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INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT
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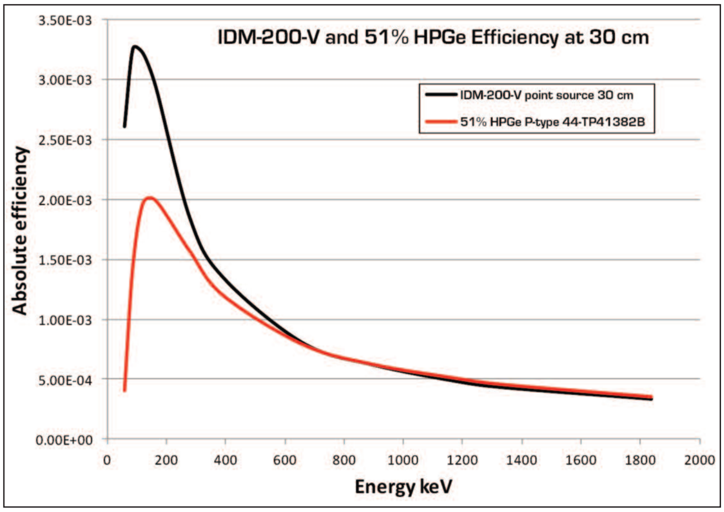

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JNMM Journal of Nuclear Materials Management

Bonus Content: www.inmm.org/fall2013

INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Conferences, Workshops, and Training…

By Ken Sorenson
INMM President

As I write this column, I am in San Francisco attending the 17th International Symposium on the Packaging and Transportation of Radioactive Materials, also known as PATRAM 2013. PATRAM is an international conference that is held every three years, alternating locations in the United States with venues outside the United States. It is the singular international conference focused on packaging, transportation, and storage of radioactive materials. And, INMM has the privilege of hosting and managing the conference when it is in the U.S. INMM Packaging, Transportation, and Disposition Technical Division Chair Steve Bellamy, and his team have done an outstanding job running this conference and representing the INMM.

This year, PATRAM has about 700 registrants and 450 papers. Registrants from twenty-three countries representing industry, regulators, and technical organizations, are engaged in presentations and discussions in advancing the safety and security of this important component of managing nuclear materials. I am very impressed with the vitality and engagement that this community has brought to the conference. It speaks to the sustaining power of this conference over the past fifty-one years.

This brings me to the 54th INMM Annual Meeting held in Palm Desert this past July. Even though PATRAM and INMM conferences are composed of different communities, the adjectives that I used to describe PATRAM 2013 are completely applicable to our annual meeting in Palm Desert. Yes, registrations were down about 200 from a year ago. But, this did not dampen the spirit and engagement of the professionals in attendance. As with PATRAM 2013, I was struck by the positive attitudes and spirits exhibited throughout the week at our annual meeting in Palm Desert. We are going through a difficult period with the U.S. government travel policy for conference attendance, but I remain confident that we will work through this in a positive way that will make us a stronger institute.

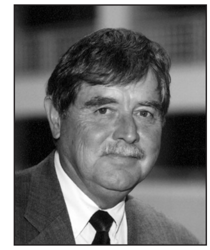
There are other events on the horizon that I would like to highlight as evidence of INMM engagement across the board in areas associated with nuclear materials management. First, the 29th INMM Spent Fuel Seminar is scheduled for January 15-16, 2014, in Crystal City, Virginia near Washington, DC. This workshop continues to grow in importance as questions surrounding the disposition of commercial spent nuclear fuel continue to remain unresolved. We have had preliminary meetings at PATRAM 2013 to develop the agenda for this workshop. Second, INMM is sponsoring the Risk Informed Security Workshop, February 11-12, 2014, in Stone Mountain, Georgia, USA. This workshop is listed as evidence of completion of a U.S. government activity milestone that was identified as an outcome of the Nuclear Security Summit in Seoul, 2012. Originally this workshop was to be held October 15-16, but due to the government shutdown it was rescheduled.

These are just two examples of the horizontal and vertical engagement of the INMM making important contributions to international nuclear materials management. Technical divisions, regional chapters, committees, and individual members collaborate to make INMM relevant and engaged in this vital aspect of nuclear materials management to make the world safer and more secure.

Erratum

In the topical paper, Issues Concerning the Security and Continued Use of Cesium-137 Irradiators, by Mark L. Maiello in the Winter 2011, Volume XXXIX, No. 2 edition of *JNMM*, an incorrect unit was used on page 17 when referring to Class C radioactive waste. Class C waste was implied to be >4600 Curies per gram. The correct value and unit is >44 Curies per cubic meter. At >4600 Curies per cubic meter, the waste is classified as not suitable for near-surface burial. This does not negate the observation discussed in the paper that at the time, disposal of Class C sources of Cs-137 was considered to be very problematic. The author regrets any confusion that may have resulted from the error and his imprecise wording.

A First for *JNMM* and INMM



By Dennis Mangan
INMM Technical Editor

This is an important issue for the *Journal of Nuclear Materials Management.* We have taken a big step forward in the way the *Journal* is delivered to readers. *JNMM* editorial board considered digital publishing at length before recommending this change to the INMM Executive Committee. Our timing was excellent. INMM was facing a tough financial situation, and converting to a digital journal means great savings in printing and mailing costs for the Institute.

This will be an adjustment for many readers, we know. But it is also a great opportunity for *JNMM* to deliver more high-quality content, to link to online resources, and to expand our reach. Learn more about the benefits of our new format.

As in the past fall Issues, this issue focuses on the INMM Annual Meeting held in this past July in Palm Desert, California, USA. This was the first meeting chaired by our new Technical Program Committee Chair, Teressa McKinney. McKinney was highly successful in leading her first annual meeting and provides us an excellent summary article. Her observation, "It takes a village to make the annual meeting a success, so thanks to all of you for doing your part," is definitely an appropriate comment.

In this issue are three J. D. Williams Student Paper Award winning presentations at the Annual Meeting: first and second place papers and the first place poster. The first place paper, Multispectral Active Neutron Interrogation Analysis, was authored by Jason Kewism Dominik Ratz, and Kelly Jordan, University of Florida, Nuclear Engineering, Gainesville, Florida, USA. The second place paper, Spectrally Matched Neutron Detectors Designed Using Computational Adjoint S_n for Plug-in Replacement of ^{3}He was authored by two investigators: Scottie Walker and Glenn Sjoden, Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia, USA. The first place poster paper, Digital Pulse Shape Discrimination with the XIA Pixie-500 and EJ309, was authored by Zachary Bailey and John Mattingly, Department of Nuclear Energy, North Carolina State University, Raleigh, North Carolina, USA. The prizes for the J. D. Williams Student Paper Competition are $1,000 each for the first place paper and first place poster, and $500 for the second place paper. The winning papers are also published in the fall issue of the *JNMM.* The winning papers traditionally have not been peer reviewed. The award winners are determined by the Awards Committee as the best student papers presented at the Annual Meeting. To be eligible, the author must be a graduate or undergraduate student at a university or college and the paper must have been submitted by the June 9 deadline (for presentation in July at the annual meeting). Members of the Awards Committee attend the presentations of all the student contest participants and the awards are based on the written paper as well as the student's presentation of the paper or poster. Beginning with the next annual meeting, the winning papers will be peer reviewed before publication in the *Journal.*

In his President's Message, Ken Sorenson addresses the importance of conferences and workshops in INMM fulfilling its mission of "responsible nuclear material management."

The *JNMM* Roundtable with our two Annual Meeting Plenary Speakers, Anita Friedt and Neile Miller, was excellent and is included in this issue. The speakers were quite interesting and candid in this interview.

James Larrimore, past chair of the INMM International Safeguards Technical Division, and Katherine Bachner of Brookhaven National Laboratory, provide a summary of special session at the annual meeting addressing the topic International Safeguards Challenges. Also, Eric Smith, Alain Lebrun, and Rocco Labella, all of the International Atomic Energy Agency, have a Topical Paper, Potential Roles for Unattended Safeguards Instrumentation at Centrifuge Enrichment Plants. Both of these papers will be of interest to those of you who have an interest in IAEA international safeguards.

Assistant Book Review Editor Mark Maiello provides us an interesting review of the book, *Nuclear Energy—What Everyone Needs to Know,* by Charles D. Ferguson. Maiello speaks highly of this book and applauds it being a good learning book on Nuclear Energy.

In his column, *Taking the Long View in a Time of Great Uncertainty*—Working Towards Solutions, Jack Jekowski, Industry News Editor and chair of the INMM Strategic Planning Committee, gives us some insights of efforts being pursued to reduce the impact of recent government decisions impacting meeting attendance.

In closing, I would like to acknowledge an exceptional and much appreciated Letter to the Editor from Jerry Johnson, the wonderful wife of our departed member and friend Ed Johnson (see page 64).

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

JNMM *Technical Editor Dennis L. Mangan may be reach via email at dennismangan@ comcast.net.*

Report of the 54th INMM Annual Meeting

Teressa McKinney, Chair
Technical Program Committee

I have had the privilege of attending the INMM Annual Meeting since 2000, but until this past year when I took over the role of the Technical Program Committee Chair, I did not realize all the detailed planning that goes into the annual meeting. Anne Czeropski and Jodi Metzger provided expert guidance on every detail from the design of the annual program to online abstract submissions. There are so many deadlines spread throughout the twelve months for each annual meeting that it would be difficult to list them all. I thank all the INMM Headquarters staff at the Sherwood Group—Jodi Metzgar, Anne Czeropski, Lyn Maddox, Kim Santos, Patricia Sullivan, Jake Livsey, and Abra Alscher—for ensuring that everything ran so smoothly.

As in most years, a number of events took place prior to the annual meeting. The Executive Committee (EC) met on Saturday to discuss INMM business. A sampling of the topics discussed by the EC included:

- Ken Sorensen and Larry Satkowiak worked with representatives from the American Nuclear Society to develop a joint letter requesting relief from the Office of Management and Budget (OMB) travel restrictions. Read the letter.
- The EC is encouraging U.S. members to contact their senators and representatives to make them aware of the impacts of the OMB travel and conference restrictions on technical exchanges such as our annual meeting. There is a link on the INMM home page to a sample letter that could be used.
- The Annual Meeting represents the majority of the Institute's income and also a significant portion of the cost. The EC is discussing a variety of cost-cutting measures to reduce the cost of the annual meeting without significantly impacting the value of the meeting.
- Jack Jekowski, chair of the Strategic Planning Committee, developed a list of potential revenue generating ideas that were also discussed at the EC meeting. If you have any ideas regarding additional revenue generation opportunities, please email Jack (jpjekowski@aol.com).
- The EC is also encouraging topical workshops by technical divisions and chapters, in addition to the annual meeting, as another potential source of income.
- The *Journal of Nuclear Materials Management (JNMM)* will be converted to an electronic format [effective this issue]. This has several positive features, including color graphics, reduced cost, easier distribution, etc. I previewed the e-version and think it looks fantastic!
- Mona Dreicer will become the new chair of the Nonproliferation and Arms Control Division. Thank you Joyce Connery for serving as the interim chair.
- Congratulations to Brian Boyer and Joyce Connery, our newly elected EC Members-at-Large. Their two-year terms begin October 1. Thank you to Shirley Johnson and Mona Drecier for serving as Members-at-Large to the Institute for the last two years.

Another Saturday event was the Annual Meeting of the New Brunswick Laboratory Measurement Evaluation Program.

Sunday morning started with an early morning golf tournament with twenty-five golfers participating. Thanks to Sherri Garrett and Obie Amacker for organizing this event. D. L. Whaley and his registration team opened the registration and were available throughout the remainder of the week. The NDA Users Group, organized by Stephen Croft, DA Users Group, organized by Jon Schwantes, and ANSI/INMM 5.1 Analytical Chemistry Laboratory Measurement Control Committee, organized by Melanie May, all held meetings on Sunday, as did all of the technical divisions. The President's Reception was held in the Exhibit Hall on Sunday evening and gave everyone a chance to preview all the exhibits. An INMM New Student Orientation and Student Mixer, organized by Steven Ward, was held on Sunday evening. A Student Career Fair was held on Wednesday evening, providing student participants an opportunity to meet with industry partners and INMM leaders for one-on-one Q&A, and to discuss potential career opportunities.

Monday morning opened with two plenary speakers: Neile L. Miller, Former Acting Administrator, National Nuclear Security Administration, and Anita E. Friedt, Principal Deputy Assistant Secretary for Nuclear and Strategic Policy, Bureau of Arms Control, Verification and Compliance. Both speakers gave overviews of their respective agencies and vision for the future. Another opportunity to discuss issues with our opening plenary speakers occurred during the *JNMM* Roundtable on Tuesday; so make sure you read the article in this issue of the *Journal*.

The technical sessions began after the opening plenary. Although attendance was down (< 600), there were 326 papers presented in 55 sessions, 50 of those were student papers. There remains strong international participation with greater than one-third of the attendees being from outside the United States. The Technical Program Committee worked closely with the Technical Division chairs to pull together the program for the annual meeting. We experienced more withdrawals this year than average; however, the overall impression of the 54th INMM Annual Meeting was excellent.

Tuesday proved to be the longest day for INMM attendees starting with the annual charity run/walk. This year there were thirty-four participants who braved the early morning hour to join for a worthy cause. The technical sessions continued through most of the day while allowing extra time to view the eighteen posters featured in the poster session. Taner Uckan was responsible for organizing the Poster Session and did an admirable job.

Tuesday night, the annual INMM Business Meeting was held and the results of the annual election of officers were announced. The results are Ken Sorenson, President, Larry Satkowiak, Vice President, Chris Pickett, Secretary, Bob Curl, Treasurer, Joyce Connery, Member-At-Large, and Brian Boyer, Member-At-Large.

The business meeting was followed by a reception before the Annual Awards Banquet. Several awards presented during the banquet presentation were:

2013 Edway R. Johnson Meritorious Service Award:

- Glenda Ackerman, Retired, Pacific Northwest National Laboratory
- Brian Boyer, Los Alamos National Laboratory
- Paul Ebel, BE, Inc.
- James Larrimore, Consultant

The recipient of the first INMM Early Career Award was Corey Hinderstein, Nuclear Threat Initiative, a former INMM Member-at-Large.

A Resolutions of Respect was presented to the family of Edway R. Johnson. (See a thank you note from Jerry Johnson, his wife, on page 64.)

Sorenson and Satkowiak also recognized the newest INMM Fellow, Scott Vance.

The outgoing Executive Committee Members-at-Large, Shirley Johnson and Mona Dreicer, were recognized as well.

During the Closing Plenary session on Thursday, INMM President Ken Sorenson and Vice President Larry Satkowiak presented the following student awards:

2013 J. D. Williams Student Paper Awards:

- 1st Place Oral Presentation—Jason Lewis, University of Florida
- 2nd Place Oral Presentation—Scottie Walker, Georgia Institute of Technology
- 1st Place Poster Presentation—Zachary Bailey, North Carolina State University

(Their papers are published in this issue.)

Robert J. Sorenson Scholarship:

- Tasneem Bani-Mustafa, Jordan University of Science & Technology, Jordan

A thought-provoking Closing Plenary was hosted by Vice President Larry Satkowiak in an "Oprah-style" setting allowing all four of the plenary speakers to have a more casual panel discussion on nuclear programs regarding education and training. Panelists included: Catherine Haney, Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission; James Larkin, Director of the Radiation and Health Physics Unit, University of the Witwatersrand; Masao Senzaki, Director, Integrated Support Center for Nuclear Nonproliferation and Nuclear Security, Japan Atomic Energy Agency; and Klaas van der Meer, President, ESARDA, and Head, Society and Policy Support, Environment, Health and Safety, Belgian Nuclear Research Center.

During the week we also had the usual activities such as the daily Speaker's Breakfast featuring Paul Ebel's "Best Practices on Giving a Better Presentation," the *JNMM* Roundtable, organized by Dennis Mangan (read the transcript beginning on page 6), the POTAS Coordinator's Meeting, organized by Ray Diaz, and New Member/New Senior Member reception, organized by Al Garrett and Michelle Romano. There were numerous lunch meetings and additional evening professional meetings scheduled throughout the week.

INMM continues to value the input from attendees regarding the annual meeting through the electronic survey. I encourage you to take the opportunity to let us know your thoughts on ways to improve the annual meeting. Some of the feedback received after this year's meeting included several suggestions on how to reduce cost for the annual meeting.

Our attendees are becoming more aware of the impact that the OMB restrictions are bringing with reduced attendance. Some participants wanted to shorten the meeting and have more parallel sessions, others wanted fewer parallel sessions. There were several recommendations for eliminating the banquet. Some recommendations for eliminating Thursday and, in particular, the closing plenary session, perhaps add plenary speakers up front. Many requests were made for free wifi in the conference area and eliminating the pocket schedule. Some respondents wanted to eliminate the speakers' breakfasts, or the President's Reception; some suggested leaving the posters up longer. There were many others and we welcome your suggestions, as these are taken into consideration for upcoming meetings. It takes a village to make the annual meeting a success, so thanks to all of you for doing your part.

Our 55th Annual Meeting will take place in Atlanta, Georgia USA, at the Atlanta Marriott Marquis, July 20-24, 2014, so mark your calendar. I look forward to seeing you there!

JNMM Roundtable

July 15, 2013

Opening Plenary Speakers

Neile L. Miller
Former Acting Administrator, National Nuclear Security Administration

Anita Friedt
Principal Deputy Assistant Secretary for Nuclear and Strategic Policy
Bureau of Arms Control, Verification and Compliance

Roundtable Attendees

Susan Burk
Special Representative of the President of the United States for Nuclear Nonproliferation

Glenn Abramczyk
JNMM Associate Editor

Obie Amacker
Chair, Fellows Committee

Brian Boyer
Chair, INMM Communications Committee

Joyce L. Connery
INMM Acting Nonproliferation and Arms Control Technical Division Chair

Robert Curl
INMM Treasurer

Felicia Durán
JNMM Associate Editor

Leslie G. Fishbone
JNMM Associate Editor

Olli Heinonen
IAEA, Former Deputy Director General

Jack Jekowski, *Chair*
INMM Strategic Planning Committee
JNMM Industry News Editor

Markku Koskelo
JNMM Assistant Technical Editor

Dennis Mangan
JNMM Technical Editor

Teressa McKinney
INMM Technical Program Committee Chair

Chris Pickett
INMM Secretary

Bernd Richter
JNMM Associate Editor

Larry Satkowiak
INMM Vice President

Ken Sorenson
INMM President

Gotthard Stein
JNMM Associate Editor

Patricia Sullivan
JNMM Managing Editor

Scott Vance
INMM Immediate Past President

Dennis Mangan: Let's go ahead and get started. The first question I'm going to ask is of Neile Miller. In your plenary speech you mentioned that when you got familiar with the NNSA (National Nuclear Security Administration), it was primarily weapons, yet NNSA when formed it was NA-10, which is weapons, and NA-20, which I consider to be everything else that has to do with nuclear. Could you explain, was it like the weapons program was an 800-pound gorilla and the rest of it was small? What did you mean by that comment?

Neile Miller: Thanks for giving me a chance to clarify that. Here's what I meant: Of course when NNSA was created it was created with more than just the weapons mission. But in fact the way the place operated for pretty much the first ten years at least, I would say, was as though it were still the '80s and '90s. It was all about defense programs and then there was this other stuff stuck on the back of it, which, by the way, included naval reactors, which is a pretty big thing to be stuck on the back, if you think about it.

But the 800-pound gorilla was the weapons program and that epitomized all of the infrastructure, the sites were run through defense programs, through NA-10. So if you think about it, and I sat down and really thought about it, it meant there was almost a shadow organization in the agency. Every site has lawyers and public affairs people and all sorts of things going on, right? So did the NNSA at large. They didn't report to each other or even through each other.

You had what I refer to as this half-evolved system, even with respect to what at that point were called site offices, which previously had been called operations offices. Yes, we had changed the name. We knew what we weren't anymore. We were no longer quite the same 800-pound gorilla that we had been in the Cold War. They weren't ops offices; they were something called site offices, and other than the offices being smaller, no one really knew what it meant.

At some point maybe six months after I started, we brought in as the number two in NA-10 a man who had been a colleague of mine at OMB (Office of Management and Budget) and in fact had preceded me at OMB as the examiner for NNSA. We brought him in as the principle deputy. So he was coming in with knowledge but also with an outside view and he said, "You know, all these people at the sites who claim to be part of NA-10, we don't know who any of these people are. So we're not doing weapons at those offices anymore." The connections were all broken, but it was still organized as though that's how it all worked.

