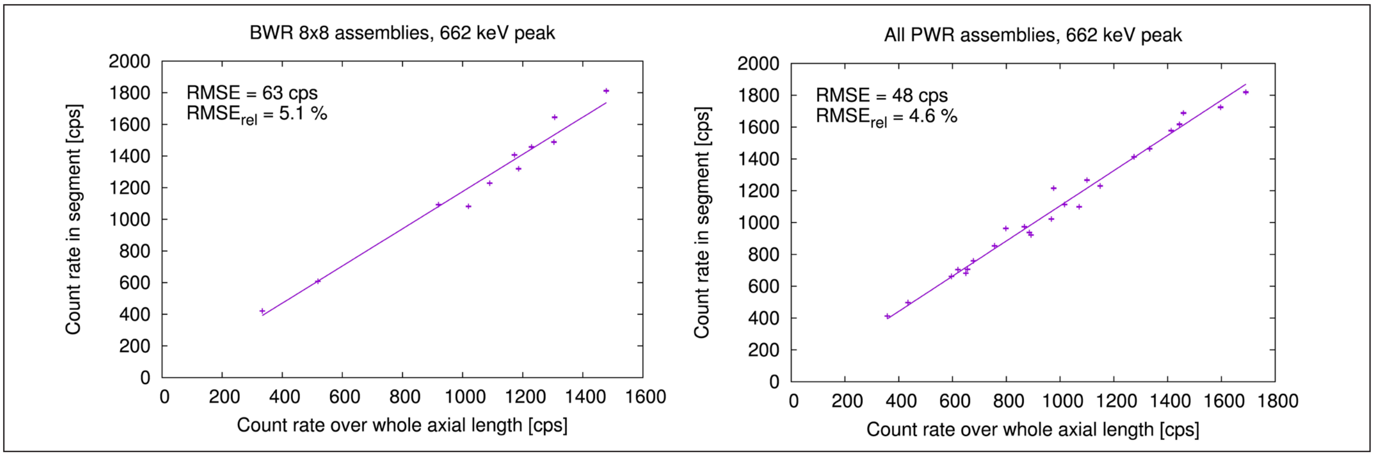
In this section, we use the axial profile measurements to evaluate how well the whole axial average count rate is represented by various cut-outs of the axial profile. For ^{137}Cs, which has an activity that is nearly linearly proportional to burnup,[8] an axial segment over the plateau of the axial profile is expected to correlate well with the axial average. For ^{134}Cs and ^{154}Eu however, which follow more complicated production chains during reactor operation, it is not evident how well an axial segment over the plateau of the axial profile will correspond to the axial average; data illustrating this variation is presented later in this paper.

Figure 5 shows how a defined cut-out section, or segment, of the axial profile was defined. The beginnings and ends of the ^{137}Cs net count rate profile, as determined with the procedure described in appendix A, is the basis upon which the time at which the profile measurement beginning and end are defined also for ^{134}Cs and ^{154}Eu.

In cases where measurements of a segment's count rate correspond well to the whole axial average count rate, a linear correlation with a small uncertainty is expected in the graph of the segment average count rate as compared to the average count rate for the entire assembly. In other cases, the uncertainty of the linear correlation is larger. Figure 6 shows two examples of this correlation for the measurements performed in this study. In Figure 6, the root-mean-square error deviation from the fitted linear correlation is indicated by the value RMSE (root-mean-square error). The relative RMSE value calculated according to Equation 1 is also indicated in Figure 6. Here, y_i is the count rate in a segment and $\hat{y}_i$ is the count rate in the segment predicted by the fitted line. N is the number of segments.

$$RMSE_{rel} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{y_i - \hat{y}_i}{\hat{y}_i}\right)^2} \quad (1)$$

Figure 6. The measured count rate in a segment on the middle (48-52 percent) of the axial plateau is illustrated as a function of the count rate over the whole axial length for 137Cs from BWR 8x8 (left) and PWR assemblies (right). The legend displays the RMSE of the deviations from the fitted line and the relative RMSE calculated according to Equation 1.



To perform a study on the sensitivity of how well the whole axial average is represented by the segment, a set of segments was selected, see Table 2. Repeating the exercise in Figure 6 for each segment and for each set of fuel assemblies, the $RMSE_{rel}$ values were calculated and plotted in Figures 7, 8, and 9. Several observations can be made, based on Figures 7, 8, and 9:

- For ^{137}Cs at 662 keV, the $RMSE_{rel}$ values over all variations of segments are generally smaller than for the ^{134}Cs and ^{154}Eu peaks at 796 and 1274 keV, respectively. This larger scatter observed with ^{134}Cs and ^{154}Eu compared to ^{137}Cs is anticipated to be due to both the poor counting statistics for the ^{134}Cs and ^{154}Eu peaks as well as the greater sensitivity to reactor operating conditions of these isotopes.
- An axially centered segment generally produces the best correlation to the axial average over the entire assembly, there $RMSE_{rel}$ is at the minimum of the data presented here. Hence, if there is the desire to restrict the axial extent of the passive gamma measurement, correcting the count rate determined from the axial midplane for an expected deviation from an assembly average, is a viable option.
- When the count rate was integrated over any 10-cm axial segment, the $RMSE_{rel}$ value varies within about ±10 percent for both BWRs and PWRs, except on the outer most edges of the assemblies, using ^{137}Cs whereas it varies more for ^{134}Cs and ^{154}Eu.
- For measured intensities of ^{137}Cs, ^{134}Cs and ^{154}Eu from BWR 8x8 assemblies, the $RMSE_{rel}$ value for an axially centered segment of 15-cm axial extent is 5.1 percent, 10 percent and 7.2 percent, from the axial average intensity, respectively, including the uncertainty due to counting statistics.
- For measured intensities of ^{137}Cs, ^{134}Cs and ^{154}Eu from BWR 10x10 assemblies, the $RMSE_{rel}$ value for an axially centered segment of 15-cm axial extent is 5.3 percent, 5.2 percent and 5.1 percent, from the axial average intensity, respectively, including the uncertainty due to counting statistics. The smaller values for ^{134}Cs and ^{154}Eu, compared to BWR 8x8 assemblies, is probably due to smaller cooling time resulting in smaller counting statistics uncertainty.
- For measured intensities of ^{137}Cs, ^{134}Cs and ^{154}Eu from all 25 PWR assemblies, the $RMSE_{rel}$ value for an axially centered segment of 15-cm axial extent is 4.6 percent, 12 percent and 6.6 percent, from the axial average intensity, respectively, including the uncertainty due to counting statistics.
- It is difficult to make conclusion about the optimum axial length to use for ^{134}Cs and ^{154}Eu given the elevated uncertainty in the counting statistics for most assemblies. What is clear is that the emission from these two isotopes vary significantly between the central and end regions of the assembly.

Table 2. The defined segments of the axial profile are listed

Segment(s)	Note on segments' represenation
1 piece at 48 - 52 percent	One measurement at 1/2 height with an axial view of about 15 cm.
74 equal pieces	Measurements at about 5 cm intervals along the height.
37 equal pieces	Measurements at about 10 cm intervals along the height.
19 equal pieces	Measurements at about 20 cm intervals along the height.
5 equal pieces	Measurements at about 74 cm intervals along the height.

Figure 7. The relative RMSE deviation from a fitted line between measurements in a segment and the corresponding whole axial average for BWR 8x8 assemblies is depicted. The horizontal bars represent the extent of the segment. Bars are not plotted for the 5-cm segments to avoid clutter.

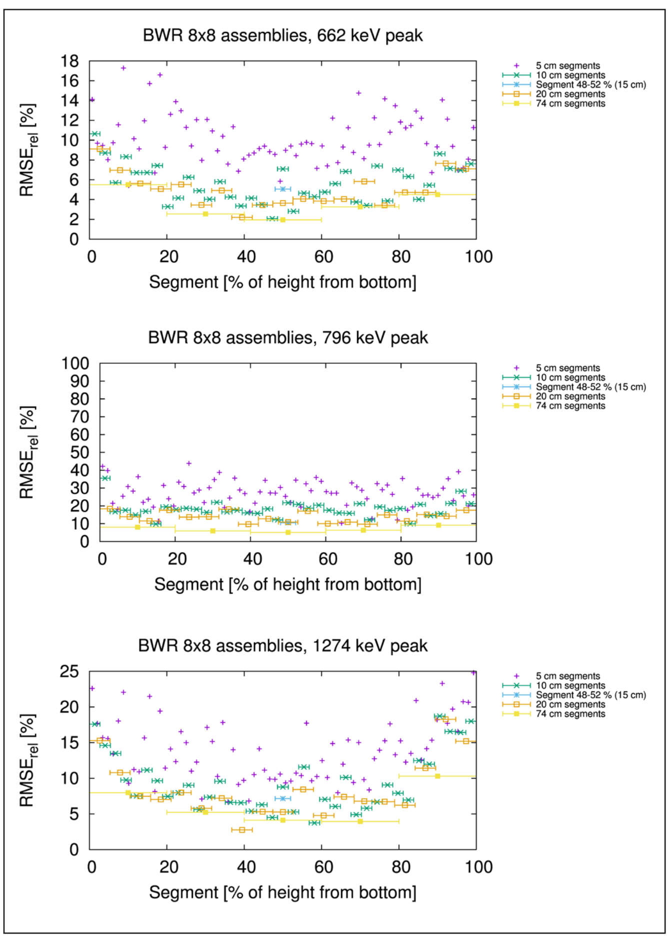
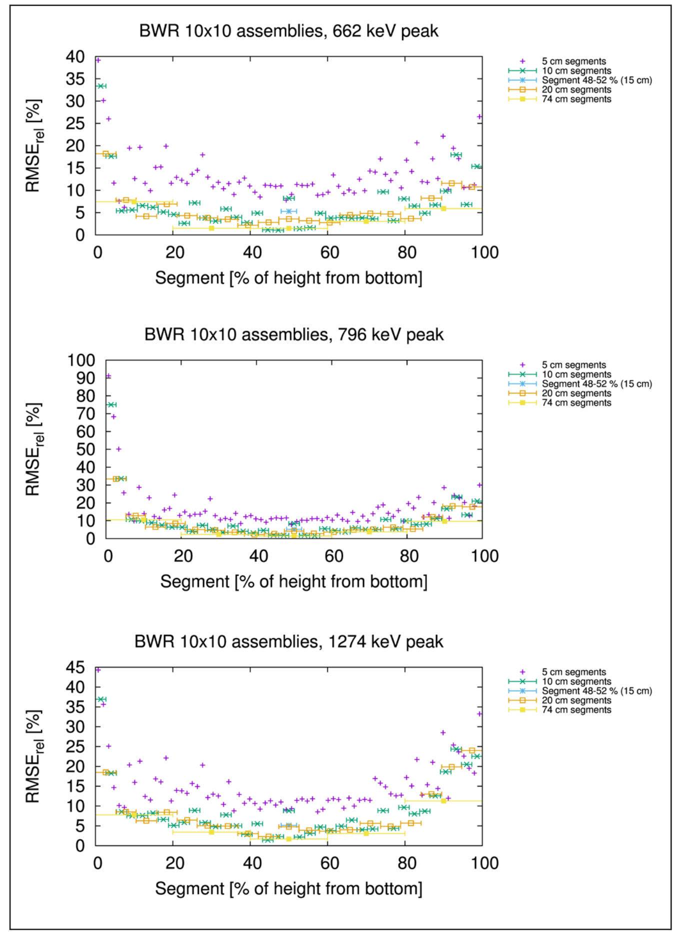
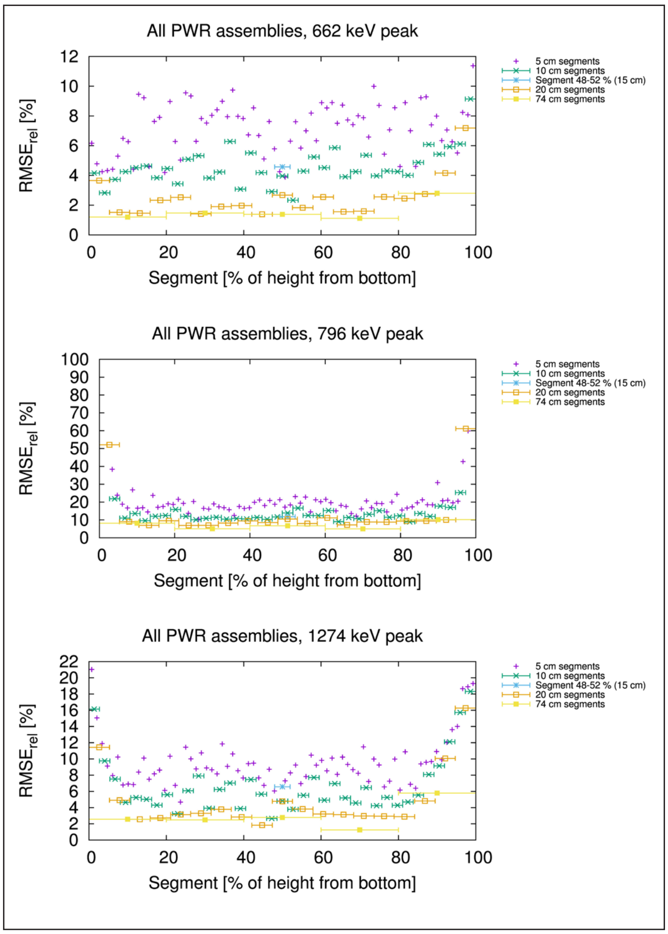