Then again, as I mentioned this morning, at no one site were we only doing weapons anymore. But no one ever talked about that. If you wanted something done from NA-20 and in this case a good example is, what if a facility, many of which were created to serve the weapons program and have now become essential to the work that people in this organization do among others, was slated for shutdown? Or reduced funding because the weapons program frankly doesn't use it or need it there because it's not a priority?

This all then had to be funneled through NA-10 to try to get them to support it. I didn't see this as a way to run what was meant to be the NNSA.

Jack Jekowski: This is actually for both Neile and Anita. Neile, you mentioned this morning the burden that these conference restrictions have created at the highest of levels in the NNSA, and some things I learned you're doing that I wasn't aware of. We've heard a rising voice in the scientific and technical community about the potential long-term strategic impact these restrictions might have on the benefit of the nation. I think Dr. Charles Shank in congressional testimony made an analogy to the restrictions as the dark days of the Soviet empire and the restrictions that were placed on their scientists in terms of participating in conferences. What is it that we can do better or do differently with respect to the INMM and its role in bringing together an international community relative to things nuclear to make sure that we're well ensconced in people's mindsets when they look at these restrictions and work with us to, for example, get the waiver that we were able to finally get for this conference and to facilitate all those other workshops and meetings that we have throughout the year? Are there other things that we can be doing on both of your agency's behalves?

Anita Friedt: First of all, invite me again, I will certainly go. I really had no idea how valuable and how much this organization really does in terms and the potential for cultivating new ideas on issues such as verification of strategic arms control, but also on the whole range of nonproliferation issues. It's helpful to keep inviting people like me and others who have not come here yet so they have greater exposure to the value of this meeting. I certainly can support this conference and I certainly will as far as the U.S. Department of State is concerned although I think you need U.S. Department of Energy approval.

Then the other thing is I think we need to continue to try to get the word out to the U.S. Congress, to the Hill in various formats. I don't know if there are other opportunities where you have to speak to the Hill. That would be helpful. I think persistence in making sure the word gets out is very important.

Miller: I'm not usually accused of being Pollyanna but I do think that it's actually going to be better next year – because we've been through this now. People spent a lot of time scrambling to figure out how we justify this. It's almost second nature to think that you shouldn't have to justify it. It's a scientific meeting. What's to justify? Everybody understands, don't they? Well, it turns out they don't.

Particularly when you have questions being asked about who are all of these attendees? What are they doing? Why does it cost so much? You can't believe the questions that come up. Why are you holding it at a resort? You're holding it at a desert resort in July; it doesn't take a lot of brains to figure out that it's actually far less expensive to do this. I think all of this has now been reported for this conference and from all the others. So I don't actually think it's going to be that bad a year from now. It's going to become another way we do business. Unfortunately, and I think this is the part for me personally that I find so difficult to justify, it's become another piece of the bureaucracy, which everybody spends their time railing about. And yet here we are. We're all forced to just generate more junk and spend taxpayer dollars on things that are producing no value.

As far as what this organization or any other organization could do to help, apart from what I sort of flippantly say, but actually really mean, write your congressmen. I do think the organizations should be prepared to talk about in a very straightforward way what things cost and who the attendees are, what the value of it is. Be prepared to answer questions like, how does this change from year to year and what have you seen over time with it. We had to provide that, we had to actually provide what the benefit is. We were able to do that certainly, but something concrete is useful and I think that's something the organization itself is best placed to do.

Bernd Richter: Coming from a non-weapon state, I'm kind of exotic in this discussion. I was very much interested in both of your presentations, but I heard neither of you mention the International Atomic Energy Agency (IAEA) in your presentations. Why is this?

Freidt: I thought I had a reference; in fact a few references.

Richter: You expanded on nonproliferation and disarmament. IAEA plays a major role in nonproliferation. But I didn't hear you mention the IAEA.

Miller: I'll let Anita speak for herself. I actually read her speech ahead of time. I think she mentioned it several times because she talked about a number of meetings that have been held under the aegis of the IAEA. In fact it's hard to talk about this without mentioning that. So I know for a fact she did. But I would say that both of us were here to give our perspectives as American government officials and we could tell you what everybody here probably knows better than we do about what the IAEA is doing because so many people here are either participants there, like yourself, or have participated in the past. What perhaps they don't see as much of is how things are working at the level we've been serving in the U.S. government. I think that's why we focused on that. I don't think it was meant to be an editorial statement about the role of the IAEA.

Friedt: I fully agree. I remember mentioning it several times. Perhaps I spoke too fast, but absolutely the IAEA is certainly a very important, critical part of this.

Gotthard Stein: I liked very much your remark on innovations and research in the field of nonproliferation and disarmament. In this context I would like to point to the state-level safeguards concept of the IAEA, which is just in the phase of development and implementation. We heard a lot of presentations about this new safeguards approach here at this conference.

My question and also my proposal goes in the direction whether this new verification philosophy, which is risk- and information-driven, might also be applicable for other relevant disarmament fields, such as for a future FMCT (Fissile Material Cutoff Treaty) and whether it is reasonable to put further research efforts into this field to elaborate the potential of the state-level concept?

My second remark and question relates to the structure of future research and cooperation in the disarmament field and I would like to mention as a model the joint UK and Norwegian initiative in the field of nuclear weapons dismantlement. VERTIC (Verification Research, Training and Information Center) as an NGO (non-governmental organization) was also engaged in this project. It is my strong belief that the INMM constitutes an excellent platform to talk and start such cooperation.

As another example of a successful cooperation I would like to refer to the importance of joint workshops between INMM and ESARDA in the field of safeguards where we offer experts and scientists from different regions in the globe, from weapon and non-nuclear weapon states to gather together and start joint projects.

Would you both support these efforts and especially here in the United States the important role of the INMM?

Friedt: I completely agree with you. And in fact (U.S. Ambassador) Susan Burk and I were at this Trilateral Conference last week in which we started talking off line but also during the conference about this. And Susan's presentation today addressed some of these issues. I came into this job before seeing the Norwegian-UK presentation, but everybody talks about it. I will have to look at it. But it's time we do something. We are actively looking at it. I started something last week at the State Department, an effort to look at this and we will certainly be looking at what we can do.

We'll certainly take a look. First we need to have the kernel take shape and mold the idea within the U.S. government, which is often a bigger challenge. I very much appreciate your recommendation. I totally agree with it.

With respect to innovative technology, my Under Secretary, Rose Gottemoeller, I think many of you have heard her speak quite eloquently on innovation and technology. This is something that actually goes back many years. But I think there are countless areas where we can take advantage of this technology. Yes, we need innovative and perhaps complex technologies for some verification, but simple, why not? There are all sorts of things, if someone can see something on Twitter or report something via a cell phone, that is interesting and a very simple way to look at this. Certainly, absolutely take advantage of that.

Miller: I think it's not only at this point interesting, it's probably essential because there isn't going to be a lot of extra money for the things that have to get done. And to the extent that people are constantly looking at ways to not fund what has to get funded, the innovative use of the money we have is kind of essential at this point or we're not going to get any of the work done. And some of that will require us figuring out what not to do anymore so that we free up the funds and plow it into the stuff that we have to get done and try to do it in a way that is more imaginative. And I think you're right about the conferences; there's no question that the best work is coming out of the collaboration. No question about it.

Chris Pickett: All treaties and agreements require effective verification tools. The acceptance of these tools many times is better when they're jointly developed by both the monitored side and the side doing the monitoring. In the past we had agreements like the Warhead Safety and Security Exchange Agreement (WSSX) that provided a means for the joint development and testing of verification tools, but we seemed to have lost our political motivation for implementing these types of agreements. What would you see that needs to be changed to implement more agreements of this type?

Friedt: From my part, certainly the WSSX program was controversial, but it was also very important in terms of, as you point out, the joint development. And I agree that we do need to have joint development for future arms control treaties. I think the best thing that would help is if our Russian colleagues, for example, would actually become more interested in moving more closely toward taking the next steps. That could certainly help to build support.

I think we have several challenges. I know when I was at the National Security Council I started to try to work on new verification technologies along with the interagency and such and it seemed there's not enough momentum in terms of moving forward toward the real goal. I think that's a major challenge.

Of course, funding is certainly a challenge. As Neile pointed out here, that's why some of the more innovative, less expensive verification measures are certainly worth considering and need to be considered, but that may not be a substitute for some of the other technology that we need especially in some of the more sensitive areas.

Leslie Fishbone: Anita, you mentioned the institutionalization of P5 meetings now dealing with a lot of arms control issues. Typically we at the laboratories have gotten our research agenda from the U.S. Department of Energy and NNSA and we supply our ideas up through those channels. I'm wondering, if there is some alternative way of hearing about research needs and support of the P5 work or if there is another way we can channel our ideas that would be helpful.

Friedt: That's a very good question. We're always looking for new ideas. I'm afraid we are guilty of not reaching out certainly to all of the labs. As you point out we certainly work very closely with our DOE colleagues. There are a lot of good ideas. But maybe we should be more open about reaching out personally, not just through DOE but also through State (Department) channels.

Fishbone: If the DOE and NNSA channels are sufficient that's fine, but I just don't know.

Friedt: The point is that maybe we don't do a good enough job sometimes of communicating what we are actually talking about or doing.

There's a big question, I know, certainly from many countries about what is more transparency and on what the P5 are actually doing. We want to see more and we are looking at that. So maybe greater transparency both within our government and with others is something we need to look at.

Ken Sorenson: As president of the INMM I have my own special ulcer right here; it's called travel restrictions. I'd like to go back to that just a moment and Neile you mentioned some of the things we could do at the Institute to help that.

I wonder if it would be useful at all to have an advocacy statement maybe from the U.S. Department of State come across the DOE upper levels to indicate why it's important from the State Department perspective. I think the ANS (American Nuclear Society) for example, people know and understand who they are, and they understand the importance. Sometimes I think because the INMM is a relatively small institute and some people just don't understand what it is we do and the impact we have and the programs and such. I just wonder if collaboration of advocacy with different agencies within the government might help the argument.

Miller: I don't want to downplay the struggle we've had with this year. The first time in our lives we've had to actually go to the mat to get these conferences to happen. But honestly I don't think there is anything more or different that we could have or would have done with respect to advocating it. I think the point was we never had to do it before. So what is it you have to do? And in the absence of anything, we had to do something and that something we hadn't done before.

I think the people who were charged with defending it, which is to say mostly Joyce (Connery) and me at a certain point, were fine and were able to make the effective case because we knew what we were talking about and the people who were listening to us—in this case the Deputy Secretary and the Secretary—got it.

I don't know that it was, "gosh I wish I had the State Department write a statement about it." First of all, sometimes that kind of thing could backfire. Because I could imagine a Secretary of Energy saying "well, that's great, let them put the money in," which you certainly would not want to see happen because they have far less money for this type of thing than DOE does because of the work that it does. So I think the onus frankly should be on the Department of Energy for that. But I'm not so concerned about that. I mentioned and I kind of alluded to it earlier in the talk this morning, I'm not so sure that institutions that are sending people here aren't sometimes using the bugaboo of the Department of Energy, that vast bureaucracy, as the reason why it's more difficult or it's bad or we don't want all these people going. They're having to make choices themselves because funding overall is down. Whether it's our funding for a conference or their funding for various programs they want to conduct. But it's kind of an easy thing to push it all under this.

I always say the problem with this is the burdensome aspect of it and the fact that it has taken a long time. I would be really surprised if a year from now, assuming these restrictions are still in place, you had quite the same heart failure scenarios you had this year of "will they or won't they." I still think you're going to have to go through the hoops, but I don't think it's going to be kind of a last minute, eleventh hour sort of decision. I hope.

Sorenson: So my ulcer may improve.

Miller: You should see a doctor because it's actually caused by bacteria. (laughter)

Markku Koskelo: First of all, both of your answers around this table and the talks this morning were very thought-provoking and I could ask any number of questions. But as one of the very few individuals here representing a non-lab entity, I'm going to ask a very specific question. First of all, we have to remember that the INMM is not just labs. There are a tremendous number of people who choose to be members of this organization without being members of any of the laboratories. My company happens to be one of them. And there are a number of other companies who see a lot of value in that.

Given that premise and my perspective on things and the lack of funds within the DOE and the comment you made about a gazillion small projects as opposed to the big weapons mission, what's the role of privatization and private industry that you see going forward? We've gone through the cycle a couple of times in the past, especially in the '90s when a lot of the waste assay business was privatized. Is it time to consider privatizing some of the other functions that are currently in the DOE, very carefully, because there are classification issues and other such things? But is it time to consider some things to be privatized?

Miller: As I mentioned this morning I was most closely associated with DOE in 1987 when I was first time at the Office of Management and Budget and that was the height of the Reagan administration and one of their favorite terms was privatization. I'm certainly happy to tell you I didn't share all of the politics of that administration; I was a clear civil servant but working at the White House.

But the privatization approach was very attractive (or cost-sharing as it often manifested), was very interesting and I thought justifiable for some things. Not for others, but for some things. But this has kind of waxed and waned over time. I personally think the private sector has a significant role to play but I think that public and private partnership has to be negotiated by people who really understand what they're getting involved in on both sides.

The federal government I think in some cases is the correct entity and the only correct entity to run certain things. I also think there are plenty of things the federal government is doing that it doesn't have to be doing, or at least it doesn't have to be doing on its own. In those years that I worked in the beginning at OMB and my portfolio was radioactive waste management, there were a number of projects that were cost shared and the private sector did a terrific job in carrying them through. I think some of the rules were well laid out and the understanding of whose responsibilities was whose was well laid out. When it was, that's when it worked well. If I look at the development of DOE's environmental management program, which is what my portfolio became while I was there, the record is mixed—very mixed. To a large extent that is the inexperience I think often of federal officials in working together with the private sector as to what is required for the private sector to be able to do its job for the government.

I think it has a strong role to play. And in this area, to the point you made about classified actions and materials, there's certainly a lot of precedent for the private sector to be involved in classified activities. That, in and of itself, should not necessarily be a barrier except in some really extreme situations. That doesn't concern me as much. For example, DOE will sign a contract with an organization or a business and then never manage that contract. No sense of what acquisition policy actually means. This has just not been the DOE way and why not? Well, there are enough people in this room that know that the whole place has been based on M&O (management and operation) contracting where you sign and that's it. The rest of it is delivered by the contractor.

The kind of thing you're talking about requires actual management of the contract, if it's a contract between the government and a business to get something done. If you're talking about the government maybe divesting itself of certain activities and letting that be done by the private sector, outsourcing is that what we called it?

Koskelo: I'm not advocating one or the other.

Miller: I know you're not; I was just trying to reference what you were. So regarding outsourcing in the last Bush administration, there was a period of time when they were looking to outsource, they called it, certain functions and trying to determine what was an inherently governmental function and what was not. This got mixed results. But I don't think the results again necessarily say this is not something that needs to be considered. I'm sort of choosing my words carefully here. I've got a project in mind that for years I thought this is perfect for a public-private partnership. It hasn't happened yet, but it might. But expectations on all sides have to be managed.

Joyce Connery: My question is mostly for Neile. In your remarks you talked very eloquently about kind of advocating for some of the weapons programs in terms of human capital and actual physical capital and how that would have a detrimental effect on the operations activities at those labs who are involved in it. I was wondering if you could comment on the fact that now that NNSA is a semiautonomous agency separated from the Department of Energy, how NNSA is looking at things like shutdown of San Onofre, Crystal River, Suwanee and the effect of the deterioration of the nuclear power sector and how that's going to have an effect on our national security from the point of view of human capital and physical capital resources that have synergy.

Miller: I don't think anybody, especially those of us who have spent our careers around nuclear things, and I've gone back and forth between the commercial side and the security side, I don't think anybody can look at the situation today and not be deeply concerned. I think there has been somewhat of a resurgence in nuclear engineering programs around the country. At least there was up until Fukushima maybe, I have no data to know whether that had the effect that's it had at least on people wanting to build something. But I think it's hard to look at the situation and not be concerned. So I have to say I'm struck by you two gentlemen coming here from Germany and the fact that you're looking at a country that had to take the word nuclear out of the titles of their research facilities.

We haven't gotten there. In fact I think we've avoided that from a political standpoint. But of course the reality is the funding and everything else. If you're in school, you want to go into something you can have a job at. So what are you going to do about that? It's certainly has to be troubling from a nuclear safety perspective and yet people around the world as we know, want nothing more than to learn from the U.S. regulatory regime, that's without question. The Chinese are all over us to learn from the regulatory regime. Because we have the knowledge.

But I think it's very troubling and this is the one thing that has made me crazy, and I mentioned this yesterday in that session you ran yesterday, really made me crazy from both a White House and Congressional perspective that the shortsightedness to understand what needs to get government funding to bring that generation along. It's terrible. The only thing I keep wondering is why there isn't more of a hue and cry from the nuclear industry. From this community it's all kind of there, but it really needs to come from people whose future bottom line is going to depend on this.

Glenn Abramczyk: I started at the Savannah River Site back when Savannah River was a plant run by DuPont and everything inside the fence was DuPont or DOE. Now there are so many contractors it's hard to tell without a scorecard who works for whom. But part of this is the manifestation of, as you've talked before, NNSA was weapons and now weapons are no longer the 800-pound gorilla in the room anymore. It appears if all the national labs are kind of playing nuclear musical chairs. As the available money keeps going down, they're circling and trying to find things that they do and then elbowing somebody out when the music stops. Except for waste, if anyone will take waste, they're happy to send it to him.

The other constant is the time keeps going on and so the workforce keeps getting older. Things like these conferences, the sequestration and the budget cuts. We've had a number of young engineers come and go because they don't want to stay around in this environment. My son being one; he only lasted eighteen months and then went off into industry.

Has somebody put together a unified vision of where NNSA is going in the next ten or fifteen years? H Canyon is getting older. If we want to process nuclear materials through it for disposition, plans need to be made for it's going away.

Miller: No one has put together a plan for the next ten to fifteen years. And now I can get to speak as a former official, since I have resigned my appointment. I absolutely think that you just put your finger on something important. By the way, I have a hard hat with my name on it that says Savannah River DuPont. I got it in 1987, and in 1988 as you know, DuPont said after forty-two years "we're out of here." So I kept the hat. It's been interesting to pull out every now and then. It's sort of a cautionary tale of what could happen.

I think this kind of gets back, Denny, to your opening question about what I said this morning about it all being weighted on weapons. Actually a lot of what drove me for the last three years was to fix that, to remake that. Because everywhere around me were people doing very vital and exciting work that has a strong future to it.

You said NA-20. In fact there's a NA-40 and NA-80 in NNSA now, all doing related work. The people leading those areas have recognized that, well we wound up with these different organizations because over the last twelve or fourteen years of NNSA's existence, as time has gone by and this area has taken off, we saw a need for response to possible radioactive emergency. We saw a need for a stronger counterterrorism group. So these groups came up. But, in fact, the whole thing is due for a rethink. Not only in that area which covers all of those things and now has just overlapping programs, which in any time you wouldn't want to do, but especially in a tight budget time you want to rethink that. So they are, in fact, undertaking a major rethink of the planning for the programs in those areas going out. And I hope they get the support they need to do that rethink.

It's hard, by the way. There's a whole constituency of people, some very well-intentioned, who are scared to death anytime you talk change. To your point and about the weapons program and everything else, I felt it was very important to finally go forward with NNSA as an organization that does nuclear security work, not just nuclear weapons, not just nonproliferation, and by the way, you all should meet each other.

One of the things I found interesting when I was at OMB, I had the whole NNSA portfolio and I realized at a certain point that most of the people who would come to my office from NA-10 had never met the people in NA-20. And the reason this became crazy to me was because often people in one part of NNSA were dealing with problems that someone else in another part of NNSA had already faced and dealt with in a really good way and there was nothing connecting it.

One of the things I did shortly after the START Treaty finally passed, because that consumed my first three months, was to start throwing weekly lunches of second line managers from across NNSA. Guess what? They had a lot to talk about. They just didn't know each other. Isn't that crazy? But that's how it works in the government. Nobody is running that stuff. If you don't do it, it doesn't happen.

Mangan: I hate to say it but sometimes in the lab that same atmosphere exists.

Miller: No, no, no, don't blow my fantasy of the labs. It's all better at the labs, just ask a fed.

I think that this has become the same thing with the weapons program. The integration of programming and planning in NNSA has been launched. Actually an office of programming and planning has been set up by the program plans and analysis, something like this. Along the lines of how the DOD (U.S. Department of Defense) actually thinks through five years, to your point. It actually thinks through and programs and plans their money five, ten years at a time.

In particular in NNSA though, this is such an interesting problem because you're looking five, ten, fifteen years out. So I think some of you are aware we had, and some day may even get awarded, a contract to jointly run the Pantex and Y-12 facilities. Really, you would have thought we were killing small children the way some people reacted to the idea that we would do those differently.

I do believe that will all get resolved and it will go forward and I think it changes significantly the idea of how you can conceive of all of this. I think it needs to be done for the whole place because you have to start thinking and planning. Your point about H Canyon is very well taken. By the way, there are people that can't get off the dime who think H Canyon is going to be used for reprocessing; they don't want any money going to it because they think it's going to be used for reprocessing. Sometimes we're all our own worst enemies.

Pickett: Joyce and Glenn asked some of the context of my question so I'll rephrase it. One of my foreign colleagues asked me about the perception that this administration has put forth major nonproliferation objectives and goals such as the Path to Zero. However, when we put forth a budget, the weapons refurbishment programs seem to have about five times the money allocated versus our nonproliferation programs. For us to kind of put our money where our mouths are, do you see a path forward to get these budgets more in balance?

Miller: No, I don't. And the reason I don't is it's not five times although it feels like five times. But it is significant.

I don't see it becoming an equal thing any time soon for a couple of reasons, some of which are sort of budget, if you'll forgive me for a minute. In the proposal for the budget that's currently under consideration and will, of course, not get passed by Congress, the proposal has the funding for the site, the infrastructure itself, actually not part of defense programs for the first time. If we ever get a budget passed, maybe that will go through. And you will then see the weapons budget itself look smaller than it has. But it all comes out of the same appropriations account, which is a different account than the nonproliferation stuff. As a result, if you only look at those numbers, it will continue to look like it's much bigger. Because the infrastructure has to get funded and it's expensive.

By the way, that was the other thing that we did to change that 800-pound gorilla problem. We took infrastructure and operations out of defense program and had it stand up as the fulcrum by which the entire place has to manage. And it is really.

But the other thing is if nonproliferation programs, and here I will actually put it together with the counterterrorism and the emergency nuclear incident response, I think we formally call it, program. If all of that had as much money as the weapons program, what would it be spent it on?

I think that the weapons program does, particularly the life extension programs are labor intensive and these other things are not actually as labor intensive. But the difference is with a small amount of money in those programs you can make a huge difference. It isn't really a question of can't we spend the same amount of money on it. It's why aren't we spending the little bits that will make a difference in some of these places.

Pickett: Especially the support for the human capital development that the previous question addressed.

Miller: All I can tell you right now is, first of all there's a huge disconnect that has been going on now for a number of years and I don't see any soon end to it. A huge disconnect exists between budgets that in fact are developed from plans and what actually gets appropriated, which is completely disconnected from that, if it gets appropriated. If you're on a continuing resolution it doesn't matter what you plan. Your plans are irrelevant at that point. And that's where we really are actually. And we have been for a number of years now.

I went into DOE this time in 2007. As three years as the budget director, we were appropriated one of the three years and I think once since then. So in six years, two actual budgets. Think about it. You guys are all working off this money, you know what I mean.

But I will also say that many of the other objectives and goals that this organization, or at least a lot of members of this organization, strongly support to-wit: the New START Treaty. The dismantlement of the stockpile, things like that. We only got the New START Treaty through the Senate in the end by signing in blood that we were going to take care of the stockpile and the infrastructure, not because we said we are definitely going to fund more of that human capital stuff on the other side. By the way the Congress itself, in the end, as you know, doesn't continue to support the money; and the Budget Control Act like everything else I talked about this morning put the lie to that.

When you want to actually get something done like this you have to work with what you have. I think that just gets back to what some people said earlier about the absolute essential part of finding innovative ways to get the work done, whether it's cooperatively with the private sector or with other countries and in particular coming up with technological advances that allow us to get it done differently that's less capital intensive.

Susan Burk: This issue of the 800-pound gorilla and this is an interesting discussion. I think the issue for people and this is really for State and DOE; For the international community and some domestic constituencies what they see is this 800-pound gorilla and they don't see the rest of it. I think there is more that could be done, but are there resources or an appetite for doing more with DOE? Maybe working with states to get the word out on what in fact these labs are doing because when you go into these international venues, it's like you're caught in a time warp, back to the future and it's 1985 again. That's where the transparency information and that sort of thing are so important because as you say it a hundred times eventually someone will get it. I'm just wondering with all of this whether there's any kind of office at DOE or some resources that are available to manage the public face of this, get the word out about what is being done and not being done because the view outside I think is that it's weapons, weapons, weapons. And of course when you see with the debates in the Congress, it's not unrealistic to think they would reach that conclusion. How can that narrative be countered?

Miller: We actually produce press releases and give talks all the time. That removal of HEU (highly enriched uranium) from Vietnam that I mentioned this morning, they put out all sorts of stuff on that. Who picks it up? Isn't it much more interesting to have story after story after story about a nun who didn't get to the weapons at Y-12? I'm just telling you what I see. Nuclear weapons are so damn sexy and everybody wants to talk about that.

Here again I'll feel very liberated about this. In the so-called non-pro community what we face, to get to your point about funding for this program, here are your options, you go to fund everything, you have limited dollars, a lot of things to do. Your limits are worse than you can imagine. Got to get some things done because you've got to keep support on a lot of places plus you've got actual imperatives and an aging stockpile and an aging infrastructure. So you put forward a budget proposal that says this big huge project called MOX is sucking the life out of us. Maybe we ought to rethink how we do this. And what happened? We have been excoriated all over the place.

The non-pro community, I think, has tried it frankly between thinking well, it's about time and others saying what do you mean you're walking away from the project? It's like any time when we talk about being discreet or do this and that. There is no model, obviously. But as soon as you think you've got something good to show, you're fighting a lot of beef.

When I was with my colleagues briefing the House Arms Services Committee a few weeks ago on the employment strategy for the change in the nuclear approach, it was vicious on a lot of sides with people looking to either make the point of "why are you spending any money on weapons?" and people on the other side of that were saying, "What do you mean you're not spending more money on nuclear weapons? How can you even think about getting rid of even one of them?"

It's so interesting. It's a discussion that the general public doesn't get involved in at all. What I said this morning, does anybody even really know that this is a huge effort? I don't know the answer to what you're saying.

Friedt: Listening to Neile and she's made very good points. I have to say in my career, certainly in the last four or five years, I can't think of a time that we've worked more closely together. Certainly I have with the Department of Energy. In certain other administrations it was an out and out combat. But we really do work very closely together. For example on the B61 modernization, I went to several conferences and discussions in Russia where the Russians really grilled me; the question is really more than just life extensions. State immediately went to DOE, we worked closely together on points to clarify the USG position.

I can think of time after time that we worked very closely together and very collaboratively. Comprehensive Test Ban Treaty (CTBT) is another issue, the whole technical of the CTBT Organization (CTBTO) and making sure that we made progress toward the upcoming exercise in 2014. We work very closely together. As Neile pointed out, this whole employment strategy, I've really seen it. I thought it was a wonderful opportunity to discuss it yesterday if we really had each other's back and explained it. But if you look at the reaction on the Hill, there was no good that could come out of it.

Miller: I just want to add one thing related to your question. Because our world was kind of a world created on the fly, which is to say we invented it as we went along, the discipline required to bring a project in at a reasonable cost is not something that is really engraved on the soul of the people who work on weapons projects. That's understandable in many respects. I've said this to people a hundred times over the last three years: for the duration of the Cold War, the complex or the enterprise produced what needed to be produced when it needed to be produced. As I said it invented things as it went along.

In the context of defense spending, overall it did it for a drop in the bucket. The nuclear defense was nothing compared to what we've spent even certainly at the height of the Cold War at the DOD. But the Cold War ended quite a long time ago and what this is often about nowadays is not inventing nuclear science, it's about managing projects in a way that's somewhat mundane but it's got to be done. It's not anything that the weapons business is used to doing.

I wouldn't sit here and argue to you do we need every last dollar that we're claiming we need for the B61 for example? Maybe. That maybe if we ran it differently, and maybe eventually we'll all decide that even though we right now absolutely believe B61 refurbishment is critical to U.S. defense and to defense policy, we may get somewhere else if that proves to be too expensive. For me, and that might be my jaundiced view, I think that's where actually the action is right now, trying to do that better. And that will free up money.

Abramczyk: Have we discussed what's going on at our treaty partners, how well they've fared in meeting their commitments and goals?

Friedt: Ah, I was waiting for that. It's one of the first questions I get on the Hill. It's mixed. You're referring to Russia, I take it, first and foremost. We have some treaty partners, Iran and NPT, that needless to say is a complete disaster. But Russia, I would say, it is a mixed record. The State Department issues an annual compliance report that was issued on July 9 and it's now on the website, if you'd like to take a look at it.

It says that the U.S. has complied with all of our treaty obligations. Russia, the Conventional Forces in Europe Treaty, obviously not complying with it. There are some problems with the Open Skies Treaties. There are problems with a number of treaties as well. On the other hand, they're complying with the New START Treaty, no problem there. We have issues but it's a bilateral treaty so we have implementation commissions where we meet regularly as mandated by the treaty but it's also very good because there are things that come up. Nothing is ever perfect. So when we have questions about how we are implementing the treaty, it gives us an opportunity to discuss it. And I think we do that so well.

So is it perfect? No. Is it in our national security interest to continue to seek treaties with Russia? I think absolutely, without a question.

Fishbone: You mentioned the CTBT Organization. It's always perplexed me that in the absence of a concluded treaty there's still this organization in Vienna that apparently functions quite well technically and provides the information that the world wants on this issue. Can you explain this apparent contradiction of no treaty but a very well-functioning organization?

Friedt: It's a very good question; it's an anomaly to be sure. When I started work in the Arms Control Bureau last year, one of the first things I had to sign in my capacity was a huge bill for the CTBTO and I said, "Why am I signing away all this money? We haven't ratified this treaty." Well, lo and behold, I quickly learned that the U.S. is largest contributor to the CTBTO Prepcom. The U.S. paid its contributions even during the previous administration, which, as you probably all know, adamantly opposed ratification of the treaty. The previous administration recognized the importance of building out the monitoring regime. It's now up to 85 complete and the Organization is still bringing more monitoring stations online; China just came back online.

And of course people in Congress also are surprised sometimes when they hear, but when you ask them does the United States need to monitor nuclear explosions? They say, of course, without question. Do we have our own resources to monitor nuclear testing? Well, yes, we do but isn't it better to have an international regime where there are sites around the world that can monitor and you have an international organization that paid for this? Absolutely. Cost-savings, there's the whole working together with bringing other countries into the fold. It is an anomaly but it's a fortunate one. It demonstrates once again why it is so important and why certainly the United States and the other Annex II countries that need to ratify the treaty for it to actually come into full force. Unfortunately two of the Annex II countries are very troublesome, our North Korea and Iranian partners. But nonetheless it is important and, as I mentioned this morning, the United States certainly has a political challenge ratifying CTBT, but that doesn't mean that other Annex II countries, the countries that need to, the ones other than DPRK and Iran, need to move forward. China is one of them. It is important and it is an anomaly and it's a very good one.

Mangan: It's time to close. Thank you ladies for coming and being so straight-forward with regard to your answers. And the rest of you, thanks for asking questions. Thank you again. You did a nice job on the plenary and you did a nice job here.

International Safeguards Challenges

International Safeguards/Nonproliferation and Arms Control Session at the 54th INMM Annual Meeting, July 2013

James Larrimore, INMM International Safeguards Technical Division Chair Emeritus, and
Katherine Bachner, Brookhaven National Laboratory

At the 54th Annual Meeting of the Institute of Nuclear Materials Management (INMM) in Palm Desert, California, USA, in July 2013, an informative session addressed the topic *International Safeguards Challenges*. The session included presentations followed by a panel discussion by an illustrious set of current and former government and International Atomic Energy Agency (IAEA) officials: Olli Heinonen, former deputy director general for safeguards at the IAEA; John Carlson, former head of the Australian Safeguards and Nonproliferation Office (ASNO); J. Stephen Adams of the U.S. Department of State; and Susan Burk, formerly of the U.S. Department of State. James Larrimore, International Safeguards Technical Division, and Corey Hinderstein, Nonproliferation and Arms Control Division, Nuclear Threat Initiative, moderated the session.

The themes and questions that dominated the presentations and the ensuing discussion addressed both the diplomacy and safeguards spheres, ranging from the upcoming Nonproliferation Treaty (NPT) 2015 Review Conference policy challenges to challenges in technical safeguards implementation and questions regarding safeguards legal matters. The outcome of the panel discussion indicated that both international safeguards and the nonproliferation regime are encountering significant challenges that need to be addressed, and that steps need to be taken if both systems are to stay up to date with the times and overcome the hurdles to treaty diplomacy and technical inspections existent and looming on the horizon.

The audience was reminded that the NPT states the purpose of safeguards is to verify fulfillment of obligations assumed under the treaty, "*...with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons...*" To accomplish this objective of *prevention*, timeliness is essential for the IAEA, meaning early detection and providing timely warning if there are grounds for concern. In resolving questions arising about a state's actions in regard to nuclear proliferation, cooperation with IAEA is key, not only for addressing the international community's concerns but also for the state itself, as cooperation gives it the opportunity to dispel suspicions. The repercussions of a weakened ability on behalf of the IAEA to resolve questions about proliferation would affect more entities than merely the inspected state and the IAEA, by impacting other states and international organizations also.

There was much discussion of the role of the IAEA in verifying that states are meeting their nonproliferation obligations under the NPT. Panelists emphasized the essential function of NPT safeguards in providing assurance to other states about observance of the NPT peaceful use commitment. Safeguards are not a zero sum game; safeguards are not about the IAEA versus the state, but about the commitments given under the NPT to the NPT membership (which is almost the entire international community). It was emphasized that safeguards have an essential confidence-building function, in addition to being key in detecting diversion of nuclear material. The IAEA safeguards system has to be able to provide confidence in the strictly peaceful nature of a state's nuclear program. If safeguards are interpreted in too legalistic a fashion by a state, confidence building will not occur. A failure of the safeguards system due to unnecessary legalistic quagmires would lead to loss of confidence in the safeguards system.

Regarding resolving questions of noncompliance, the question of an enforcement mechanism was at the fore. The panel entertained a lengthy discussion of the role of the IAEA and the standard of proof required for action in sending a report of noncompliance to the Security Council. The issue of enforcement continues to be a key challenge to the NPT and the IAEA, but responsible reporting and implementation of safeguards can act as a preventative measure both by deterring noncompliance and also by allowing states the opportunity to demonstrate their good standing and transparency.

The panel and participants discussed the need to improve the IAEA's capabilities to look for undeclared activities. The panel underscored that safeguards on the front end of the fuel cycle are important in early detection of proliferation. It was pointed out that past proliferators had imported yellowcake and experimented with uranium conversion without reporting to the IAEA as required under the terms of their safeguards agreement.

One of the discussion topics was the use of "special inspections." The IAEA has used the special inspection provisions of comprehensive safeguards agreements (CSAs) only twice and as a result there seems to be considerable reluctance to use this important mechanism. Special inspections could function as a very useful tool in the inspection toolbox that could work to help the IAEA make more comprehensive and more precise determinations regarding a state's nuclear program. A general consensus prevailed that if use of special inspections where required came to be considered the norm, it would enhance the safeguards system significantly.

The possible military dimension (PMD) to Iran's nuclear program was a topic that was present during many discussions at the INMM meeting. During this session, panelists discussed what impact Iran's ratification of the Additional Protocol to its CSA could have on the ability of the IAEA to resolve the PMD question. Panelists were asked if a hypothetical ratification of the Additional Protocol (AP) to its CSA by Iran would result in resolution of the PMD question. It was noted that the politicization of the AP increases the complexity surrounding such a scenario. Panelists considered that ratifying the AP would be an important first step, but not in and of itself sufficient to resolve the PMD issue.

The panel experts discussed how IAEA reporting on safeguards could be improved. It was noted that the IAEA's reports often present findings and conclusions, but leave out details regarding how those conclusions were reached. Transparency was mentioned as a key element, but the participants noted that balancing transparency with confidentiality would be essential. One method would be to revitalize the annual Safeguards Implementation Report (SIR). Another path forward mentioned by the panel was to create a Wikipedia-type platform for country-specific information, so that it would be possible for States and interested parties to have access to comprehensive histories and facts regarding a country's nuclear program.

Regarding the current IAEA effort to evolve safeguards with the state-level concept (SLC), in order to increase effectiveness and efficiency of international nuclear safeguards through more targeted activities, panelists supported the SLC but noted that there would be a continued need for effective facility safeguards in the SLC's state-level approach, in order to ensure the continued efficacy of the safeguards system.

Another key challenge to safeguards noted by panelists is the fact that much of the current expert workforce will be retiring in the near future, and there is an attrition of knowledge that will likely occur with the retiring of that expertise.

The NPT is one of the key tools in the nonproliferation toolbox, and was at the center of much of the discussion, both on upcoming meetings and regarding enforcement. The upcoming 2015 Review Conference (RevCon) to the NPT will face several challenges, which impact both international nuclear nonproliferation broadly as well as, potentially, safeguards and IAEA work specifically. Of the multitude of challenges, the foremost include serious, unresolved instances of noncompliance, the burden on the NPT nuclear-weapons states (NWSs) to produce evidence of complying with Article VI (disarmament), engaging with members of the Non-Aligned Movement (NAM) and other developing countries in a dynamic and useful manner, and the impact of the uncertainty surrounding the long-planned conference on a Middle East Weapon of Mass Destruction Free Zone (MEWMDFZ). The conclusion of the panel was that the NPT parties, as a group, have an important role to play in promoting compliance with the Treaty, and that sustained, substantive engagement between NWS and NNWS (non-nuclear weapon states), and developed and developing countries will support collective efforts to strengthen the NPT regime.

From the presentations and panel discussion at this session on *"International Safeguards Challenges,"* the following conclusions can be drawn. Nonproliferation in all states must be robust. In order to achieve this, foundational elements such as Comprehensive Safeguards Agreements (CSAs), the IAEA Statute, and the NPT must take priority. The detection and determination of noncompliance is only the first step. The course of action for such an instance must be defined. The methods used to communicate findings and the significance of findings of the IAEA must be scrutinized and updated where necessary. Unique situations within the regime must be balanced with challenges to the overall system of safeguards. While governments and international organizations will have the leading role in utilizing core tools to respond to nonproliferation challenges, this session showed that the many knowledgeable experts in the field from academia and think tanks can also bring critical ideas to the table.

Notes

The papers presented were *IAEA Safeguards—Evolving its 40-Year Old Obligations to Meet Today's Verification Undertakings*, Olli Heinonen; *The IAEA Safeguards Function—Responsibilities under safeguards agreements, the NPT and the Statute*, John Carlson and Andreas Persbo; *Enhancing the Effectiveness of the International Atomic Energy Agency's Safeguards System*, Adam M. Scheinman, Dunbar Lockwood, Mark W. Goodman, and J. Stephen Adams; and *Challenges to the 2015 NPT Review Conference*, Susan Burk and Katherine Bachner.

These papers are available for download at www.inmm.org/fall2013.

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Multispectral Active Neutron Interrogation Analysis

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Abstract

The non-destructive assay (NDA) of spent nuclear fuel is an increasingly important research area due to the need in international safeguards for a direct and independent method of determining plutonium mass in spent fuel. A new method has been developed that iteratively determines the isotopic masses of fissionable isotopes in a fuel sample from the fission rates induced in the fuel sample at different interrogating neutron energies using readily available neutron generators and neutron sources. This method, called MANIA (Multispectral Active Neutron Interrogation Analysis), uses the fission rates from the active neutron interrogation in a system of linear equations that is solved using a convex optimization algorithm that allows for a variety of constraints to be placed on the sought after solution. To compensate for the effects of self-shielding, iteration occurs between the measured fission rates and the simulated fission rates from an MCNP model of the irradiation setup. This method has been tested with synthetic fission rates generated in MCNP for a variety of sample geometries, dimensions, and isotopic compositions; and converges to the correct isotopic composition.