Figure 8. The relative RMSE deviation from a fitted line between measurements in a segment and the corresponding whole axial average for BWR 10x10 assemblies is depicted. The horizontal bars represent the extent of the segment. Bars are not plotted for the 5 cm segments to avoid clutter.



The main purpose of using NDA to measure spent fuel assemblies is to enable the estimation of fuel assembly properties of interest. One of the properties of interest to a safeguards inspectorate is the assembly average burnup as this is the value declared by the state. It is well known that a nearly linear relationship exists between the count rate of the 662 keV line of ^{137}Cs and burnup.[8] A question that the current data set can give insight on is if, and by how much, the assembly averaged intensity of the 662 keV line of ^{137}Cs might improve the estimation of burnup as compared to the more standard practice of measurement at one axial location on the assembly. In Figure 10, six graphs are depicted. Each graph illustrates the correlation between the measured 662 keV line of ^{137}Cs and burnup for all the assemblies in Table 1. The top two graphs show this correlation for the eleven 8x8 BWR assemblies only,

Figure 9. The relative RMSE deviation from a fitted line between measurements in a segment and the corresponding whole axial average for PWR assemblies is depicted. The horizontal bars represent the extent of the segment. Bars are not plotted for the 5-cm segments to avoid clutter.



while the middle two graphs show this relationship for fourteen 10x10 assemblies. Note, the assemblies were divided into 8x8 and 10x10 primarily because the pin size and pitch of the fuel was different enough between these two full types so as to impact the photon transport from the fuel to the detector as evidenced in the publication by Reference 4. The bottom two graphs are for twenty-five PWR assemblies. The three graphs on the left side of Figure 10 were measured from a 15-mm[4] axial section of the assembly located on the burnup plateau; in the graph this small axial section is labeled as an "Axially Localized 662 keV Count Rate." The three graphs on the right side of Figure 10 were measured while the assembly scanned up and down past the collimator; hence, the intensity measured is averaged over the assembly. The axis for this measurement is labeled as the "Axial Averaged 662 keV Count Rate." Note that for all these graphs the count rate value used was averaged over all four corners of the assembly.

The RMSE of the deviations from the linear regression models fitted for each of the six images in Figure 10 are summarized in Table 3 along with the statistics obtained when the BWR assemblies were not split into 8x8 and 10x10 groups. Additionally, the RMSE of the burnup variation is also listed when the input and output variables in the analysis were switched relative to those depicted in Figure 10. For three of the four cases listed in Table 3 the RMSE values were reduced when the axially averaged count rate for the 662 keV line of ^{137}Cs was used to predict burnup as compared to the localized point on the assembly. For the 8x8 assemblies the one-sigma uncertainty in the count rate when the localized measurement was used was 124 cts/s, which corresponded to a burnup variation of 1.5 GWd/tU. The use of the axial scanned data reduced the one-sigma uncertainty of the burnup estimate to 1.1 GWd/tU for a difference of 0.4 GWd/tU. A reduction was also noted when all BWR assemblies were analyzed as a group from 2.0 GWd/tU to 1.8 GWd/tU for a difference of 0.2 GWd/tU; as well as when all PWR assemblies were analyzed as a group for which the RMSE changed from 2.1 GWd/tU to 1.2 GWd/tU for a difference of 0.9 GWd/tU. Yet, when the 10x10 BWRs were analyzed as a group, the change in both the count rate and burnup uncertainties was roughly an order of magnitude lower so as to be negligible. To put these RMSE values in context, it is useful to note that the burnup of most assemblies at Clab are in the 30 to 50 GWd/tU range. Assuming an assembly irradiated to 40 GWd/tU, the reduced uncertainty values listed above 0.2, 0.4 and 0.9 GWd/tU correspond to burnup uncertainties of between 0.5 percent and 2 percent.

The one case when an improvement was not noted was for the 10x10 BWR assemblies. One possible reason for the lack of an improvement with the 10x10 assemblies is that the 8x8 assemblies were irradiated about twenty-five years ago while the 10x10 assemblies were irradiated about nine years ago. In between these two time periods, the operators ability to more evenly irradiate assemblies was improved.

Figure 10. The count rate for the 662 keV line of 137Cs is illustrated as a function of burnup for six different situations. The top two graphs are of 8x8 BWR assemblies, the middle row is for 10x10 BWR assemblies, while the bottom two graphs are for PWR assemblies. The count rates illustrated for the three graphs on the left side of the Figure were from a 15 mm localized section of the assembly,[4] while the count rates illustrated for the three graphs on the right side of the figure were measured as the assembly moved past the collimator.