Introduction

The increased availability of compact neutron generators allows for the investigation of an NDA technique that leverages the energy-dependence of microscopic fission cross-sections to quantitatively estimate isotopic masses. This active neutron interrogation technique, called MANIA (Multispectral Active Neutron Interrogation Analysis), involves irradiating a fuel sample at several different neutron energies and using the resulting induced fission rates in a system of linear equations that can be solved for the isotopic composition. The different fission cross-sections give a unique fission rate for a specific isotopic composition and incident neutron energy. The following work shows the details of the numerical algorithm used to determine the isotopic composition from measured fission rates. This method is unique because it determines the composition from the fission rates induced at different interrogating neutron energies. It assumes induced fission rates can be measured from any choice of techniques, including measurements of delayed gammas or neutrons.[1] In this context, it augments other existing work.[2]

Theoretical Model and Solution Algorithm

This numerical algorithm involves using the fission rates produced by irradiating a fuel sample at several different neutron energies using neutron generators, solid neutron sources, or a research reactor in a system of linear equations that can be solved for the isotopic composition. The second part of this algorithm will strive to overcome the challenge of the complicated effects of neutron self-shielding by comparing measured fission rates to results from a simulation and iterating until they converge.

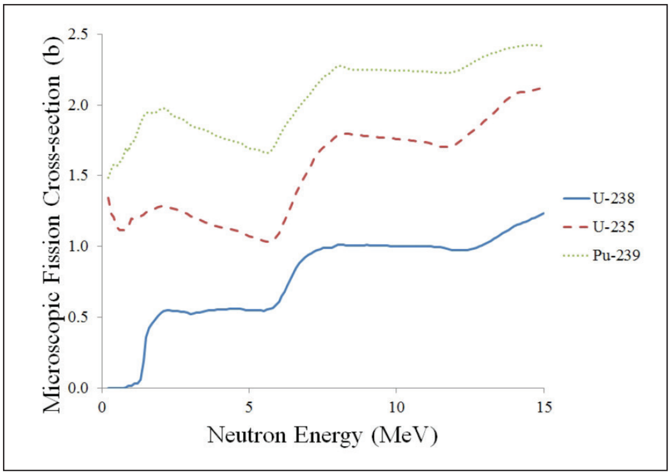
Basis for the Numerical Algorithm

The basis of the numerical algorithm for using fission rates to determine isotopic composition is from time spectral analysis of spent fuel using a lead slowing down spectrometer (LSDS). Briefly, the LSDS technique takes advantage of the linear correlation between neutron energy (between 10keV and 1eV) and slowing down time (few µs to 1000µs) of a pulse of high-energy neutrons in a large volume of lead. During this time, spent fuel and fission chambers with the fissile isotopes of interest are irradiated by a known energy of neutrons, which sets up a time spectral correlation between the fission neutron signal generated by the isotopic composition in the fuel sample and the signals generated in the fission chambers related by the amount of mass of each isotope. The composition can be determined to find the best fit for the combinations of fission chamber signals to equal the spent fuel signal.[3] MANIA will use a similar method to determine the isotopic composition of each fissionable component from a combined fission rate signal produced at varying neutron interrogation energies.

This new method improves upon the LSDS technique by accurately accounting for the self-shielding in the fuel sample, using relatively small neutron generators instead of approximately 35 tons of lead and a linear accelerator to induce fission, and relies on higher energy incident neutron nuclear data that is typically more accurate than the resonance region data. The different fission cross-sections give a unique fission rate for a specific isotopic composition and incident neutron energy. Figure 1 shows the variation in fission cross-section over a range of energy for three common isotopes in spent fuel.

Measuring the fission rate (F) at different neutron energies leads to a system of linear equations in the form of (1) that can be solved as an inverse problem for the unknown masses (N) of the fissionable materials because the total fission rate of an unknown sample is expected to be a linear combination of the isotopic.

Figure 1. Comparison of the fission cross-section for ^{235}U, ^{238}U, and ^{239}Pu from 200keV to 15 MeV



$$\Lambda_{i,j} N_j = F_i \tag{1}$$

In this system the number of equations i is determined by the different neutron energy irradiations and the fissionable isotopes determine the number of unknowns j. Λ is a matrix of microscopic cross-sections with i being the ith energy and j is the jth fissile isotope and each row is multiplied by the flux, Φi creating macroscopic cross-sections.

Solving the inverse problem for N has several significant challenges. Simply inverting the Λ matrix and multiplying will not work due to the ill-conditioned nature of the Λ matrix that causes small errors in values in the F vector to be greatly magnified. Also, once self-shielding becomes significant, the flux varies throughout the sample and therefore this simple relation no longer produces accurate results. Finally, neutron multiplication in the sample is not accounted for. The solutions for these issues are addressed in the following sections.

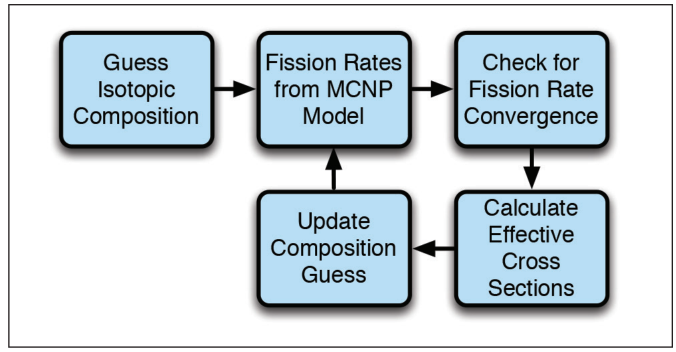
Convex Optimization to Solve System of Linear Equations

There are several excellent methods for solving the basic inverse problem. A convex optimization numerical algorithm[4] is chosen to solve Equation 1 by modeling it as Equation 2. This algorithm allows for constraints to be placed on the answer sought and calculates the least squares fit of the resulting vector.[5]

$$Minimize||\boldsymbol{\Lambda N} - \boldsymbol{F}||_2 \tag{2}$$

This optimization method reduces the effect that small errors on Λ have on the resulting solution vector. It also has the ability to solve for a least squares solution to Λ when both N and F are known. This benefit becomes important in the next section where an iteration method is used and the Λ matrix is an unknown.

Figure 2. Iteration diagram for using an MCNP model to compensate for the effects of self-shield on the overall fission rate in a sample



Iterative Method with MCNP Model to Compensate for Self-Shielding

Self-shielding by the fuel during irradiations causes large errors in similar methods and it is difficult to create analytical expressions for this effect. To account for the effects of self-shielding on the measured fission rate an MCNP model of the irradiation geometry and materials is created and used to produce simulated fission rates for comparison. MCNP allows three dimensional modeling of the actual experimental setup including the neutron source and interrogated sample. It is able to accurately determine fission rates induced in a sample and includes the effects of self-shielding.[6]

An iterative process shown in Figure 2 is used with an initial guess for the isotopic composition of the unknown sample. This model assumes that the self-shielding effects lead to a lower effective fission cross-section for each isotope at each energy.

The initial guess of the isotopic composition is used in the MCNP model of the irradiation geometry for the unknown sample to determine the expected fission rates for that composition. The simulated fission rates are compared to the measured fission rates and if they have converged the correct composition has been determined. If convergence has not occurred, the isotopic composition and fission rates from the MCNP simulation is modeled as a convex optimization problem and equation (2) is used determine a least squares solution for the effective cross-sections matrix (Λ) of the isotopes at each irradiation energy level with constraints (3).

$$\boldsymbol{\Lambda} \geq 0.0, (\boldsymbol{\Lambda}_{Real} - \boldsymbol{\Lambda}) \geq 0 \tag{3}$$

The constraints are set so that the effective cross-sections are greater than zero and are less than the actual cross-sections for each material and each irradiation energy. The second constraint makes the assumption that the self-shielding of the neutron flux leads to a reduction in the overall fission cross-section in the material for each isotope.

Table 1. Different geometries and dimensions tested with given isotopic composition and irradiation energies

Shape	Dim 1 (cm)	Dim 2 (cm)	Source Loc.	Isotope	w/o	Energy
Cylinder	H=9, D=1.5	H=9, D=4	? to H	^{238}U	70%	2.5 MeV
Plate	9x9x1.5	9x9x4	? Large Surface	^{235}U	5%	14 MeV
Cubic Shell	9x9x9, T=1.5	9x9x9, T=4	Center Shell	^{239}Pu	25%	AmLi Spect

Now that the effective cross-sections for the MCNP model are known, (2) is used again but with the fission rates of the unknown sample and the calculated effective cross-sections to obtain a new guess for the isotopic composition (N). These constraints for this convex problem are set so that each isotopic fraction (w_j) is > 0 and the sum of the isotopic fractions is equal to unity. The new isotopic fractions are used in the MCNP simulation to produce simulated fission rates and convergence is checked. This iterative process is continued until the unknown fission rates converge to the simulated. This iterative method is an innovative solution to the unique and significant problem of neutron self-shielding during active interrogation of spent fuel.

Accounting for Neutron Multiplication Using the MCNP Model During Iteration

Equation 1 does not take into account the additional fission rate generated by the fission neutrons created from the incident flux. Experimentally measured fission rate values will include this additional fission rate and therefore a correction factor for the multiplication of neutrons is determined to utilize this model. MCNP has the capability of running a simulation without fission neutrons using the NONU card. During the iteration two MCNP simulations are executed, one to determine an expected fission rate with multiplication from fission neutrons (F) and one without fission multiplication (F_{NONU}) at each energy. The ratio of the fission rates generated by this is a subcritical multiplication factor (m) of the sample with respect to each different interrogation source energy.

$$\frac{\boldsymbol{F}}{\boldsymbol{F}_{NONU}} = \boldsymbol{m} \tag{4}$$

There is a unique m at each of the irradiation energies. The unknown fission rates are multiplied by m and the minimization equation becomes (5) when solving for N.

$$Minimize||\boldsymbol{\Lambda N} - \frac{1}{m}\boldsymbol{F}||_2 \tag{5}$$

Testing and Results

A Python script was created to automate the iteration process and perform all of the necessary calculations. Initial testing of this model and iteration scheme consisted of an MCNP model of an isotropic point source irradiating a fuel sample. To test the robustness of this algorithm several different fuel sample geometries, starting conditions, and isotopic compositions are explored.

Three Isotopes with Varying Geometry

To initially test the algorithm, different geometries and dimensions with the isotopic composition and irradiation energies all shown in Table 1 were selected. The isotopic composition was chosen so that convergence of the weight percent of each isotope would be easily distinguishable. The irradiation energies were chosen as characteristic neutron energies produced by neutron generators and a well characterized spectrum of energy.[7] The fission rate in each geometry was calculated with the MCNP model for each irradiation energy and used as the 'unknown sample fission rates' input for the iteration algorithm. Due to self-shielding effects, the initial guess at isotopic composition using known fission cross-sections for each isotope at each energy was not accurate and so the iteration process was required. Ten iterations for each variation were completed to allow comparisons between the final results.

Results for each of these trials are shown in Figures 3, 4, and 5. Each figure shows the relative error of the guessed isotopic on the top and the weight percent of each isotope on the bottom per interaction. All trials were able to converge close to the correct answer. Only the ^{235}U isotope of the thick cylinder was not within 2% relative error after 10 iterations, however; five additional iterations did reduce it to < 1 percent.

Each trial required less than ten minutes to complete on a standard Intel i5 dual core processor with the vast majority of the time being spend on the MCNP simulation. The initial isotopic composition guess was determined using Equation 2 with the ENDF VII fission cross-section values for each isotope at each energy and the "unknown fission" rates. This also shows that the initial guess for the isotopic composition is quite inaccurate. To further prove the robustness of this algorithm a trial was run for each geometry with dimension 1 for a purposefully bad initial guess. Figures 6 and 7 show these results. The algorithm was able to overcome the poor guess and still find the correct isotopic composition.

Figure 3. Cylinder results for both dimensions more than ten iterations

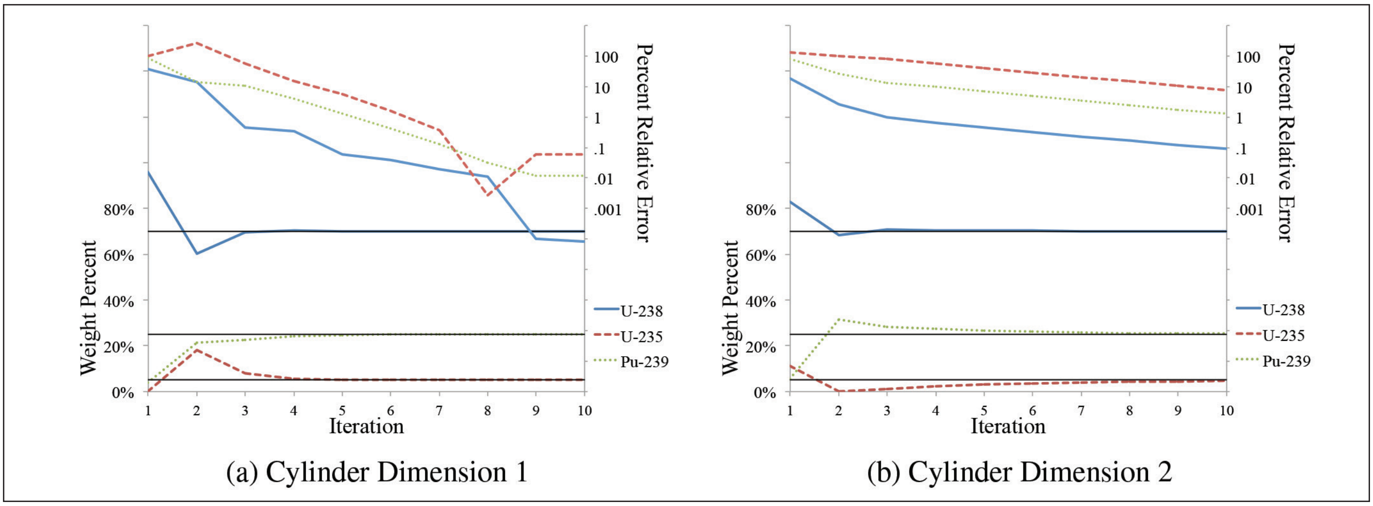


Figure 4. Plate results for both dimensions more than ten iterations

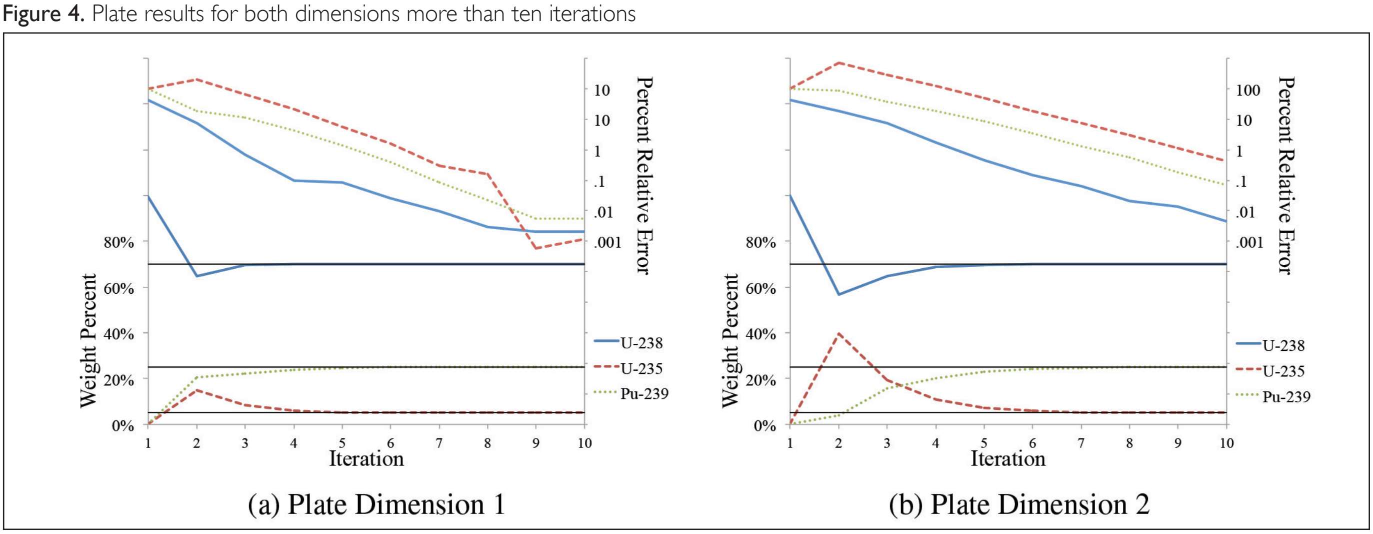


Figure 5. Cubic shell results for both dimensions more than ten iterations

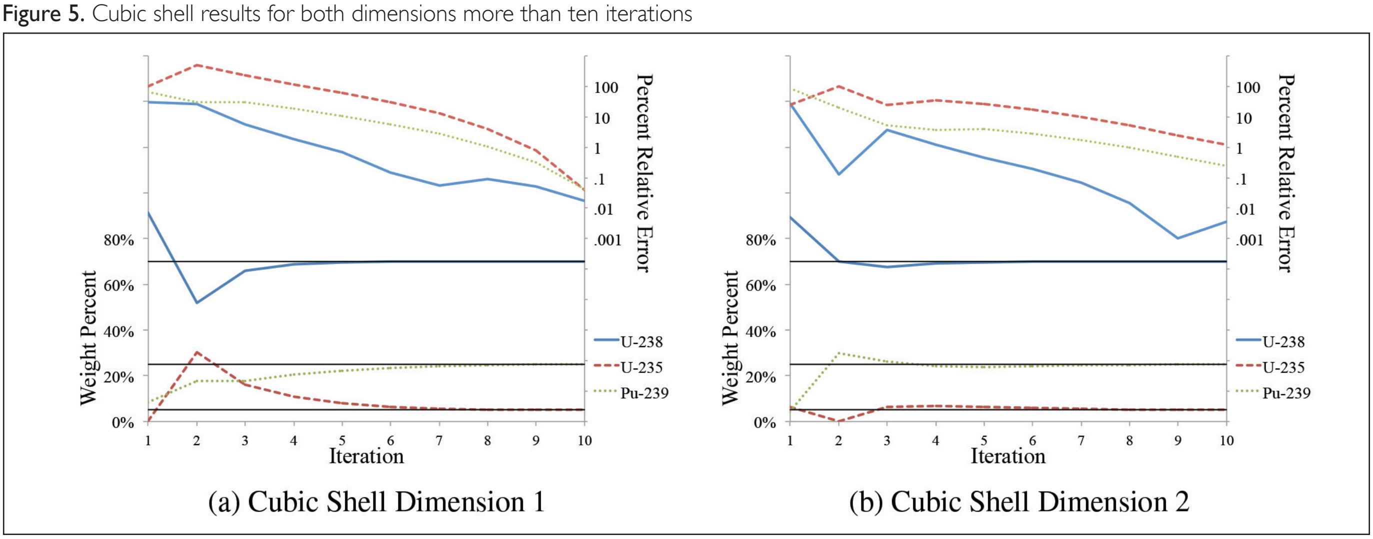


Figure 6. Cylinder and plate geometry with purposefully bad initial isotopic composition guess more than ten iterations

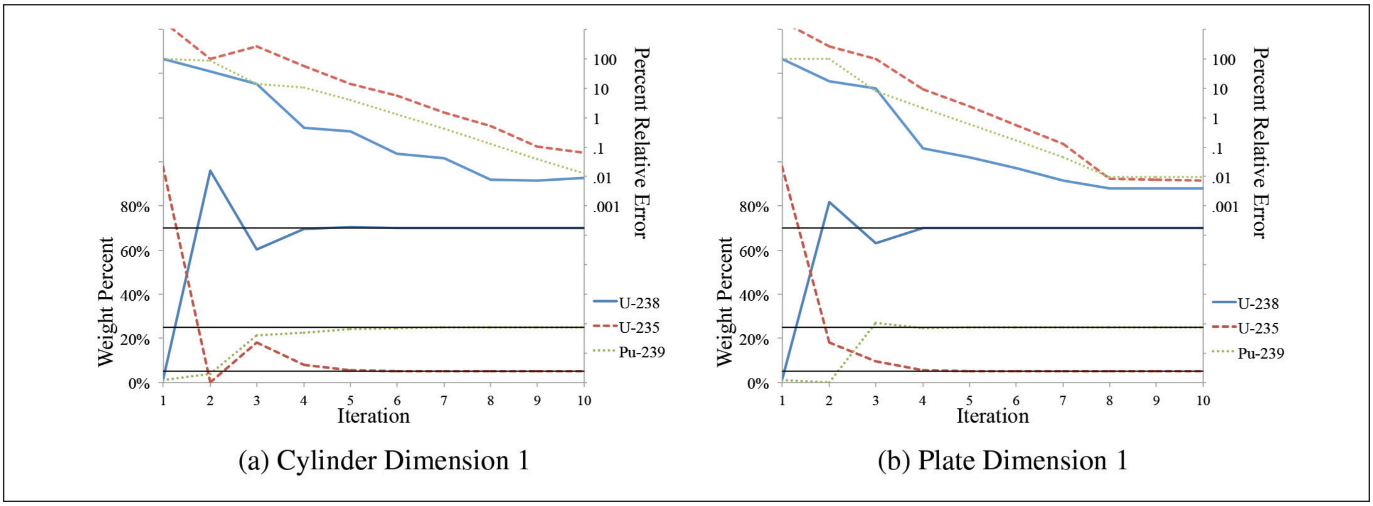


Figure 7. Box with purposefully bad initial isotopic composition guess more than ten iterations

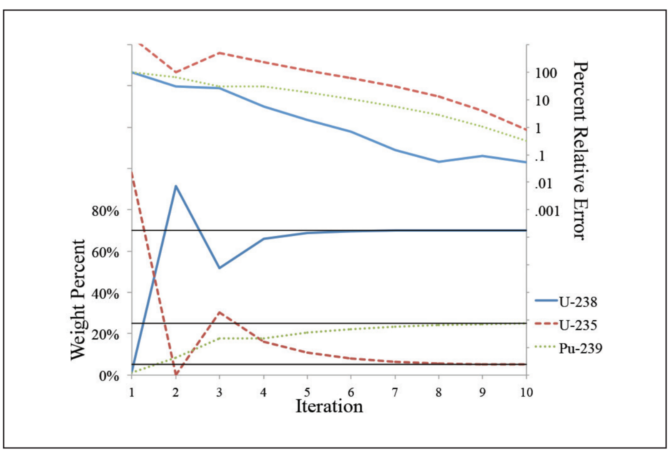
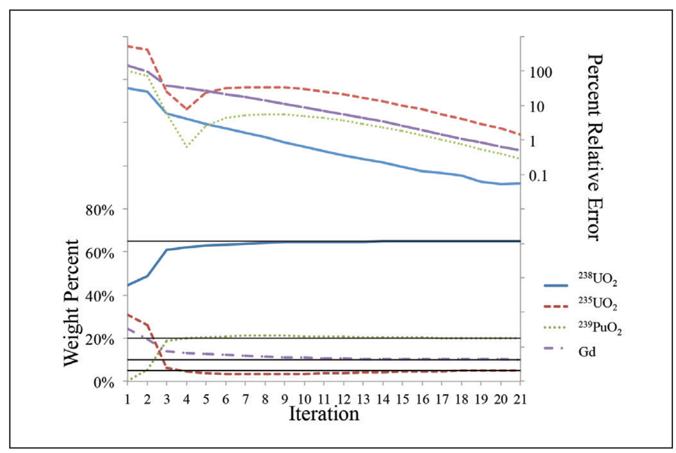


Figure 8. Results of fissionable isotopes as oxides and gadolinium added



The success of this initial test shows the potential of this algorithm to overcome the problems caused by the self-shielding of the neutron flux because it was able to determine the isotopic composition of an irradiated sample with various geometry, dimensions, and starting conditions without any derived self-shielding factor.