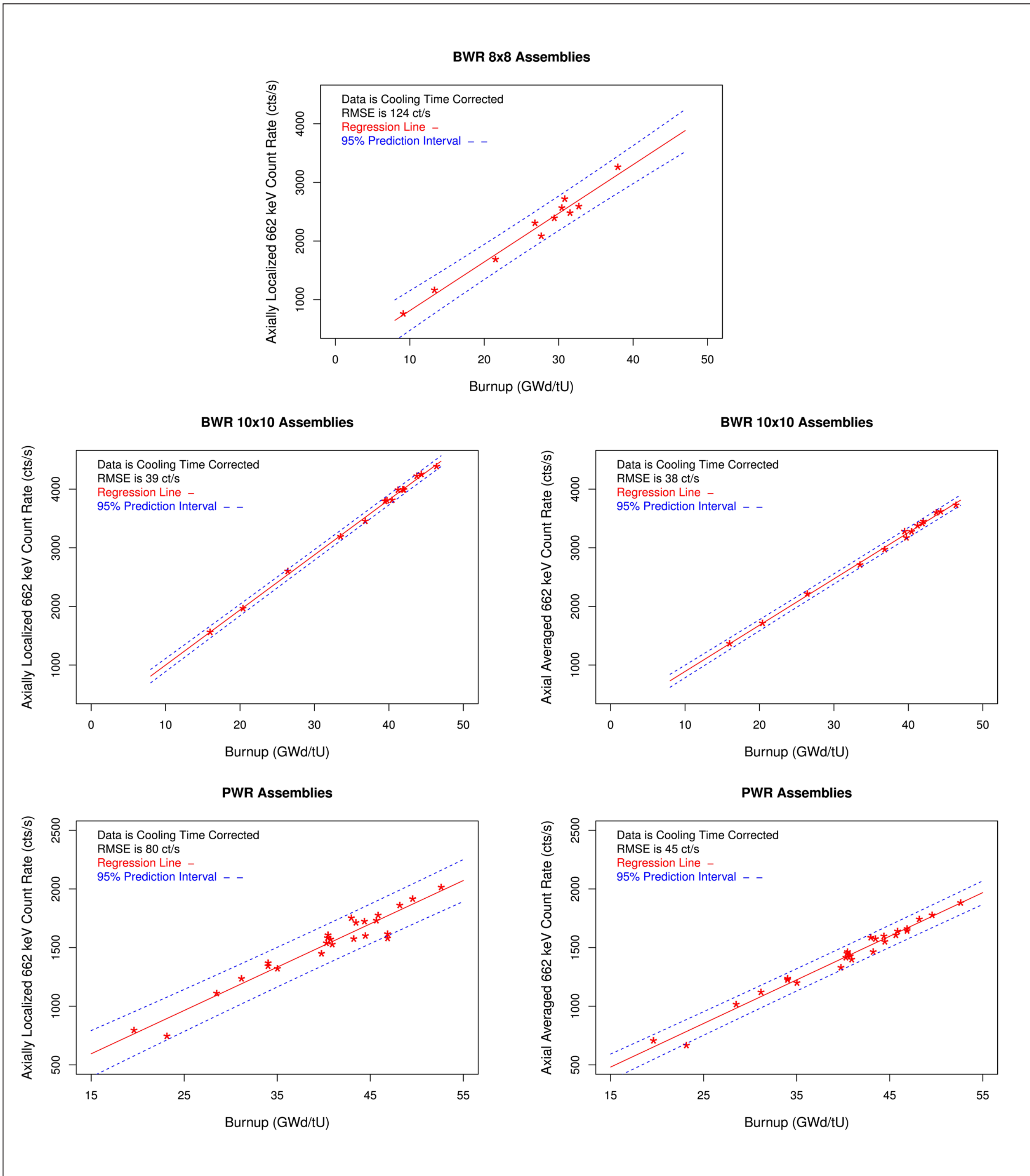


Table 3. The root-mean-square error (RMSE) of the count rate variation from the fitted line for each of the six images in Figure 10 is listed as well as the variation calculated when all BWR assemblies were analyzed together. Additionally, the RMSE of the burnup variation is also listed when the input and output variable in the analysis were switched relative to those depicted in Figure 10.

Assembly	Localized measurement		Axial average measurement	
Type	Count rate	Burnup	Count rate	Burnup
	RMSE	RMSE	RMSE	RMSE
	[cts/s]	[GWd/tU]	[cts/s]	[GWd/tU]
8x8 BWR	124	1.5	86	1.1
10x10 BWR	39	0.42	38	0.48
all BWR	207	2.0	154	1.8
all PWR	80	2.1	45	1.2

Azimuthal Variation of Measured Intensity

The measurement of gross ^{137}Cs count rate as a function of azimuthal angle show dips when the flat plane of the assembly side faces toward the detector at every flat side of the assembly, see Figure 3. We have identified three reasons for these dips; (1) changing self attenuation of gamma rays by the fuel itself, the attenuation is greatest when the flat plane of the assembly side faces toward the detector; (2) changing attenuation of the gamma radiation in the water due to variation in the water-to-detector distance as the assembly rotates (this behaviour varies as function of angle for each fuel pin); (3) changing solid angle occupied by the fuel within the field of view of the detector as a function of azimuthal angle.

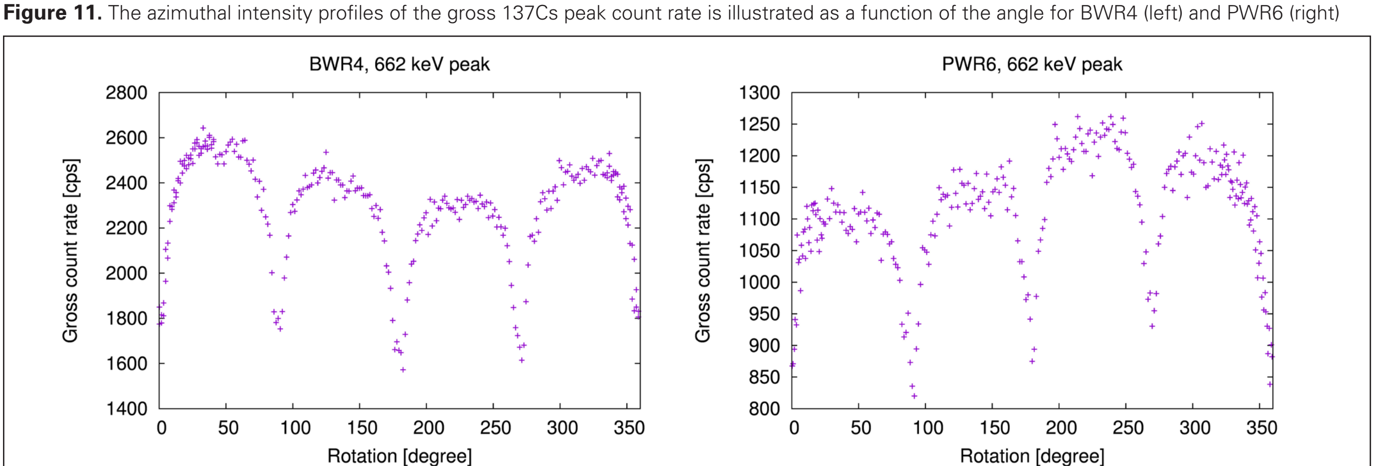
The dips were used to establish a linear fit between rotation angle and acquisition time, thus enabling the determination of the angualar speed to about 4.68(2) and 4.64(3) minutes per turn, for BWR4 and PWR6 respectively. Using this linear fit, the intensity as function of rotation angle could be determined, the results are plotted in Figure 11.