More Complex Material Composition and Neutron Absorber

The previous results show the robustness of the algorithm for various geometries and dimensions, however; the material composition was simplified. Oxides are the most common form for the three isotopes and so the algorithm was modified to be able to calculate the weight percent of the fissionable isotopes in oxide form. Additionally, Gadolinium (Gd) was added to show the ability of the algorithm to overcome the effects of a strong neutron absorber. Table 2 shows the isotopic composition and irradiation energies. The cylinder geometry with dimension 1 was chosen because it is the most realistic geometry with dimensions similar to a fuel pin. Figure 8 shows the results of the trial. Twice as many iterations were required for the relative error of all isotopes to be < 2 percent.

Table 2. Isotopic composition and irradiation energies for oxides and neutron absorber

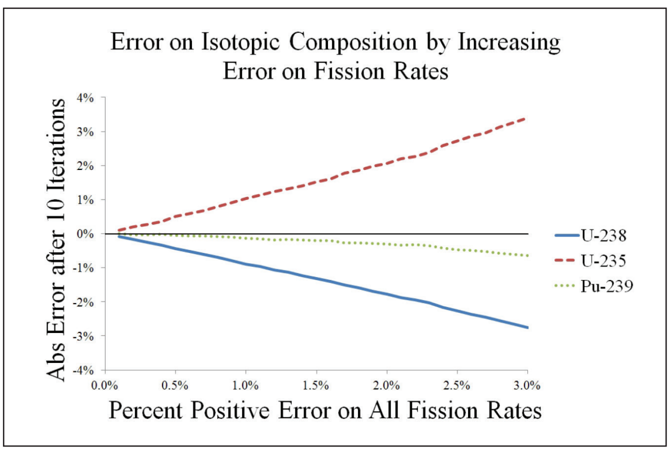
Isotope	w/o	Energy
$^{238}UO_2$	65%	2.5 MeV
$^{235}UO_2$	5%	14 MeV
$^{239}PuO_2$	20%	AmLi Spect

These results show the ability of the algorithm to handle fissionable materials, neutron absorbers, and neutron transparent materials. It also shows that the increased complexity did increase the required number of iterations for a converging solution.

Constant Error on Fission Rate

To test the sensitivity of the isotopic composition calculated by the iterative method, a uniform error on the input fission rates in the range of 0.1percent - 3.0 percent was applied. These results, Figure 9, show that as uniform error on the fission rates increases, the absolute error on each of the calculated output weight percentages rises at a predictable rate. The slope of the lines is representative of a linear sensitivity coefficient between the inputs (fission rates) and outputs (isotopic composition) for uniform input error. The prediction of ^{235}U is the most sensitive to errors in the input fission rate, with a sensitivity coefficient of nearly unity. Future work will examine the effect of non-uniform uncertainties (assuming that each active measurement does not have the same uncertainty) to continue to test the feasibility of this method with different measurement error scenarios.

Figure 9. The effect that positive uniform error on the fission rates has on the calculated isotopic composition after ten iterations



Conclusion

This iterative algorithm has been able to determine the isotopic composition of a homogenous sample of fissionable materials in various geometric shapes and dimensions using a model that takes into account the effects of neutron multiplication and self-shielding. The inputs to the algorithm are induced fission rates at various neutron energies, interrogation geometry, and list of fissionable isotopes. The ability to overcome self-shielding effects without a derived term is significant. Additional simulated testing will consist of additional isotopes, realistic spent fuel compositions, and non-homogenous samples.

This method will be experimentally verified by irradiating a well characterized fuel sample in different neutron spectra using D-D and D-T neutron generators. Additionally, advanced fission rate measuring techniques and a novel He-4 neutron detection system will be used to accurately measure fission rates in the presence of the large passive signal characteristic to spent fuel.

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Spectrally Matched Neutron Detectors Designed Using Computational Adjoint S_N For Plug-In Replacement of ^{3}He

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Abstract

The current very limited supply of ^{3}He is attributed to a lack of tritium production for the nuclear weapons complex along with a significantly increased demand for the gas in various neutron detection applications. Circa 2000 more than 200,000, liters (standard temperature and pressure) were in the ^{3}He stockpile, but today less than 45,000 liters remain, and the U.S. Department of Energy (DOE) is rationing the supply to only 8,000 liters per year. A number of research efforts have been conducted to determine if existing materials could serve as an adequate substitute for ^{3}He and additional efforts have also evaluated new materials that might serve adequately as replacements. Regardless of the effort, each study almost always focuses solely on "simple" detection cases where the overall system efficiency for one specific source (e.g., ^{252}Cf) is the only concern (e.g., handheld devices, backpack units, and portal monitoring systems). In these cases, inserting additional detectors and/or materials can address the issue of cumulative counts, because the spectral response is essentially irrelevant. However, in many applications such as for safeguards, nonproliferation efforts, and materials control and accountability (MC&A) programs, including fissile material assessments for plutonium and actinides, measurements are often calibrated to responses in a ^{3}He proportional counter. In these cases, a mismatch in the neutron response function can produce serious quantification errors and potentially dire consequences. The application of a *simple* detector addition approach in these instances is neither appropriate nor possible due to influences resulting from the complex nature of neutron scattering in moderators, cross-sections, gas pressures, geometries and structural interference. These more challenging circumstances require that a detailed computational transport analysis be performed for each specific application. A leveraged approach using computational adjoint transport, validated by forward transport and Monte Carlo computations and laboratory measurements can address these complex scenarios. This paper will present novel designs that are spectrally matched to a baseline ^{3}He detector that can directly serve as a "plug-in" replacement with equivalent system efficiency.

Introduction

Neutron radiation detectors are an integral part of the U.S. Department of Homeland Security (DHS) efforts to detect the illicit trafficking of radioactive or special nuclear materials into the U.S. In the past decade, the DHS has deployed a vast network of radiation detection systems at key positions to prevent or to minimize the risk associated with the malevolent use of these materials. Many neutron detection systems have been equipped with ^{3}He because of its highly desirable physical and nuclear properties. However, a dramatic increase in demand and dwindling supply, combined with a lack of oversight for the existing ^{3}He stockpile has produced a critical shortage of this gas which has virtually eliminated its viability for detector applications.[1] Although a number of research efforts have been undertaken to develop suitable replacements, none of these efforts are attempting to closely match the ^{3}He detector response across different neutron energy spectra, which is critical for certain nonproliferation programs and special nuclear material (SNM) assessments. Therefore, the objective of our research was to produce several spectrally matched and validated equivalent neutron detectors for the direct replacement of ^{3}He when a spectral match is important.

Prior to developing any actual designs, the fidelity of our computational approach was validated by executing radiation transport models for existing BF3 and ^{3}He tubes and then comparing the results of these models to laboratory measurements conducted with these exact detectors. Both tubes were 19.6 cm in height, with a 1-inch diameter, and operated at 1 and 4 atm pressure respectively. The models were processed using a combination of forward Monte Carlo and forward and adjoint 3-D discrete ordinates (S_N) transport methods. The computer codes MCNP5 and PENTRAN were used for all calculations with the Evaluated Nuclear Data Files Version 7 (ENDF/B-VII) continuous-energy neutron cross-sections (MCNP5) and multi-group cross-sections derived from the BUGLE-96 library by the GMIX utility (PENTRAN).[2–3] The multi-group energy structure of the BUGLE-96 library is shown in Table 1.

Once the computational methods were validated, six distinct plug-in ^{3}He replacement models were developed via a computational adjoint S_N approach. These designs, which match the neutron spectral importance and reaction rate of a 1-inch diameter ^{3}He tube with an active length of 10 cm at 4 atm, are shown in Table 2 and are composed of singular and dual detector configurations utilizing BF3 gas, ^{10}B lining, and/or ^{10}B-loaded polyvinyl toluene (PVT).[4] Only Designs 1 and 3 will be discussed further in this paper due to length. The overall design approach followed an iterative process as given in Figure 1.

Table 1. Forward energy group structure of the BUGLE-96 broad-group library[A]

Group	Energy (MeV)	Group	Energy (MeV)	Group	Energy (MeV)	Group	Energy (MeV)
1	1.73E+01	13	2.37E+00	25	2.97E-01	37	1.58E-03
2	1.42E+01	14	2.35E+00	26	1.83E-01	38	4.54E-04
3	1.22E+01	15	2.23E+00	27	1.11E-01	39	2.14E-04
4	1.00E+01	16	1.92E+00	28	6.74E-02	40	1.01E-04
5	8.61E+00	17	1.65E+00	29	4.09E-02	41	3.73E-05
6	7.41E+00	18	1.35E+00	30	3.18E-02	42	1.07E-05
7	6.07E+00	19	1.00E+00	31	2.61E-02	43	5.04E-06
8	4.97E+00	20	8.23E-01	32	2.42E-02	44	1.86E-06
9	3.68E+00	21	7.43E-01	33	2.19E-02	45	8.76E-07
10	3.01E+00	22	6.08E-01	34	1.50E-02	46	4.14E-07
11	2.73E+00	23	4.98E-01	35	7.10E-03	47	1.00E-07
12	2.47E+00	24	3.69E-01	36	3.35E-03		

Table 2. ^{3}He-equivalent designs produced by computational adjoint S_N evaluations

Design	Sensitive Material	Number of Detectors	Length/Cylinder Radius (cm)	Pressure (atm)
1	BF^3	1	10.00 / 2.00	2
2	^{10}B lining	1	10.00 / 1.90	10 (^4He)
3	^{10}B lining	2	10.00 / 1.27 (rear & forward)	10 (^4He)
4	BF^3	2	10.00 / 2.05 (rear) & 1.27 (forward)	1
5	BF^3	2	10.00 / 2.20 (both tubes)	1
6	PVT with ^{10}B	1	4.50 / 1.27	--

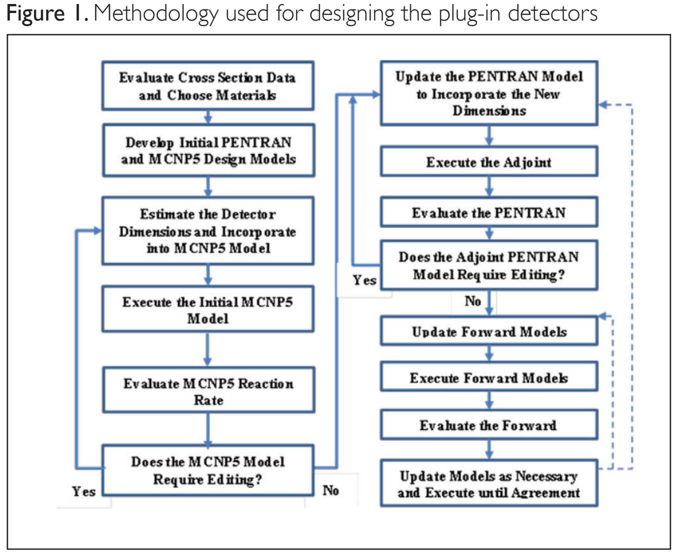
Parallel Environment Neutral Particle Transport (PENTRAN) Code System

PENTRAN is a multi-group, anisotropic S_N code for Cartesian geometries that was specifically designed for distributed memory and scalable parallel computing using the MPI library.[3] This code optimizes parallel decomposition and also automatically optimizes memory allocation.

The code has demonstrated an excellent agreement with various standard deterministic transport codes such as TORT,[B] THREEDANT, and PARTISN as well as the current reference Monte Carlo code MCNP5.[C] PENTRAN has also performed quite well in comparisons against experimental measurements that have been conducted for a variety of problems in reactor physics, radiation detection, and medical physics applications.[5–7]

PENTRAN solves problems such as multi-group, isotropic/anisotropic scatter, fixed-source and criticality in Cartesian geometry. The code can operate in either the forward or adjoint transport modes, which allows for maximum flexibility in detector design.

Figure 1. Methodology used for designing the plug-in detectors



Deterministic Adjoint Transport and the Adjoint Importance Function

In the design of a radiation detector, it is essential to account for particle importance, which reveals the specific spatial locations and corresponding energies where neutrons will contribute the most to the detector response. The solution to the adjoint form of the linear Boltzmann equation (LBE) provides such insight, which are unavailable through forward deterministic or Monte Carlo methods. The adjoint form of the LBE can be derived using the adjoint identify for real-valued functions, where the Dirac brackets ‹ › represent integration over all independent variables:

$$\langle \psi_g^\dagger H \psi_g \rangle = \langle \psi_g H^\dagger \psi_g^\dagger \rangle \, , \tag{1}$$

where

$$H = \hat{\Omega} \cdot \nabla + \sigma_g(\vec{r}) - \sum_{g'=1}^{G} \int_{4\pi} d\Omega' \; \sigma_{s\;\; g' \to g}\left(\vec{r}, \, \hat{\Omega}' \cdot \hat{\Omega}\right) . \tag{2}$$

In Equations 1 and 2, $\psi_g^\dagger$ is the angular adjoint (importance) function and H is the forward transport operator. We can develop the adjoint transport operator ($H^\dagger$) by applying the boundary condition that all particles leaving a bounded system have a zero importance for all groups and also requiring that a continuous importance function exists in order to arrive at

$$H^\dagger = -\hat{\Omega} \cdot \nabla + \sigma_g(\vec{r}) - \sum_{g'=1}^{G} \int_{4\pi} d\Omega' \; \sigma_{s\;\; g \to g'}\left(\vec{r}, \, \hat{\Omega} \cdot \hat{\Omega}'\right) . \tag{3}$$

The minus sign on the streaming term reflects that, in the adjoint condition, particles travel in a reversed direction, where particles scatter from group g to other groups g′ (groups formerly contributing to group g in the forward equation).[1-2] For the case of a fixed forward detector problem, the neutron flux must satisfy the following relation:

$$H\psi_g = q_g \, , \tag{4}$$

because the source term (q) is purposely omitted from the forward operator (H) relation. Likewise, the inhomogeneous adjoint equation must be satisfied with an adjoint source that is aliased to the group detector response cross-section ($\sigma_{d,g}$) by

$$H^\dagger \psi_g^\dagger = \sigma_{d,g} \, . \tag{5}$$

Substituting Equations 4 and 5 into Equation 1 and simplifying yields the important relation

$$R = \langle \psi_g \sigma_{d,g} \rangle = \langle \psi_g^\dagger q_g \rangle \, , \tag{6}$$

where R is the detector response or reaction rate in counts per second. This relation is valuable because it demonstrates that the detector response can be computed directly from several forward transport computations for each source or a single adjoint transport computation. Although PENTRAN provides the capability to calculate reaction rate using the angular flux shown in Equation 6, the scalar flux or scalar adjoint function can be substituted in cases where they are deemed adequate.

This simplification, which is shown in Equation 7 below significantly reduces the output file size and speeds the deterministic computations.

$$R = \int_E dE \int_{V_q} \sigma_d^\dagger(x',y',z',E) \; q(x',y',z',E) \; dx',dy',dz' \approx \sum_{\substack{\Delta V_i \in V_d \\ g=1,G}} \phi^\dagger_{d\;g,i} \; q_{g,i} \, \Delta V_i \, , \tag{7}$$

where:

V = source volume (V_q in cm^3) or i^{th} cell volume (ΔV_i in cm^3)

(x', y', z') = spatial location of non-zero source cells (adjoint)

$\phi_d^\dagger\,(x', y', z', E)$ = spatial and energy dependent scalar adjoint function for detector d

$q(x', y', z', E)$ = spatial and energy dependent source ($n\ cm^{-3}\ s^{-1}$)

$\phi^\dagger_{d,g,i}$= i^{th} cell scalar adjoint function for detector d and group g.

The ability to determine R for an arbitrary source distribution, weighted by the adjoint function, demonstrates the power of the adjoint method and its application for radiation detector design.

Test Facility and Source Description

The measurements for the gas-filled detectors were conducted in a secure room with a large CONEX (Container Express) that was being used for various cargo monitoring experiments. The neutron source used for the experiments was a plutonium-beryllium (^{239}PuBe) source with a capsule density of 4.35 g cm^{-3} and containing 15.02 g of ^{239}Pu (0.94 Ci). The stated emission rate of 1.93 x 10^6 $n\ s^{-1}$ was extensively studied by Ghita et al.[8] using both Monte Carlo and PENTRAN models and the average calculated emission rate of (1.925 ± 0.0001) x 10^6 $n\ s^{-1}$ was within round-off of the manufacturer's claim.[9–10]

One of the main objectives of any special nuclear material (SNM) detection system is to identify plutonium in cargo that is passing through a border crossing or into a port of entry (POE). The testing of such systems has been hampered over the years by a lack of (α, n) sources, security issues associated with plutonium metal, and/or the availability of another suitable source such as ^{252}Cf due to radioactive decay or supply limitations. Ghita was able to overcome these technical issues by discovering that a nickel scatter shield could alter a PuBe neutron spectrum to match that of subcritical multiplication in Pu metal, with average emission energy of only 2.11 MeV;[8] therefore, the nickel-shielded source was selected as a natural fit for this experiment. The shielded source was measured in both the bare and reflected conditions inside the CONEX container, although only the bare case was used for direct comparison with the computational models. This decision was made because the arrangement and openings between the water bottles produced variations that would skew the comparisons. The comparisons of the computational modeling results and the experimental measurements are provided in Tables 3 and 4. The excellent agreement of the computational techniques confirmed the reliability of the models and established the fidelity of the computational adjoint approach toward detector design.