From Figure 11, it can be noted that the gross ^{137}Cs count rate varied between 2.3 and 2.6 kcps for BWR4 and between and 1.1 and 1.3 kcps for PWR6 among the four measurements made as the detector was pointed directly at each of the four corners for each respective assembly. Over the whole 360-degree turn however, the gross ^{137}Cs count rate varies between about 1.5 and 2.6 kcps for BWR4 and between 0.8 and 1.3 kcps for PWR6. Thus, the 360 degree variation is about 40 percent for both BWR4 and PWR6.

To put this angular count rate sensitivity into a safeguards deployment context, if a measurement setup were designed to make a measurement with the assemblies face normal to the detector and if the assembly happened to rotate 15 degrees away from the expected position, then the count rate could change significantly. Using two measurements made near the 90 degree side of BWR4 as an example, a 15 degree rotation from directly measuring at this angle resulted in a change in the count rate of 33 percent. The count rate at 90 degrees is about $2.0{\cdot}10^3$ count/s while the count rate at 105 degrees is about $2.4{\cdot}10^3$ counts/s. In comparison, if the measurement were made with a corner facing the detector, the assembly could rotate by more than 30 degrees in either direction, a rotation range of 60 degrees, without much change in the measured count rate per the data in Figure 11.

Another example of the azimuthal sensitivity is identified in the context of operators' need to measure decay heat of nuclear fuel assemblies. Using calorimetry, the decay heat can

Figure 11. The azimuthal intensity profiles of the gross 137Cs peak count rate is illustrated as a function of the angle for BWR4 (left) and PWR6 (right)



be measured as described in, e.g., Reference 10, and the results of the calorimetric measurement is corrected for losses due to gamma radiation escaping from the calorimeter. In the specific example of Reference 10, the escaping gamma is measured using a set of non-collimated gamma dosimeters positioned statically outside the calorimeter. The dosimeters are positioned radially out from the calorimeter and are therefore unable to detect an axial and azimuthal variation.

Assuming that ^{137}Cs dominates the energy spectrum of the escaping gamma radiation, the variation observed in Figure 11 implies that the measured gamma escape radiation will vary with the same order of magnitude, depending on the azimuthal angle of the gamma dosimeter probes. This observation is provided to indicate that such datasets could be used to quantify the uncertainty introduced by the current passive gamma system used with the Clab calorimeter.

Summary and Conclusions

In summary, several axial and two azimuthal profiles of the ^{137}Cs, ^{134}Cs and ^{154}Eu intensities from twenty-five BWR and twenty-five PWR fuel assemblies have been measured using a high-purity germanium detector at the Swedish interim storage for used nuclear fuel, Clab. The time-stamped list mode format of the acquired data enabled analysis of a potential improvement in accuracy in results from using either static or axially averaged data in future measurements to quantify any of our technical goals outlined in the introduction.

Several conclusions can be drawn from the analysis presented in this work. For a measurement at a static axial position to be representative of the assembly average, the following conclusions are drawn:

- A static axial measurement is generally best performed at the middle height of the assembly.
- A measurement of ^{137}Cs at the middle height of the assembly can be performed using a 15-cm segment of the fuel height. For this axial extent a correlation to the assembly average was measured to be within about 5 percent.
- A measurement of ^{134}Cs or ^{154}Eu at the middle height of the assembly requires a larger height of the field of view from the detector to the fuel. Typically, measuring in a 15-cm segment of the fuel height implies a correlation to the assembly average within about 10 percent for ^{134}Cs and ^{154}Eu.
- When a localized measurement from the burnup plateau of the 662 keV line of ^{137}Cs and an assembly average measurement of the 662 keV line of ^{137}Cs were each used to predict the assembly average burnup, the accuracy of the estimate depended on the fuel type. For PWR and 8x8 BWR assemblies the burnup estimate was more accurate by about 1 percent (one-sigma) when the assembly average data was used; while for the 10x10 assemblies, the linear fits created with both the assembly average and localized measurements provided the same one-sigma variation. Hence, there was no benefit to using one data set over the other with the 10x10 assemblies.

Further measurements of the azimuthal variation of the gamma radiation intensity are required in order to make stringent conclusions regarding the implications for measurements performed at an offset from the normal measurements towards the corner of the fuel assembly. The results presented here indicate that the azimuthal variation of intensity may have two possibly important consequences for both safeguards measurements and for measurements to fulfil the need of a facility operator to determine decay heat of the nuclear fuel.

Keywords

Nuclear fuel; gamma radiation detection; characterization; encapsulation; geological disposal; nuclear safeguards; spent nuclear fuel

Acknowledgements

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Appendix A

Estimating Scan Time of Measured Axial Profiles

The axial profiles of the net ^{137}Cs counts were analyzed in order to determine the real and live elapsed time during the axial measurement. Given that the list mode data acquisition was started before the fuel was in front of the collimator and the data acquisition was stopped after the fuel had traveled past the collimator, it was necessary to search within the data set for the start and stop times of the fuel. A search over the profiles was performed to sort the time stamps of events that are associated with the axial profile from those events that are not. The following procedure was used.