General Detector Design Parameters

Although the ^{3}He replacement detector models consisted of various materials and configurations, there were several design features common to all. For example, each detector was fitted with 2 cm of polyethylene at the rear of the detector (away from the source) based on research performed by Ghita et al.[9] This specific thickness provided the highest degree of an *albedo* response, (neutrons scattering backwards into the detector). Another common feature was that each detector included 2 cm of polyethylene on the front-side of the detector (toward the source), 1 cm thick walls on either side, and a common height of either 10 cm or 19.6 cm as was discussed in the introduction section.

The 1-cm sidewall thickness was simply a procurement result; however, the forward moderator thickness was determined by conducting measurements of the PuBe source using a varying thickness of polyethylene (0 – 6 cm) to establish the maximum count rate. The only variance in the sidewall thickness occurred in the multi-detector designs with dissimilar radii. In those cases, the sidewall thickness was maintained at 1 cm from the outside radius of the larger tube. Each model also utilized a uniform source of 1000 $n\ s^{-1}$ surrounding the entire detector assembly and vacuum boundary conditions, because an initial MCNP5 investigation revealed there was < 2 percent due to an albedo effect for any surface.

Although no firm constraint exists regarding the physical size of any replacement design, serious consideration was only given for detectors that would not present any undue installation issues in existing detection systems. As a general rule, the width of a detector assembly presents the greatest challenge regarding plug-in potential and, since this was the primary research objective, an arbitrary width constraint of 7.62 cm (three inches) was chosen in order to constrain the detector possibilities. This constraint eliminated single-tube BF^3 detectors at 1 atm from consideration, although it is certainly possible to create a detector with this fill pressure that mirrors the characteristics of the ^{3}He baseline detector selected for this study.

Table 3. Comparison of the ^{3}He measured reaction rate recorded over a 2-minute interval for a nickel-filtered PuBe source and computational calculations of the same source with PENTRAN and the 47-group BUGLE-96 broad-group cross-sections[2] and MCNP5 with the continuous-energy ENDF/B-VII cross-sections.[11]

Method	Counts	Uncertainty (1.96σ)	Fractional Bias
^{3}He Measurement	16184	119	--
PENTRAN Adjoint	15780	--	-0.025
PENTRAN Forward	16120	--	-0.004
MCNP5 Forward	15582	31	-0.037

Table 4. Comparison of the BF3 measured reaction rate recorded over a 2-minute interval for a nickel-filtered PuBe source and computational calculations of the same source with PENTRAN and the 47-group BUGLE-96 broad-group cross-sections[2] and MCNP5 with the continuous-energy ENDF/B-VII cross-sections.[11]

Method	Counts	Uncertainty (1.96σ)	Fractional Bias
BF_3 Measurement	3169	109	--
PENTRAN Adjoint	3183	--	0.004
PENTRAN Forward	3218	--	0.015
MCNP5 Forward	3273	14	0.033

^{3}He Detector Baseline and Alternative Design Comparisons

The baseline detector used for design purposes was a common 1-inch diameter ^{3}He tube pressurized to 4 atm (5.39E-04 g cm^{-3}) found in many detector applications. Since alternative materials such as BF^3 (1 atm), ^{10}B-lined tubes, etc. are usually less efficient for neutron detection compared to this baseline, the only avenue for achieving an efficiency match is to increase the amount of the alternative material in a system. However, for the more difficult detection cases, the challenge of increasing the efficiency must be balanced with the requirement to maintain an overall equivalent neutron spectral response. In other words, one cannot simply insert a larger detector, obtain an acceptable cumulative count from a ^{252}Cf source at some stipulated distance, and assume the detector will respond in equivalent fashion to a ^{3}He spectral response.

The adjoint function over the forward air-filled course meshes (toward a source) and the adjoint reaction rate for all air-filled course meshes were plotted as a function of neutron energy in order to objectively evaluate each potential equivalent alternative design. The adjoint reaction rate, in particular, is the most important parameter that must be maintained within an acceptable range across the energy spectrum. A plot of the adjoint function gradient profile in the *XY* plane is also shown at the detector centerline for adjoint energy groups 47 (≤ 0.1 eV), 29 (1 MeV), and 1 (17.3 MeV). This information, which is not available in Monte Carlo applications, can illuminate behaviors that can be exploited in order to improve the overall design approach.

General Findings Regarding ^{3}He-Equivalent Tube Designs Based on BF3 Gas

The plug-in designs exhibited similar behavior compared with each other and ^{3}He in some circumstances. The first of these similarities was that adjoint energy groups 20 – 41 solely accounted for the total reaction rate, because of minimal thermal emissions from the shielded PuBe source. One other similarity of the gas tube designs was the tendency for the reaction rate to gradually increase from a minimum at ~Adjoint Group 20 (6.74E-02 MeV) to a maximum at ~Adjoint Group 25 (4.98E-01 MeV) due to a gradual increase in the ^{10}B (n, α) cross-section versus that of ^{3}He (n, p). There was also a tendency for positive biases to occur at ~Adjoint Group 29 (1.00 MeV) to ~Adjoint Group 41 (6.07 MeV) due to a rapid increase in the ^{10}B (n, α) cross-section. In fact, the magnitude exceeds that of ^{3}He (n, p) beyond neutron energies of about 4 MeV. This disparity is tempered somewhat, however, because elastic scattering with the nucleus becomes the predominant ^{3}He reaction for neutrons ≥ 150 keV. Only deviations from these general tendencies will be discussed further in order to ensure a concise presentation.

Table 5. Computational reaction rate comparisons for Alternative Design 1

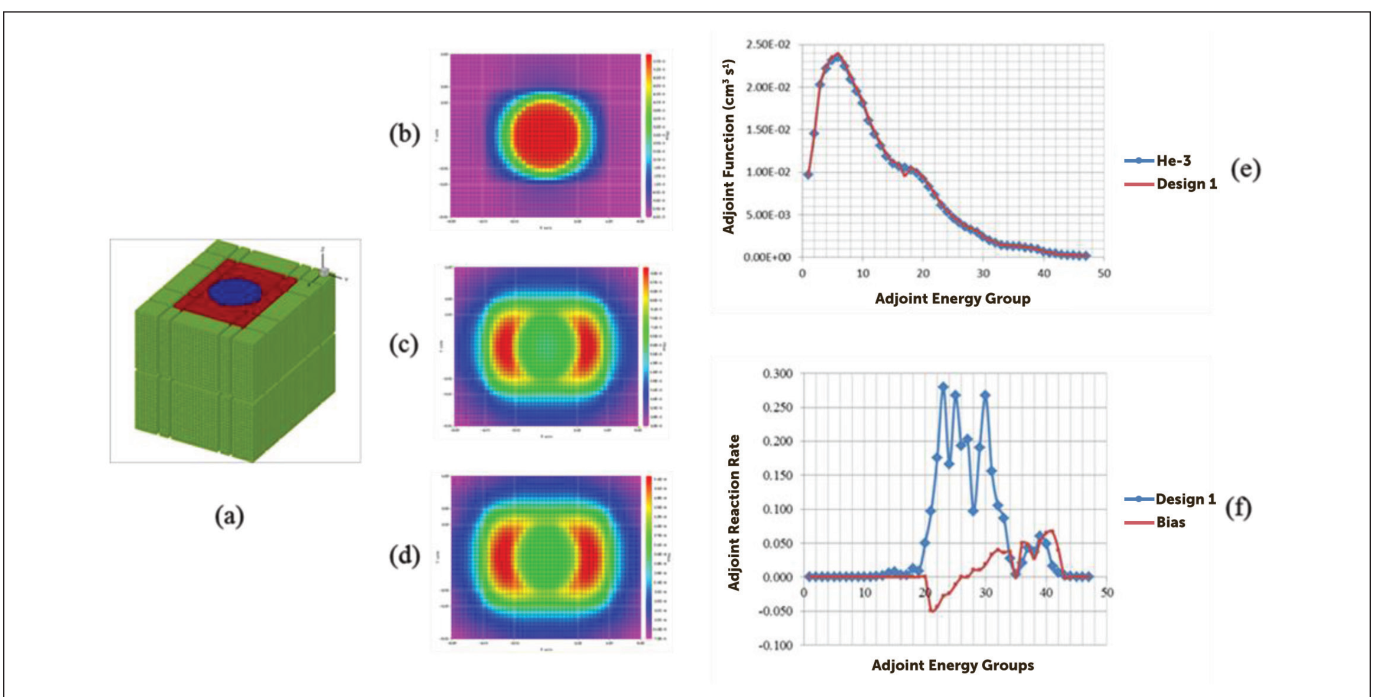
Method	Rate (s^{-1})	Uncertainty (1.96σ)	Bias (%)
PENTRAN Adjoint	2.644	--	-0.226
PENTRAN Forward	2.648	--	-0.972
MCNP5 Forward	2.587	0.004	-0.805

Large Single BF3 Tube Operating at 2 Atmospheres – Alternative Design 1

The overall reaction rate results for Alternative Design 1 are given in Table 5 and demonstrate excellent agreement with the ^{3}He baseline. The graphical information demonstrates that this design exhibits the same overall behavior as the ^{3}He baseline. The *XY* slice of the entire region of detector material inside the tube (b) demonstrates the same efficiency behavior as the ^{3}He baseline, with an orderly decrease as particles are placed farther from the detector.

As shown in Figure 2, the second outer ring around the detector shown in green (b) appears to be about twice as thick as the same region in the ^{3}He tube, and this was caused by a larger tube radius that presented a larger target to scattered thermal neutrons. There are also regions of slightly greater efficiency at the top and bottom of the detector assembly, due to the smaller degree of moderation on the sidewalls, which allowed slower neutrons to more easily penetrate the detector. The overall adjoint function behavior in (c) and (d) is essentially the same as that of the ^{3}He baseline, with the exception of a larger region with less importance at the top and bottom. These features are associated with the larger tube dimensions as well, because there is less moderator material in this area when compared with that of the ^{3}He tube.

Figure 2. (a) Alternative Design 1 configuration, (b – d) adjoint gradient profiles, (e) adjoint function per unit source density in the forward air-filled course meshes adjacent to the polyethylene (toward a source), and (f) the adjoint reaction rate across all air-filled course meshes and the fractional bias with ^{3}He.



This means there is a smaller probability for neutrons of higher energy to scatter in the moderator and be absorbed in the detector.

Figures 2 (e) and (f) display the adjoint function per unit source density and reaction rate per neutron energy group for Alternative Design 1. The excellent behavior displayed in these figures proves that this design would serve well as a replacement for the baseline ^{3}He tube. The reaction rate plot, in particular, is very telling, because all but two of the reaction rates across the entire breadth of neutron energies are within 5 percent of the ^{3}He rate, and the largest bias of only 6.7 percent occurs at Adjoint Group 41 (6.07 MeV). *Note that a positive bias means that the reaction rate for a particular design is greater than the rate for ^{3}He at that same neutron energy, and the converse is true for negative biases.* The negative bias dip at Adjoint Group 21 (1.11E-01 MeV) was noted in all BF_3 gas designs, and is associated with an energy region where the ^{3}He (*n, p*) cross-section orderly decreases, while the ^{10}B cross-section is slightly erratic.

^{3}He-Equivalent Tube Designs Based on a ^{10}B-Lining

From a discrete ordinates perspective, materials with vanishingly small dimensions, such as ^{10}B linings, present a fine mesh size issue, because the corresponding meshes must of necessity be even smaller than the parent material. Each coarse mesh in the PENTRAN models was subdivided into fine meshes that were a maximum 0.25 cm in each direction for all the gas tube designs in this work and at least two fine meshes were desired for adequate material coverage. However, this mesh size is a factor of 2500 times larger than entire ^{10}B lining of 1E-04 cm (1 mg cm^{-2}), and the 5E-05 cm thickness required for 2 fine meshes was far too small to yield accurate deterministic results (note that 1 mg cm^{-2} is the range of the alpha particle reaction product in boron). Therefore, the true material density of 2.65 g cm^{-3} ($\rho 1$) at the fine mesh requirement of 5E-05 cm (dx_1) was used to calculate the boron density (1.998E-03 g cm^{-3}) necessary for the use of a 0.5 cm (dx_2) course mesh via Equation 8.

$$\rho_1 \, dx_1 = \rho_2 \, dx_2 \quad (8)$$

The validity of this equation was verified by extensive calculations with regular and modified ^{10}B-lined tubes using MCNP5 and PENTRAN results with the modified parameters. The final plug-in designs stipulated for these tubes likely represent a minimum diameter and the actual designs will need to be adjusted for the use of a 0.28 mg cm^{-2} thickness to allow for a more efficient collection of the lithium nuclei.[12]

Dual ^{10}B-Lined Tubes with ^{4}He Operating at 10 Atmospheres – Alternative Design 3

The overall reaction rates for Alternative Design 3 are given in Table 6 and prove that this design also matches the spectral baseline ^{3}He detector very closely. The design shown in Figure 3 (a) can be easily adapted for a 0.28 mg cm^{-2} wall thickness by increasing the tube radii to ~1.84 cm. The overall behavior of this design follows a pattern similar to Design 1; however, since the sensitive volume for the neutron detection is concentrated on the periphery of the tubes, some additional discussion is warranted.

Table 6. Computational reaction rate comparisons for Alternative Design 3.

Method	Rate (s^{-1})	Uncertainty (1.96σ)	Bias (%)
PENTRAN Adjoint	2.738	--	3.321
PENTRAN Forward	2.754	--	2.992
MCNP5 Forward	2.625	0.004	0.652

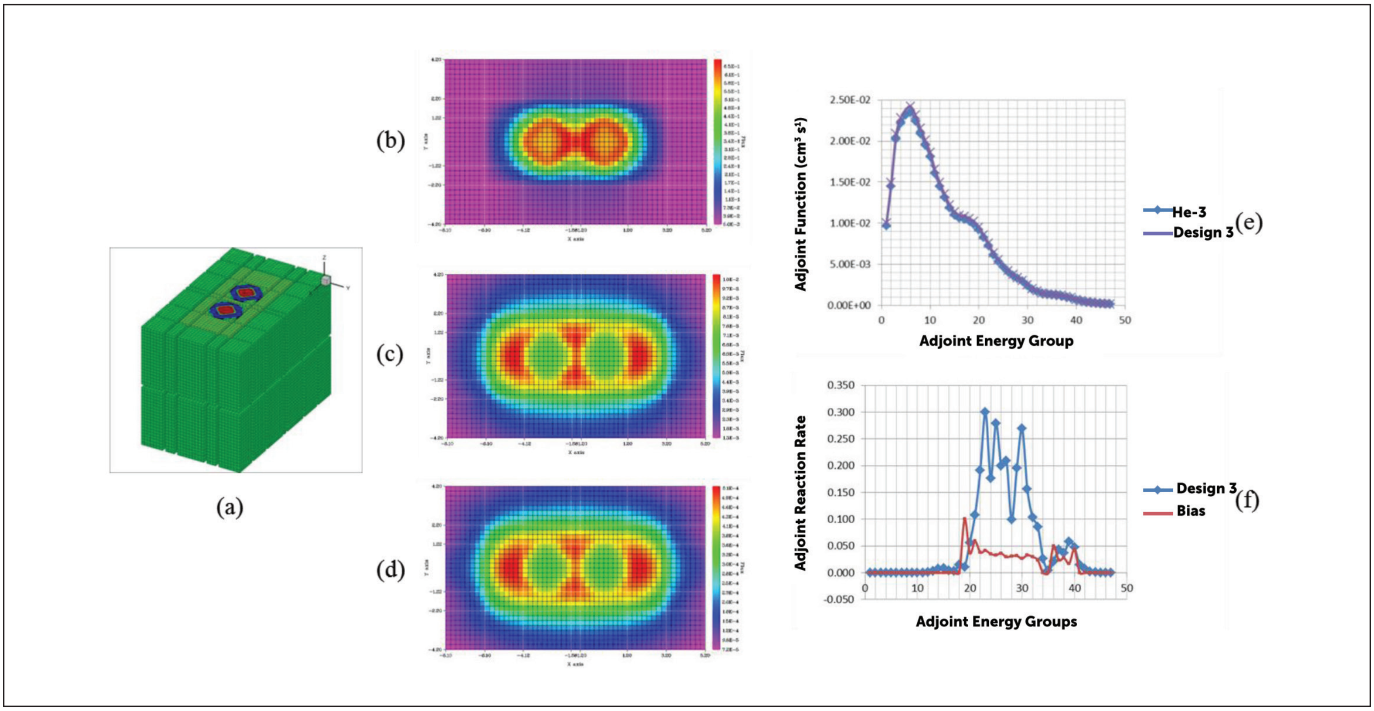
The interface region between the tubes in (b – d) exhibited an increased efficiency as occurred with the other multi-tube designs (not shown) that were part of the overall research effort; however, because of the increased ^{10}B concentration in this region, there was a factor of 20 increase in the efficiency for Adjoint Group 29 (1 MeV) compared with Design 4 (dissimilar BF_3 tubes) and more than a 25 percent improvement in Adjoint Group 47 (≤ 0.1 eV). This concentration was also responsible for the 11 percent efficiency reduction when compared with the outer portions of the model on the left and right of the tubes and also produced an overall detector response that was unique among the six alternative designs.

This design had no negative bias across the entire neutron spectrum (f), which resulted from a combination of the increased ^{10}B concentration near the sidewalls of the detector (top and bottom of b - d) and in the inner region between the detectors. The configuration of the ^{10}B in these areas allowed many more lower-energy neutrons to be detected because of a smaller moderator thickness. As a result of the positive bias behavior, the dual-tube ^{10}B-lined design represents a conservative case for criticality safety monitoring.

Conclusions

We investigated the use of deterministic adjoint SN methods in developing plug-in replacement designs for a baseline ^{3}He tube and a secondary objective was to do so using commercial off-the-shelf products to preclude the availability issues that plague the ^{3}He economy. Both these goals were achieved, while delivering a total of six plug-in designs that match the overall spectral performance of 4 atm ^{3}He. The excellent agreement demonstrated between the computational calculations and physical measurements validated the use of radiation transport simulations for designing the plug-in detectors. Since the simulations were shown to accurately represent the detection reality, the designs presented can each serve as valid plug-in detectors for a 1-inch diameter ^{3}He detector operating at 4 atmospheres pressure and with an active length of 10 cm. Furthermore, the results of this research demonstrate that the techniques developed here can be applied toward the testing of new detector materials and/or designs to determine their suitability as spectrally equivalent alternatives to ^{3}He.

Figure 3. (a) Alternative Design 3 configuration, (b – d) adjoint gradient profiles, (e) adjoint function per unit source density in the forward air-filled course meshes adjacent to the polyethylene (toward a source), and (f) the adjoint reaction rate across all air-filled course meshes and the fractional bias with ^{3}He.



Footnotes

A. Forward Group 1 (17.3 MeV) is Adjoint Group 47 (?0.1 eV) and vice versa.

B. TORT was developed by the Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831.

C. THREEDANT, PARTISN, and MCNP5 were developed by the Los Alamos National Laboratory, Los Alamos, NM 87545.

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Digital Pulse Shape Discrimination with the XIA Pixie-500 and EJ309

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Abstract
Due to the shortage of Helium-3, research has been directed toward the development of alternative technologies capable of reliable and efficient neutron detection. Liquid organic scintillators are being investigated as a possible replacement because of their ability to both detect fast neutrons and reject gamma rays in a mixed field of radiation through the use of pulse shape discrimination. Previous research by other investigators has paired CAEN and Struck waveform digitizers with a variety of liquid organic scintillators to perform digital pulse shape discrimination and time-of-flight experiments. We used the recently developed, 12-bit, 500 mega-sample-per-second (MS/s) XIA Pixie-500 with 2 EJ309 liquid organic scintillators to perform bench-top ^{252}Cf time-of-flight experiments and investigate alternative methods of digital pulse shape discrimination. The results of the time-of-flight experiment are presented. The three digital pulse shape discrimination methods that were applied include the standard charge integration technique and two alternative methods (based on pattern-recognition and curve fitting) previously investigated by D. Takaku, T. Oishi, and M. Baba.[7] We found the pattern-recognition method achieved the best neutron-gamma discrimination using a quantitative comparison of separation that estimates the neutron/gamma misclassification rate by fitting overlapping Gaussian distributions to the pulse shape parameter distribution. Due to its relative simplicity, the pattern-recognition algorithm could potentially be implemented on a field-programmable gate array (FPGA) enabling real-time neutron-gamma discrimination with low misclassification rates.