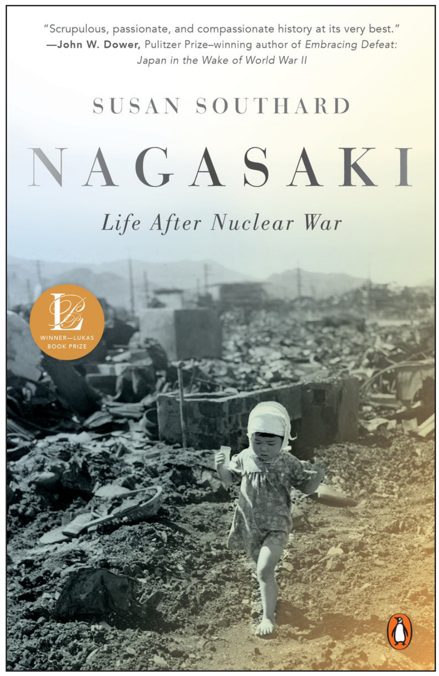
1. For each one second interval of real time measurement, the net ^{137}Cs peak count rate was calculated. Below, this is called the "axial net count rate profile". The energy spectrum established for each one second interval was used to determine the background count rate for the ^{137}Cs peak; for this calculation, a linear background under the peak was calculated using the average count on the high and low energy sides of the peak and it was subtracted from the gross peak count before the net peak count rate was calculated.
2. Set the threshold value to one count per second.
3. Across the axial net count rate profile, sort the time bin numbers of the corresponding values into groups of time bins numbers according to the following procedure.
   (a) Starting at the first time bin of the profile, create an empty current group that will contain time bin numbers that correspond to values below or equal to the threshold. This group is later removed if it is not filled.
   (b) For each value in the profile:
      i. If the current group contains time bin number corresponding to values below or equal to the threshold AND if the value is above the threshold, create a new current group that will contain time bin numbers that correspond to values above the threshold.
      ii. If the current group contains time bin number corresponding to values above the threshold AND if the value is below or equal to the threshold, create a new current group that will contain time bin numbers that correspond to values below or equal the threshold.
      iii. Save the time bin number of the value in the current group.
4. If the number of groups is larger than five then increase the threshold by one count per second and repeat the grouping process (3rd item in this list). The number of groups are typically larger than five when the threshold is too low, implying that low counting statistics at the beginnings and ends of the axial net count rate profile when ^{137}Cs is detected makes the procedure oulined above "switch between" current groups.
5. When five groups have been established, they correspond to five time intervals: (1) the time before the fuel arrived, (2) the time when the fuel was present moving up, (3) the time between up and down motions of the fuel, (4) the time when the fuel was present and moving down, (5) the time after the fuel has moved out of the view of the collimator.
6. The average of the two (real) time stamps at the edges of two adjacent groups defines the beginning and end time of the ^{137}Cs profile. The corresponding live time stamps are those that was reported by the electronics as close as possible to these defined real time stamps.

Book Review

By Mark L. Maiello, PhD
Book Review Editor

Nagasaki
Life After Nuclear War

Susan Southard
Hardcover, 390 pages
ISBN 978-0-670-02562-6
Viking, New York, New York, 10014



Too many years have passed since atomic and nuclear explosions were witnessed. Too many years have wiped clean the memory of how destructive these weapons are. To educate our future nonproliferation professionals — to recreate the suffering that must be felt to prevent future nuclear cataclysms, the words that fill *Nagasaki – Life after Nuclear War* must be read. An accounting such as this where human suffering is emphasized rather than infrastructure damage or numbers tallying urban destruction or nameless fatalities, is absolutely needed for every generation to read.

Susan Southard has put together an accounting of human misery so tragic that one may have to "prepare" before opening these covers. No matter what your profession in the realm of nuclear materials management; no matter if you are a scientist, engineer, or policy-maker, this accounting ought to make you redouble your professional efforts. This book will make you think deeply about the creation of nuclear weapons and what was done with that creation. The words it contains should both frighten and inspire you. The tragic stories it tells will make you shudder in horror — they are intended to. They may make you flinch at the human anguish one bomb can cause — they are meant to. They should give you pause and make you think how can you prevent this from ever happening again. If such is the case, Southard has succeeded.

The book follows the stories of five teenage *hibakusha* (Nagasaki atomic bomb survivors) as they struggle to reunite with their families and recover from their horrific injuries. The stories continue to the present day as again, they battle with the effort to prevent another nuclear holocaust through the public recounting of their experiences.

Southard is no mere storyteller. There is considerable research here. Hours of interviews with the *hibakusha* is supplemented with years of traditional library research, discussions with doctors and scientists and other post-nuclear survivors — much of this acquired during multiple trips to Japan. The notes section of this book exceeds forty-five pages.

The stories of the *hibakusha* are told in parallel so that chronologically, the reader follows all five along in time. Interwoven into their stories are the struggles of others who encountered the *hibakusha*, most notably the doctors who tried to treat them. Others, like their family members, coworkers, and friends are also included whenever information was available. The results are five stories of survival: five deeply personal, circumstance-driven descriptions of the horrific reality of post nuclear Nagasaki. Southard's writing is clear, descriptive, and evocative. She holds a master of fine arts degree in creative writing and is conversant in Japanese, having lived there as an international scholarship student. Her skill at crafting the historically accurate stories of these remarkable individuals will be evident from the very first chapter.

These heart-wrenching tales of immeasurable misery are, of course, the main thrust of the book. They teach us that it is possible to overcome even the most arduous and debilitating human suffering but only, as repeatedly shown, at very great cost to one's soul. Many *hibakusha* and their family members could not bear the physical torment that was inflicted by the thermal and radiation effects of the bomb. Some of the five *hibakusha* contemplated suicide many times. Many years passed before some would even venture out of their homes fearing the stares that their scars and disfigurement provoked. But as hard to believe as this may be, there is more to this book of personal memoirs, medical miracles and historical facts.

The underlying question this book asks is why Americans currently know so little about the experiences of atomic bomb victims? The book itself tries to fill that void by describing the suffering the *hibakusha* experienced — an unpleasant subject and one with moral repercussions. There was suppression of this information by the U.S. government just after the war. That of course, no longer exists. Why do we remain in ignorance?

Part of the answer lies in the ghastly human suffering itself. It is difficult, horrendous, and disturbing subject matter. In such books as *Longing for the Bomb* by Lindsay Freeman and *Building the H Bomb* authored by Kenneth Ford, both recently reviewed in this journal, this realization of the bomb's human cost, even if not fully understood by the protagonists, had, in most cases, wrenching emotional effects. The question of ignorance bridges to another question: why was the catastrophic human toll not completely known? Suppression of that information as explained by Southard was one cause. Ignorance, the historically convenient companion of many of mankind's follies, was another.