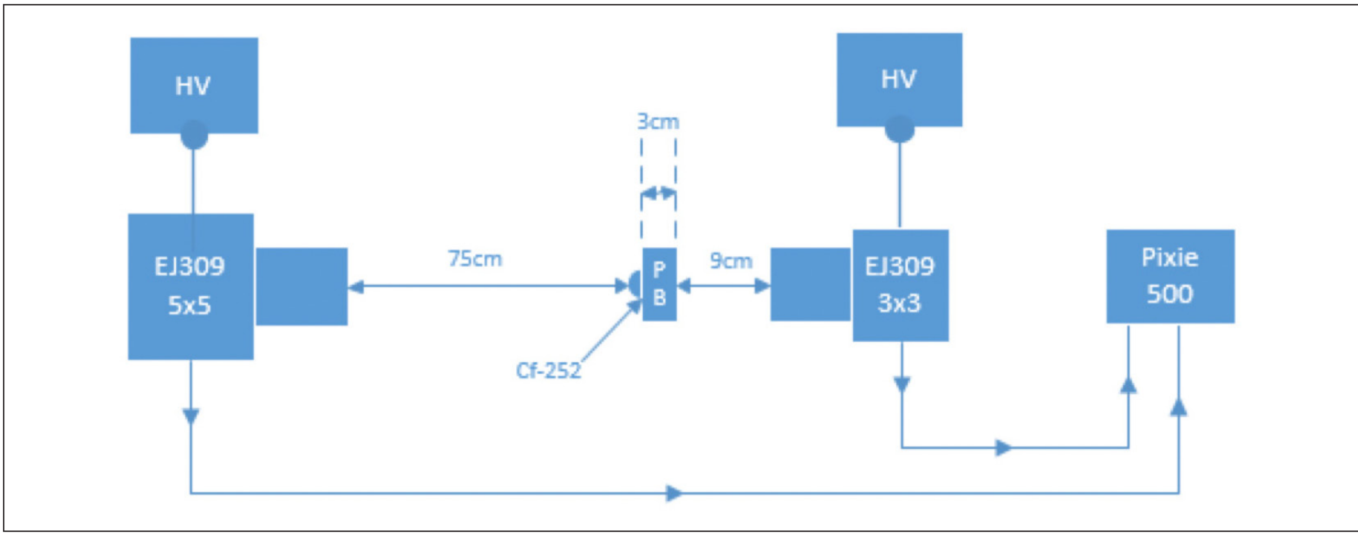
Introduction
Rapid and reliable detection, identification, and characterization of special nuclear material are capabilities essential to nuclear security. Special nuclear material (SNM) is the essential component of any nuclear weapon, and any of the following elements or isotopes are weapons-usable: plutonium, ^{235}U, or uranium enriched in the isotopes of ^{233}U or ^{235}U.[1] Unlike most other radionuclides, SNM has the unique characteristic that it emits both gamma rays and neutrons, and, in sufficient quantities, it can sustain induced fission chain-reactions. This attribute can be used to distinguish SNM from other potentially benign radiation sources if detection methods capable of distinguishing between gamma rays and neutrons are employed. Historically, ^{3}He gas-filled proportional counters have been one of the primary instruments used to detect neutrons because of ^{3}He's large (n,p) reaction cross-section at low neutron energies and the proportional counters' low sensitivity to gamma rays. The shortage of ^{3}He has made the development of alternative neutron detection technologies a high priority in U.S. research and development for domestic and international nuclear security.[2]

Organic scintillators represent one possible neutron detection replacement technology for ^{3}He proportional counters because of their sensitivity to fast neutrons and their ability to differentiate incident particle types. Pulse shape discrimination, or PSD, is the technique applied to discriminate between fast neutrons and gamma rays in a mixed field of radiation.[3] Liquid organic scintillators exhibit a time dependent light output, which can be represented by the sum of two exponential decay terms; these are often referred to the *fast* and *slow* components of scintillation decay. A greater fraction of light is produced during the slow component of decay for a neutron than is produced for a gamma ray. As a result a neutron pulse decays slower in time than a gamma pulse and this shape difference is used to differentiate between neutrons and gamma rays.

Experimental Methods
The 12-bit, 500 MS/s Pixie-500 waveform digitizer was coupled with two EJ309 liquid organic scintillators to perform a ^{252}Cf time-of-flight (TOF) experiment. A time-of-flight measurement classifies particles based on the time it takes them to travel a known distance between a *start* and *stop* detector. Since gamma rays travel at the speed of light and neutrons travel at a speed according to their kinetic energy, it will take a neutron much longer to travel the distance between the start and stop detectors. The same data can be analyzed using pulse shape discrimination algorithms; the results of which are compared to the time of flight measurement results.

Figure 1 shows the ^{252}Cf experiment layout. A 0.02-μg ^{252}Cf source was placed 75 cm from the 5x5 EJ309, the stop detector, and 9 cm from the 3x3 EJ309; the start detector. A 3 cm thick lead shield was placed behind the source to prevent the 3x3 from being overwhelmed by gamma rays. The time between a trigger in the start detector and a trigger in the stop detector represents the TOF of the particle.

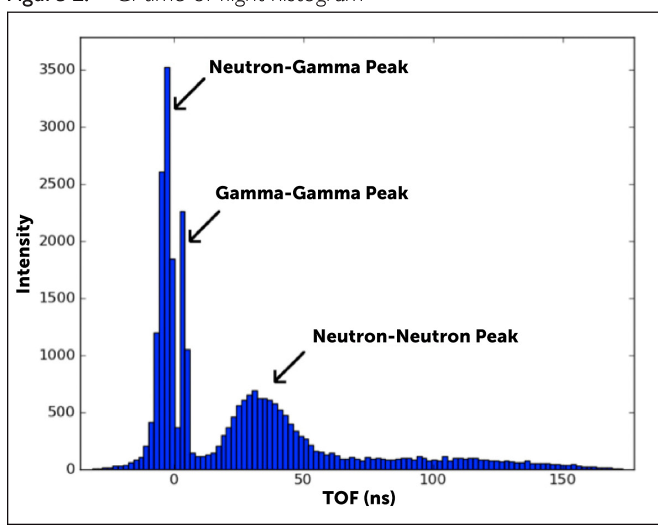
Figure 1. 252Cf time-of-flight experiment



A digital constant fraction discriminator[3] was employed to assign arrival times to each waveform. A thirty-minute data collection was taken in order to accumulate the ^{252}Cf TOF histogram shown in Figure 2.

The figure shows the three primary peaks that occur in the histogram. Each peak occurs because of a specific sequence of detection. The "Neutron-Gamma" peak occurs due to the detection of a neutron in the 3x3 and a gamma ray in the 5x5. Its width is due to the varying kinetic energy of the neutrons emitted from the ^{252}Cf. The "Gamma-Gamma" peak represents gamma detections in both the 3x3 and the 5x5 and it is relatively narrow due to the constant speed of gamma rays. The "Neutron-Neutron" peak corresponds to neutron detection in the 3x3 and neutron detection in the 5x5. Given a neutron detection threshold of 900 keV, upper neutron energy of 12 MeV, and the experiment geometry shown in Figure 1, this peak should span from approximately 13 ns to 54 ns as shown in Figure 2. Since this peak begins to rise at approximately 12 ns, the TOF measurement classified particles that triggered in the 5x5 with a TOF greater than 12 ns as "time-of-flight attributed" neutrons and particles with a TOF less than 12 ns as gamma rays.

Figure 2. 252Cf time-of-flight histogram



Pulse Shape Discrimination Analysis and Results

Three separate PSD algorithms were applied to the set of waveforms from the 5x5 that the TOF measurement classified as neutrons or gamma rays. A 100 keVee, or keV electron equivalent, light output threshold was used for the analysis. Since the scintillator light output for a recoil proton (as a result of neutron interaction) and a recoil electron (as a result of a gamma interaction) of equivalent energy are not equal, the term keVee, or keV electron equivalent, is used to place the light output on an absolute basis. A 100 keV electron will produce 100 keVee of light output (1 to 1 ratio); a recoil proton of equivalent energy will produce a smaller light output.[4] Using the University of Michigan's characterization of EJ309,[5] it was determined that a 900 keV recoil proton is required to produce 100 keVee of light.

Digital Charge Integration

The charge integration technique relies on the fact that heavy charged particles produce a greater fraction of light during the decay of the pulse than recoil electrons do. This causes the tail area of a neutron pulse (caused by a recoil proton) to typically represent a larger fraction of the total area under the waveform when compared to the tail area of a waveform caused by a gamma ray. Figure 3 shows a typical waveform that was analyzed with the digital charge integration algorithm.

Figure 3. Digital charge integration waveform

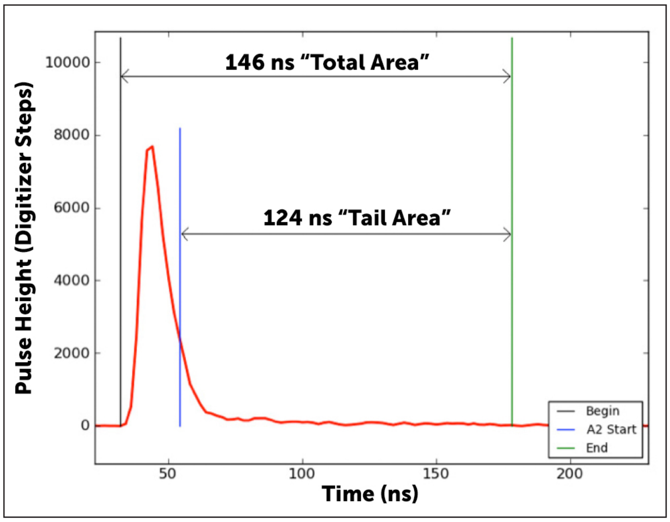
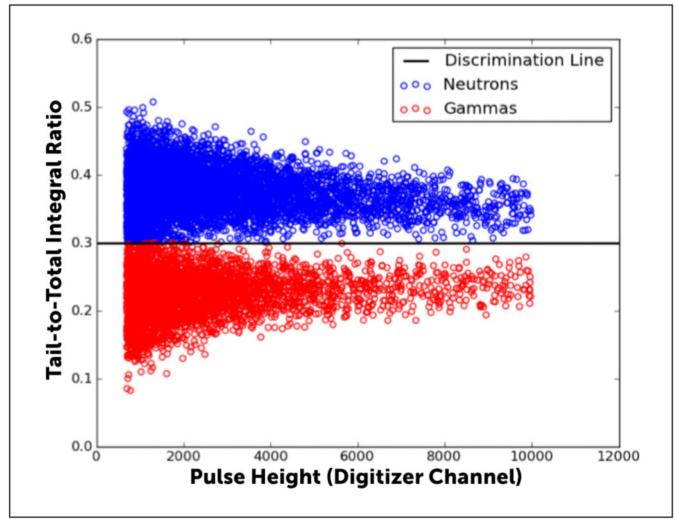


Figure 4. Area ratio vs. pulse height



For each waveform analyzed, the beginning and the end of the pulse were marked when the leading and trailing edge rose and fell below an amplitude threshold. The threshold was established by determining where the moving average of the waveform rose above or fell below the RMS level of the waveform. The tail area, A_{Tail}, is taken to start 10 ns beyond the location of the peak since this region exhibits the most shape difference for a gamma and a neutron event. The tail-to-total area ratio is the parameter that the digital charge integration algorithm uses to classify each particle:

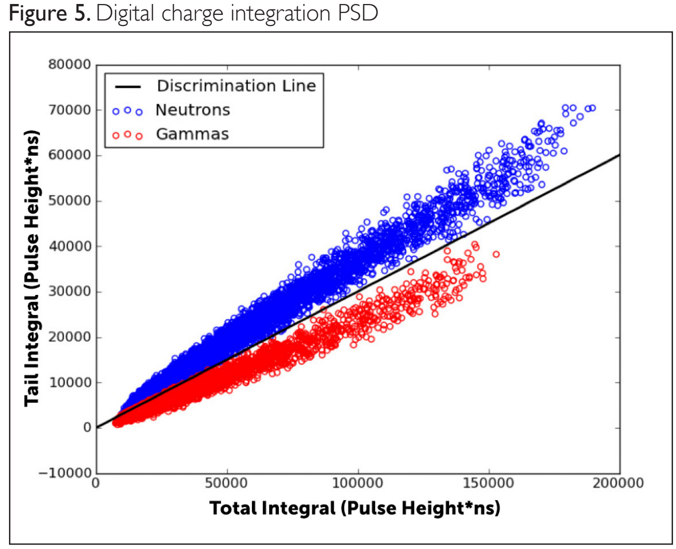
$$R = \frac{A_{Tail}}{A_{Total}} \qquad (1)$$

This process was repeated for each waveform that was analyzed (after applying a data cleaning algorithm to filter out misshaped waveforms[6]) and Figure 4 shows a scatter plot of the calculated area ratio versus the pulse height for each waveform.

Using this figure, an area ratio threshold of 0.3 was selected so that the PSD algorithm classified waveforms with an area ratio greater than 0.3 as neutrons and waveforms with an area ratio less than 0.3 as gamma rays. Figure 5 shows a scatter plot of the tail area versus the total area for each waveform.

The figure shows particles that have been classified consistently by both the charge integration algorithm (R > 0.3 as a neutron) and the TOF measurement (TOF > 12 ns as a neutron). The charge integration method shows clear separation between neutrons and gammas down to low energies where the separation is typically less clear.

Figure 5. Digital charge integration PSD



Pattern Recognition Method

The next method of digital pulse shape discrimination investigated was a pattern recognition technique. The pattern recognition method compares a known reference waveform with each waveform in question by treating each waveform as a vector and computing the scalar product between the reference and the *unknown* pulse. D. Takaku and T. Oishi have previously shown a similar method to exhibit adequate pulse shape discrimination results.[7] In this work, the reference vector was chosen to be a waveform caused by a gamma interaction in the EJ309. A gamma waveform was chosen as the reference vector because the pulse shape remains fairly constant and is independent of energy. Waveforms were collected from a ^{60}Co source and saved to construct an average gamma waveform, which was used as the reference vector for this analysis. In an attempt to fairly compare the reference waveform, which exhibits little noise, to a waveform in question, each waveform's *tail* region was passed through a five point smoothing function to reduce the noise on each waveform.

The resulting smoothed tail section was treated as a vector, X_{tail}, whose components are the digitized amplitude, x_i, at the corresponding sampling time. Taking the scalar product of the waveform's smoothed tail, vector X_{tail}, and the tail of the reference waveform, vector Y_{tail}, is the basis of which the pulse shape discrimination was performed. The scalar product is given by:

$$X_{Tail} \cdot Y_{Tail} = \sum_i x_i y_i \qquad (1.2)$$

Figure 6 shows a typical pattern recognition comparison.

The figure shows the reference gamma waveform (shown in green) compared to a sample waveform (shown in blue). The ratio, R, between the scalar product of the tails and the product of the magnitudes of each vector is the pulse shape parameter for this analysis:

$$R = \frac{X_{Tail} \cdot Y_{Tail}}{\|X\|\|Y\|} \qquad (1.3)$$

where $\|X\|\|Y\|$ is the scalar product of the two tail vectors, and $\|X\|$ and $\|Y\|$ are the magnitudes of each waveform, respectively. It should be noted that the magnitudes represent the magnitude of the *entire* waveform. Figure 6 shows that the tail was taken to start at a fixed point of 20 ns beyond the peak of the waveform so that the scalar product is computed only where the shape difference of a typical neutron and gamma waveform is enhanced. Given the scalar product of the tails and the magnitudes of each waveform, the pulse shape parameter, R, can be obtained. This process was repeated for each waveform analyzed, and a scatter plot of the pulse shape parameter versus the pulse height for each pulse is shown in Figure 7.

The span of calculated pulse shape parameters ranges from approximately 0.001 to 0.021 where values closer to zero indicate a pulse shape that is similar to the reference waveform shape. The figure shows particles that have been classified consistently by both the pattern recognition algorithm ($R > 0.009$ as a neutron) and the TOF measurement (TOF > 12 ns as a neutron). The pattern recognition method shows clear separation down to very low energies.

Figure 6. Sample waveform vs. reference waveform

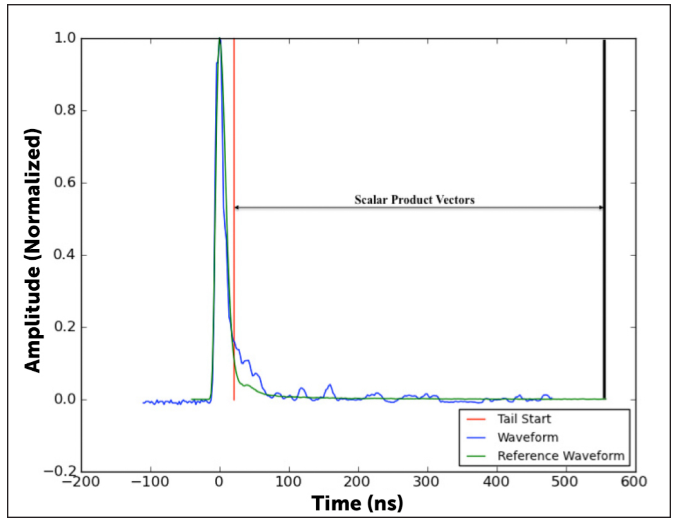
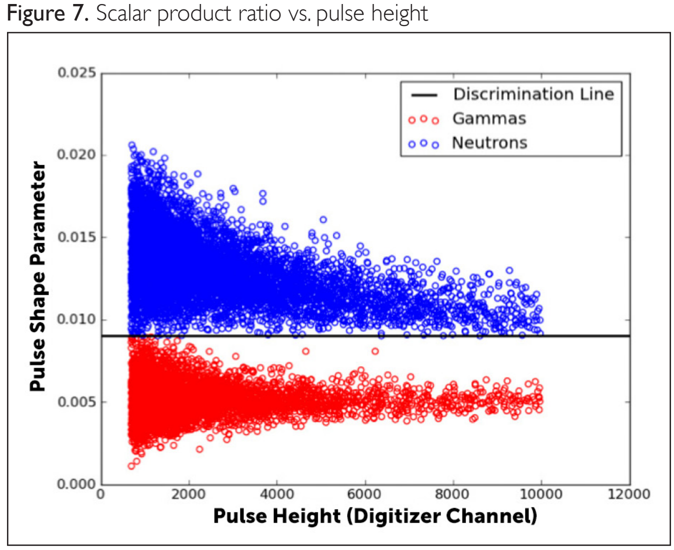


Figure 7. Scalar product ratio vs. pulse height



Curve Fitting Method

The final method of digital pulse shape discrimination investigated in this work is a curve fitting technique. This method relies on the fact that a neutron pulse will decay slightly slower than a gamma ray pulse due to its increased light output in the tail region of the pulse. Similar to the pattern recognition method, the curve fitting routine was previously shown to exhibit adequate PSD results by D. Takaku and T. Oishi.[7] To carry out the analysis, the tail of each waveform was passed through a 5 point smoothing function and fitted with the curve:

$$y = e^{-\lambda t} \qquad (1.4)$$

The decay constant, λ, is the pulse shape parameter that is obtained for each waveform. The delayed light output from a neutron interaction in the liquid scintillator causes a neutron pulse to have a decay constant that is slightly smaller than typical gamma ray waveform decay constants. A scatter plot of the pulse shape parameter, λ, versus the pulse height is shown in Figure 8.