For several reasons, the novelty of atom bomb technology, the need to deploy it quickly, the lack of empirical data about the levels of ionizing radiation produced by the bomb, and, especially, the unfamiliarity of its biological effects, all worked to undermine significant consideration about the effects the weapon would have on people. U.S. officials, particularly Manhattan Project director General Lesley Groves, made certain that discussions of radiation effects were silent ones. It was, according to Southard, a vigorous attempt to protect the reputation of the United States and the lawful use of the bomb. Groves deflected the issue away, claiming that if the end of the war was uncomfortable to ponder, remembering how it began would ease the turmoil.

It was not until September 1951 that the ten-year state of war between Japan and the U.S. ended. Not until April 1952 did the six-year U.S. occupation of Japan end. In that time, Japan's communications link with the outside world had been severed. U.S. censorship restrictions had held sway. No travel by foreigners into the country or by Japanese out of the country had been permitted. Once lifted, access to atomic bomb health effects studied and compiled by Japanese and American scientists and medical practitioners was finally allowed. The damage, death, and suffering were finally made known to the Japanese public. Illegally withheld photographs and film were released by their Japanese concealers. In the U.S., information began to flow as well. *Life* magazine published photos of the *hibakusha* in 1952 and John Hersey published his landmark book *Hiroshima*. Yet as Southard explains, U.S. policies of denial and censorship kept Americans uninformed about the ghastly effects of whole body radiation exposure — the human toll of the atomic bomb. President Truman never fully acknowledged the human impact — although as Southard explains, some of his statements indicate his awareness. Instead, the Cold War accelerated along with the proliferation of nuclear weapons. The travails of the *hibakusha* played second fiddle to the mad dash to nuclear supremacy.

To right this imbalance, Southard has chronicled the post-apocalyptic stories of 18-year-old streetcar driver Wada Koichi, 16-year-old student Nagano Etsuko, daughter of a Mitsubishi employee, 15-year-old Mitsubishi Arms Factory employee Doh-oh Mineko, 16-year-old post-office worker Taniguchi Sumiteru, and 13-year-old student Yoshida Katsuji, from the moments just before they were all ravaged by the thermal and blast effects of the Nagasaki bomb to their later, remarkably productive senior years. The tales are riveting. Southard has compiled first-hand accounts of nuclear survival: what it was like to be in the midst of a cataclysmic atomic maelstrom. All survived by luck. All depended on distance, what lay between the victims and the blast, even which way they were facing and what they were wearing. The tragic poignancy of Mineko's story exemplifies the horror each faced though truth be told, their individual anguish was/is unique and cannot be compared. The Mitsubishi factory, located three quarters of a mile from the hypocenter, collapsed literally on top of her. Fellow workers were thrown by the blast across the factory floor. She was able to extricate herself and, following a fellow worker through the darkness and smoke, made it outside where she met two fellow students who had also emerged from nearby ruins. The world around them had been transformed into a nightmare. Scorched corpses lay on the ground amidst splintered glass, twisted metal and wire. Mothers were sobbing over dead children. Hundreds of men and women were staggering around, many already with blistered skin falling from their outstretched arms. They looked grey or even colorless with dark holes for their eyes and mouths. Many were half naked. As for Mineko, she could not keep up with her two friends. Her injuries, at first incomprehensible to her due to the shocking circumstances, were severe. She was burned over the left side of her body. A bone protruded out of her right arm. Glass splinters in the hundreds had impacted her body and blood covered her neck. Once she realized her injuries and perhaps more so because she was now alone, she cried out for her father.

The resurrection of these five remarkable individuals reveals the brilliance of this book. Each eventually sought solace and meaning to their lives not only by surviving, but also by finding some acceptance in Japanese society — some by achieving great career success — many without publically revealing their *hibakusha* status. Doh-oh Mineko chose the latter, immersing herself in her life-long love of fashion by moving to Tokyo, forgoing marriage lest her medical history be revealed and eventually, through long hours, sacrifice and dedication, became in 1973 the first-ever woman executive at her company. Never "cured" of her atomic trauma by a lifetime of hard work, Doh-oh was periodically haunted by the self-imposed separation from her family and decades-long devotion to proving herself in business. Eventually retirement, loneliness, the death of her mother and the persuasion of her sister determined that a return to Nagasaki was in her best interest. Indeed, the return was auspicious for it put Doh-oh in contact with those in Nagasaki who protested nuclear weapons particularly those weapons supposedly on visiting U.S. naval vessels, and more importantly by the resident *hibakusha* who freely admitted their wartime experiences. A male friend who was present when she was returned home injured by the bomb, read of her business success and found her these many years later. His involvement in the Nagasaki Foundation for the Promotion of Peace and his influence convinced Doh-oh to join the organization's public speaking circuit to recount her experiences.

All five *hibakusha* have told their stories — not in the safety of the pages of magazines or books, but orally, in public and often with those in influential positions such as United Nations dignitaries. They travel to schools throughout Japan and have visited schools in the U.S. as well. Their mission is not merely to remind the world of the grotesque injuries and deaths from the use of nuclear weapons, it is to educate new generations that have little conception of the power and abject, horrific, long-lasting pain use of these weapons brings. Their advocacy is a message of prevention. The next questions are obvious. Once the *hibakusha are gone*, how will we teach future generations to forestall the use of nuclear weapons? How do we impress upon future generations an understanding about hell unleashed on earth?

The tales of the five *hibakusha* are not for the faint of heart. The stories run deep with nearly indescribable physical and emotional pain. They are studded with loss: loved ones killed or never seen again; the loss of physical normality from the scars caused by thermal burns; the loss of standing in society by their disfigurement. There were years of constant anguish from the physical pain that these scars induced. But rebirth and resurrection into Japanese and indeed world society for some of them brings hope and a sense of completion to their amazing stories of survival and accomplishment. This reviewer does not possess the talent to further describe what Southard has done so brilliantly. She has brought the horrid facts of surviving the bomb out in the open in a manner so well written that she has not only honored the efforts of the *hibakusha* to enlighten the public about the human effects of nuclear weapons, but she has also created a must-read for all scientists and policy makers who have made nuclear non-proliferation their career. Southard has not only immortalized the efforts of the *hibakusha*, she has preserved their message of rebirth from the precipice of death. She has revived their hope of peace for a world burdened by the double-sided sword of nuclear technology.

Immerse yourself in this story. You may cringe at the suffering, but it will undoubtedly give you reason, motivation, and the passion needed to prevent proliferation of the world's most dangerous weapons.

Taking the Long View in a Time of Great Uncertainty

Preparing for the Future

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

For those of you who attended the INMM Annual Meeting in Atlanta this year, it was obvious that change is in the wind:

- Four new student chapters were officially announced, with our student chapters (twenty-three) now outnumbering our professional chapters (seventeen).[1] This year we had even more significant participation by representatives from our student chapters in our annual Executive Committee meeting on Saturday, July 23. As part of the Institute's strategic effort to provide more useful information for our membership, our chapter and other pertinent organizational partnership details can be found on a web-enabled interactive.
- In addition to an informative and thought-provoking opening plenary panel discussion on "*Connecting Science, Technology, Policy and Culture for Effective Nuclear Materials Management,*"[2] and a well-attended interactive closing plenary on the "*Integrated Cyber/Physical Threat Scenario,*" the Institute also experimented with three interactive "eSessions" with social media links that were designed to engage the session attendees more directly with the speakers. Lessons learned from these efforts will be used to enhance the experience next year — all with a goal of reaching out to the technology-enabled millennials who are growing in number at our meetings.
- Throughout the week at the annual meeting an amazing array of topical papers on nuclear security culture were presented, and new relationships were formed, not the least of which was a re-engagement with the Department of Energy's National Training Center (NTC)[3] as part of a new initiative to identify how the Institute can provide additional value to its membership through the identification of training and education opportunities.
- This year's annual meeting also served as a venue for formalizing the Institute's Memorandum of Understanding (MOU) with the World Institute for Nuclear Security

(WINS), which was officially executed at the Annual Business Meeting on Tuesday night by Roger Howsley, WINS President, and Larry Satkowiak, INMM President (pictured). The new MOU not only formalizes the long-standing cooperation between the two professional organizations, but also strengthens their relationship to carry out common missions that include encouraging and supporting the safe and secure management of nuclear materials through information sharing, and a reciprocity agreement for organizational membership.
- Also, in a special Town Hall session at the Annual Business Meeting, the Institute rolled out its new three-year Strategic Plan.[4] Representing several months of work by the Executive Committee and members of the INMM leadership team, and facilitated by a nationally renowned expert in professional associations,[5] the new plan provides the basis for ensuring the Institute remains relevant to its changing membership in a

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.*

dynamic and often tumultuous world:

Each objective under the three goals is being developed by INMM Headquarters staff in collaboration with Institute leaders, and will be tracked with appropriate metrics and data analysis to ensure that not only the objectives are being met, but also to identify where changes may need to be made to make them more effective. Over the next three years the leadership will report out their efforts and successes in addressing the goals and objectives during the tri-annual Executive Committee meetings.

The new plan reflects a changing strategic environment of growing international engagement, a changing demographic in our membership with a new generation of nuclear stewards, and the increasing importance of policy influencing the outcomes of our technical efforts. Some of the efforts associated with this plan will help to feed the development of a set of long-range scenarios that the Strategic Planning Committee is developing.

Complex Drivers for the Future

Under the Community Relationships Goal of the Institute's Strategic Plan, the first objective is "*Identify emerging global security priorities to inform INMM activities.*" There is no shortage of issues that one might identify which will impact the Institute and its membership. Working with the SPC we have identified an initial list that may be of particular interest to the membership. I have mapped this list into the two "critical uncertainty" categories that were described in an earlier *Journal of Nuclear Materials Management (JNMM)* column this year, as well as an "Other" category:[6]

The Advancement and Control of Nuclear Technology

- DPRK nuclear program
- Joint Comprehensive Plan of Action (JCPOA) and Iranian nuclear program
- Fukushima repercussions and impact on the "nuclear renaissance"
- President Obama's "Prague Plan" implementation, Global Zero and Nuclear-Free Zone initiatives, and Nuclear Security Summit commitments
- Cyber threat
- Global nuclear deterrent modernization programs

Global Nuclear Security Threats

- The growing world-wide threat of terrorism and non-state actors
- Rise of nationalism in Russia and Crimea/Ukrainian conflict
- Territorial claims in East and South China Seas
- Pakistan/India tensions and related global nuclear roles
- Resolution of Syrian conflict and other Middle East issues

Other

- U.S. budget deficit and debt ceiling
- Brexit and implications for the global economic environment
- 2016 U.S. presidential election

Note that, as described in the previous article on the creation of scenario axes, we have identified some additional critical uncertainties that fall outside of the two axes identified. They may contribute to the formation of additional axes to be evaluated that tie to the global economy or geo-political outcomes in the U.S. as well as other countries. They may also simply reflect intervening events that could alter the path to the future in any given scenario construct.

The use of the scenario process, where paths to the future are mapped out, during times of great uncertainty can enhance traditional strategic planning initiatives, often stretching the mindset of management, allowing discussions of otherwise unthinkable future worlds.

The rehearsal of what actions would be needed to survive in those worlds, or alternatively, if possible, the actions needed today to change the future path, can provide the confidence needed by management to be prepared for any eventuality.

We encourage INMM members to suggest additions or modifications to this list that will become research areas for the SPC to inform the organizational activities of the Institute.

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.

Endnotes

1 See http://www.inmm.org/Chapters/6478.htm for a listing of Chapters and a link to each Chapter home page.

2 With Anne Harrington, Deputy Administrator for Defense Nuclear Nonproliferation, National Nuclear Security Administration; Tero Varjoranta, Deputy Director General and Head of the Department of Safeguards, International Atomic Energy Agency; and Rob Floyd, Director General, Australian Safeguards and Nonproliferation Office.

3 See https://ntc.doe.gov/, and in particular their newly launched DOE Training Institute (DTI) at https://dti.doe.gov/

4 See http://www.inmm.org/Member_Homepage.htm, member login required to see more detail.

5 Barnes Association Consultants, John Barnes, President. See http://barnes-consultants.com/about-us/

6 See "Taking the Long View in a Time of Great Uncertainty: Rehearsing Possible Futures," 2016 Volume XLIV, No. 3, pp. 58-61)

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