The span of calculated pulse shape parameters ranges from approximately 0.08 to 0.52. The figure shows particles that have been classified consistently by both the curve fitting algorithm ($\lambda < 0.238$ as a neutron) and the TOF measurement (TOF > 12 ns as a neutron). The curve-fitting algorithm shows more sensitivity

Figure 8. Pulse shape parameter (λ) vs. pulse height

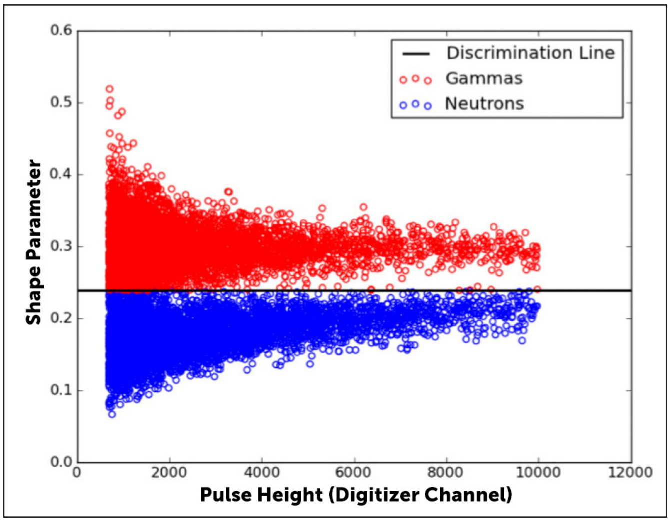
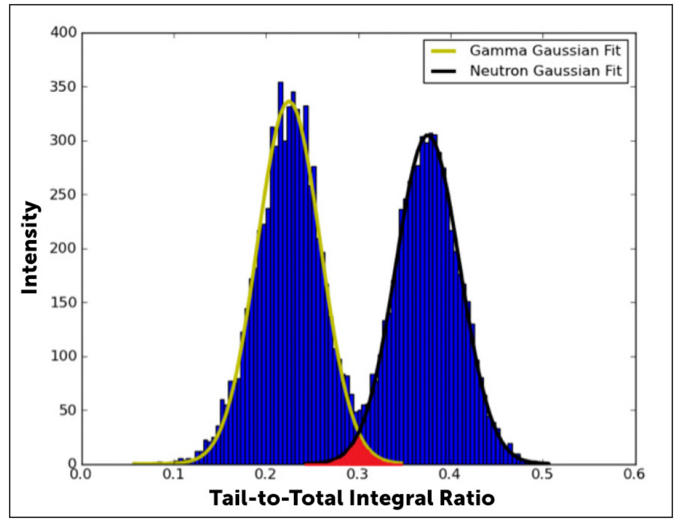


Figure 9. Digital charge integration figure-of-merit



to noise on the tail of the waveforms; separation in this analysis is not as clear as the two previous methods.

Figure of Merit

The figure-of-merit (FOM) for a particular PSD method can provide a quantitative degree of the PSD algorithm quality. In this work, we based our FOM on the particle misclassification rate, which can be obtained by calculating the area of overlap that the two peaks exhibited in the pulse shape parameter histogram. To obtain the overlap area, each peak was fit with a Gaussian distribution given by:

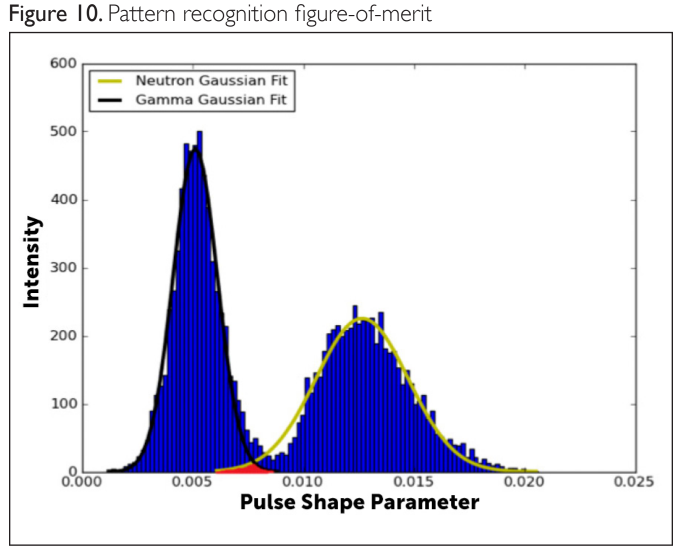
$$G(x) = Ae^{\frac{-(x-\mu)^2}{2\sigma^2}} \qquad (1.5)$$

where σ is the standard deviation about the mean μ, and A is a constant. Figure 9 shows the FOM for the digital charge integration method.

The intersection point of the gamma and neutron Gaussian distributions shown in the figure was calculated as X_o and the area under the intersection (shaded in red) is the estimated particle misclassification rate and was determined by integrating under the intersection of the distributions. The intersection point, X_o, is given by:

$$x = \frac{1}{\sigma_\gamma^2 - \sigma_\nu^2}\left(\pm\sqrt{-\sigma_\gamma^2\sigma_\nu^2\left(2\ln\left(\frac{A_\gamma}{A_\nu}\right)\sigma_\gamma^2 - 2\ln\left(\frac{A_\gamma}{A_\nu}\right)\sigma_\nu^2 - \mu_\gamma^2 + 2\mu_\gamma\mu_\nu - \mu_\nu^2\right)} + \sigma_\gamma^2\mu_\nu - \sigma_\nu^2\mu_\gamma \right) \qquad (1.6)$$

Figure 10. Pattern recognition figure-of-merit



where A is a constant, σ is the standard deviation, and μ is the mean for each distribution. The misclassification rate is then given by:

$$\text{Missclassification Rate} = \frac{\int_{-\infty}^{X_o} G_\nu(x)dx + \int_{X_o}^{\infty} G_\gamma(x)dx}{\int_{-\infty}^{\infty}\left(G_\nu(x) + G_\gamma(x)\right)dx} \qquad (1.7)$$

Using this figure-of-merit, the digital charge integration method misclassified approximately 1.41 percent of the particles that were classified.

The figure-of-merit for the pattern recognition method is shown in Figure 10.

The pattern recognition figure-of-merit shows that the Gaussian fit represents the gamma peak well, but the neutron Gaussian fit is less representative of the experimental data due to the slight asymmetry evident in the neutron peak. Evaluating Equation 1.7 with the appropriate bounds and parameters for each distribution yields 0.67 percent of the waveforms analyzed were misclassified according to this figure-of-merit. It is difficult to determine whether this misclassification rate is an over estimation or under estimation of the true area of overlap of the two distributions. It is noted that the gamma distribution discounts area that is present and the neutron distribution counts area that is not present and that these areas appear to be approximately equal, thus the misclassification rate of 0.67 percent is most likely a good representation.

The figure-of-merit for the curve fitting routine is shown in Figure 11.

Using the fitted parameters and evaluating Equation 1.6 with the appropriate bounds, it was determined that the curve fitting method misclassified approximately 2.24 percent of the waveforms analyzed. It is thought that this method is more sensitive to noise on the tail and as a result a higher misclassification rate was observed.

Co-60 Test

To test the PSD algorithms, data was collected from a Co-60 gamma source and analyzed with each PSD algorithm. A total of 18,859 gamma waveforms were analyzed using each PSD method. The neutron identification rate (neutrons per event) for each method is shown below in Table 1.

Table 1. Neutron identification rate

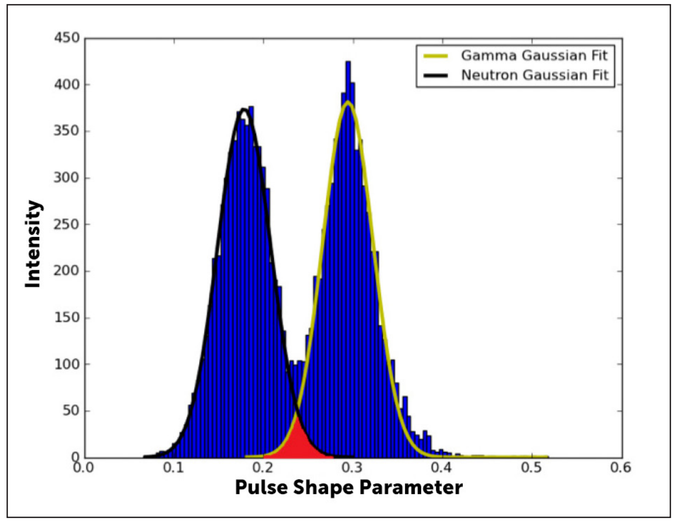
PSD Method	Charge Integration	Pattern Recognition	Curve Fitting
Neutron identification rate (Neutrons per event)	0.0097	0.0048	0.0248

The particle was identified as a neutron if the waveform's shape parameter fell in the neutron range for each PSD algorithm- a ratio greater than 0.3 for charge integration, a ratio greater than 0.009 for pattern recognition, and a decay constant less than 0.238 for the curve fitting algorithm. The curve fitting neutron identification rate is larger than the two other methods probably due to its sensitivity to noise.

Conclusions and Future Work

The ability to quickly and accurately characterize special nuclear material is crucial in nuclear security applications. The shortage of ^{3}He has made it necessary to develop alternative neutron detectors. Liquid organic scintillators have the potential to replace ^{3}He detectors because of their sensitivity to fast neutrons, their pulse shape discrimination ability, and their fast time response.

Figure 11: Curve fitting figure-of-merit



In this work the 500 MHz, 12-bit, Pixie-500 digitizer was coupled with EJ309 liquid scintillators to perform a bench-top ^{252}Cf time of flight experiment and analyze the waveforms with three separate PSD algorithms. The classifications given by the TOF experiment were compared to those made by the PSD methods. These methods included a digital charge integration technique, a pattern recognition method, and a curve fitting procedure. Each PSD method exploits pulse shape differences in a different manner, but our results indicate good agreement among the different methods applied to the same data set; each method's classifications fell within 2 percent of the other two methods. The Gaussian fitting figure-of-merit analysis indicates that the pattern recognition method exhibits the lowest particle misclassification rate. The charge integration method exhibited a higher particle misclassification rate, but still under 1.5 percent, while the curve fitting method exhibited a misclassification rate just over 2 percent, probably due to the sensitivity of noise on the baseline of the pulse.

Future work could include an effort to resolve the shape of the neutron parameter peak from the pattern recognition method in order to obtain a better fit to experimental data than the Gaussian fit used in this work. A better fit would yield a more accurate misclassification rate for this method. Future effort could also be made to classify incoming radiation in real time. A study to determine if each PSD algorithm could be implemented in the Pixie-500's DSP or the FPGA would be beneficial.

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Potential Roles for Unattended Safeguards Instrumentation at Centrifuge Enrichment Plants

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Abstract

As global uranium enrichment capacity under international safeguards expands, the International Atomic Energy Agency (IAEA) is challenged to develop effective safeguards approaches at gaseous centrifuge enrichment plants, particularly high-capacity plants, while working within budgetary constraints. New safeguards approaches should detect and deter plausible diversion scenarios, but should also strive for efficiency advantages in implementation, for both the IAEA and operators. Under the IAEA's State-level approach to safeguards implementation, the IAEA needs a flexible toolbox of technologies allowing tailoring of the safeguards measures for each enrichment facility. In this paper, the potential roles, development status and remaining development questions for three different types of unattended measurement instrumentation are discussed. Online Enrichment Monitors (OLEM) could provide continuous enrichment measurement for 100 percent of the declared gas flowing through unit header pipes. Unattended Cylinder Verification Stations (UCVS) could provide unattended verification of the declared uranium mass and enrichment of 100 percent of the cylinders moving through the plant, but also apply and verify an "NDA Fingerprint" to preserve verification knowledge on the contents of each cylinder throughout its life in the facility. Sharing of the operator's load cell signals from feed and withdrawal stations could count all cylinders introduced to the process and provide periodic monitoring of the uranium mass balance for in-process material. A fictitious "Facility X" is used to illustrate qualitatively how the data streams from these instruments could be integrated in a way that addresses all prominent diversion scenarios. An example case study in Facility X demonstrates quantitatively how unattended instruments could simultaneously improve effectiveness and efficiency over today's measures. In this case study, load-cell monitoring ensures that only declared cylinders are introduced to the process areas, and that the total uranium mass balance of in-process material indicates no evidence of undeclared excess production. The integration of load cell, OLEM and UCVS data streams provides 100% verification of declared cylinder flow and enables the periodic verification of the declared ^{235}U mass balance in the plant. The case study illustrates how the continuous presence and relatively high accuracy of the OLEM and UCVS ^{235}U assay could support the detection of protracted diversion scenarios in a way that has never before been viable for the IAEA, due to accuracy and operational limitations associated with portable instruments for cylinder verification. Such unattended instrumentation could also reduce or eliminate the need for announced inspections, and significantly reduce the need for drawing samples from gas and cylinders during inspections. This paper uses data and information gathered from technology development projects in the international safeguards community to illustrate and evolve the IAEA's vision for unattended technology in enrichment plant safeguards, and to provide the IAEA's perspective on remaining development challenges for these unattended instruments.

Introduction

The IAEA's model safeguards approach for gas centrifuge enrichment plants[1] describes the challenges associated with safeguarding large centrifuge enrichment plants, and defines the high-level verification objectives for enrichment plant safeguards approaches, i.e., the timely detection and deterrence of:

a) diversion of natural, depleted or low-enriched UF_6 from the declared flow in the plant;
b) misuse of the facility to produce undeclared product (at the normal product enrichment levels) from undeclared feed (i.e., excess production);
c) misuse of the facility to produce UF_6 at enrichments higher than the declared maximum, in particular highly enriched uranium.

At present, the IAEA's safeguards approaches at enrichment plants are based on a combination of announced and unannounced inspections, during which time a number of verification activities are performed, including: weighing and nondestructive assay (NDA) of a subset of the plant's cylinder flow and inventory, collection of UF_6 samples from in-process material and selected cylinders for subsequent destructive analysis (DA) in a laboratory, and environmental sampling (ES) for subsequent laboratory analysis. The weight measurements of cylinders are performed using either operator-owned scales or IAEA's portable hanging load cells, while the NDA measurements utilize handheld gamma-ray spectrometers combined with ultrasonic wall-thickness gauges. Some of the challenges associated with the use of these conventional measures to address the three verification objectives described above, particularly for large-capacity enrichment plants, are discussed here.

In the protracted diversion-from-declared scenario, the operator removes small amounts of material from the process over relatively long time periods, and the removal of this material is obscured by the uncertainties in the operator-declared uranium and ^{235}U mass balances. The absolute value of these uncertainties grows as the material balance time period and/or plant capacity increases. Detection of protracted diversion scenarios could be improved if the IAEA could monitor 100 percent of material flows and periodically verify, independently, the uranium and ^{235}U mass balances for the facility. However, available human and financial resources preclude continuous inspector presence at the facility to measure all of the material flow using today's attended methods. Further, the portable measurement methods currently used by inspectors have relatively low accuracy for both the total uranium mass and ^{235}U enrichment in a cylinder, which would lead to very large uncertainties on a ^{235}U balance based on such instruments. The poor accuracy of today's cylinder verification instruments necessitates additional safeguards measures, including the destructive analysis of UF_6 samples drawn from some of the cylinder population (such DA measurements can also be used for other purposes). These are among the reasons that the IAEA is exploring how unattended instruments capable of continuously and more accurately verifying material flows, for both in-process gas and cylinders, could help improve the deterrence and timely detection of protracted diversion scenarios.

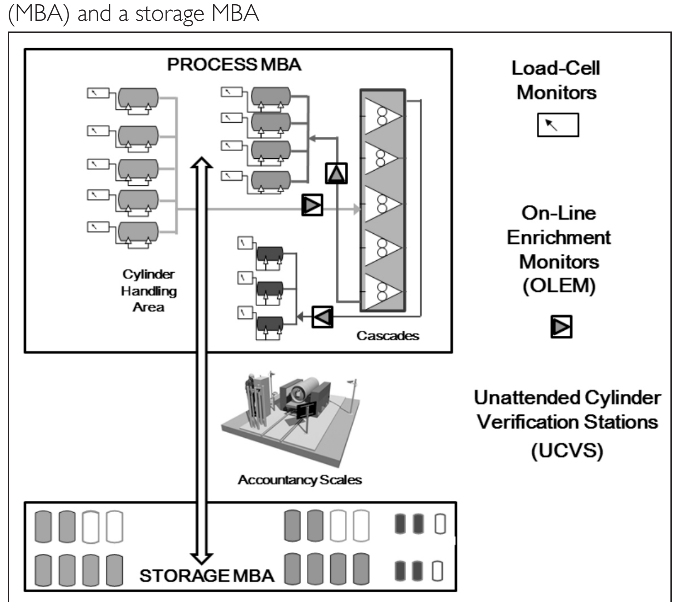
In the excess production scenario, undeclared feed is used to produce undeclared product. Detecting this scenario includes verification that only declared cylinders are connected to the cascades, and ensuring that there are no undeclared takeoff points in between the feed and withdrawal stations. Unattended weighing instruments at the feed and withdrawal stations could detect the introduction of all cylinders to the plant, and provide a periodic balance of in-process material (i.e., material flowing out of feed cylinders and into product and tail cylinders, plus the gas in the cascades). Together, these data streams have the potential to detect and deter the excess production scenario. Other important measures to counter the excess production scenario could include surveillance, unannounced inspections and possibly mailbox approaches.[2]

Current measures to meet the verification objective related to higher-than-declared enrichment include the use of portable instruments based on gamma-ray spectroscopy to measure the enrichment of in-process gas (e.g., the IAEA's Cascade Header Enrichment Monitor), and environmental samples collected by inspectors during inspections. The portable in-field spectrometer systems are relatively complex in terms of calibration for gas density and wall-deposit thickness, and such measurements during periodic inspections do not provide for the continuous monitoring desired by the IAEA. While the accuracy of the environmental sample analysis can be exquisite, the timeliness of the results, often several months, can be problematic for early detection. Unattended instruments continuously monitoring in-process gas enrichment could complement environmental sampling and inspection activities in terms of timeliness and a continuous monitoring presence.

In recent years, the IAEA has pursued innovative techniques and an integrated suite of safeguards measures to address the verification challenges posed by advanced centrifuge technologies and the growth in separative work unit capacity at modern centrifuge enrichment plants.[2-4] A prominent theme among these projects is the use of permanently installed, unattended instruments capable of performing the routine and repetitive measurements previously performed by inspectors, thereby allowing the inspectors to use their time on tasks and investigation that depend more heavily on human intuition and decision making. When combined with other safeguards measures, unattended instruments at centrifuge enrichment plants have the potential to significantly improve the IAEA's effectiveness to detect and deter the three primary diversion scenarios described previously, while simultaneously improving the efficiency of facility-level safeguards approaches. Further, the unattended measurement systems have the potential to be beneficial to facility operators, for example for process control, for meeting regional or state regulatory requirements, and to ease and expedite the process for releasing cylinders from the facility. Identifying and developing improvements in safeguards efficiency, while maintaining or improving effectiveness, are important considerations as the IAEA fully implements the State-level concept and evolves the role of safeguards technologies.[5]

This paper builds on IAEA's previously defined vision and objectives for advanced safeguards approaches, but focuses on the potential roles and development status of three unattended measurement systems (see Figure 1): Online Enrichment Monitors

Figure 1. Schematic overview of load-cell monitors, OLEM and UCVS in an enrichment facility divided into a process material balance area (MBA) and a storage MBA



(OLEM), Unattended Cylinder Verification Stations (UCVS), and sharing of the operator's load cell signals.

To support the discussions that follow, a reference centrifuge enrichment plant is defined. This plant represents the modern, large-capacity centrifuge facilities that are a primary motivation for the IAEA's study of a new generation of safeguards measures and approaches. The reference facility is 4,000 ton SWU/year, with eight process units consisting of ten cascades each, and utilizing UF_6 withdrawal by desublimation directly into product and tails cylinders. Two material balance areas (MBAs) are defined in the plant: a process MBA and a storage MBA.

Sharing of the operator's load cells signals from feed and withdrawal stations has the potential to count cylinders introduced to the process and to provide periodic balance of the uranium mass for the in-process material at the plant. Load-cell monitoring supports the detection and deterrence of excess production scenarios in a way that other unattended instrumentation cannot. More than 100 feed or withdrawal stations would need to be monitored in the reference facility. This large number of stations precludes the option of independent IAEA instrumentation on each station and encourages the sharing of weighing systems owned and maintained by the operator. Resource implications and signal-authentication considerations for the sharing of data from the operator's load cells will be discussed below.

The OLEM could provide continuous measurement of 100 percent of the declared gas flowing through unit header pipes, a key capability for the detection of the higher-than declared production and diversion-from-declared scenarios. In the reference large-capacity enrichment plant described above, 16-24 OLEM units would be required, depending on whether the feed is monitored. Under current assumptions, the OLEM would be owned and operated by the IAEA, but the OLEM design includes data-security provisions to allow sharing with the operator (e.g., for process control and criticality control purposes) or other stakeholders (e.g., regional or national authorities).

A UCVS could provide unattended verification of the declared uranium mass and enrichment in 100 percent of the cylinders moving through the plant, but also apply and verify an 'NDA Fingerprint' to preserve verification knowledge on the contents of each cylinder throughout its life in the facility, without the need for an inspector's presence to apply and verify traditional seals. (The concept of the NDA Fingerprint is described in more detail later.) The UCVS NDA features also have the potential to provide independent cross-verification of the signals from operator weighing systems. The UCVS would be built around the operator's accountancy scales, so that two or three UCVS units might be utilized in each plant. Apart from the accountancy scale, UCVS would be owned and operated by the IAEA, but include data-security provisions so that data streams could be shared with the operator (e.g., for cylinder tracking and process control).

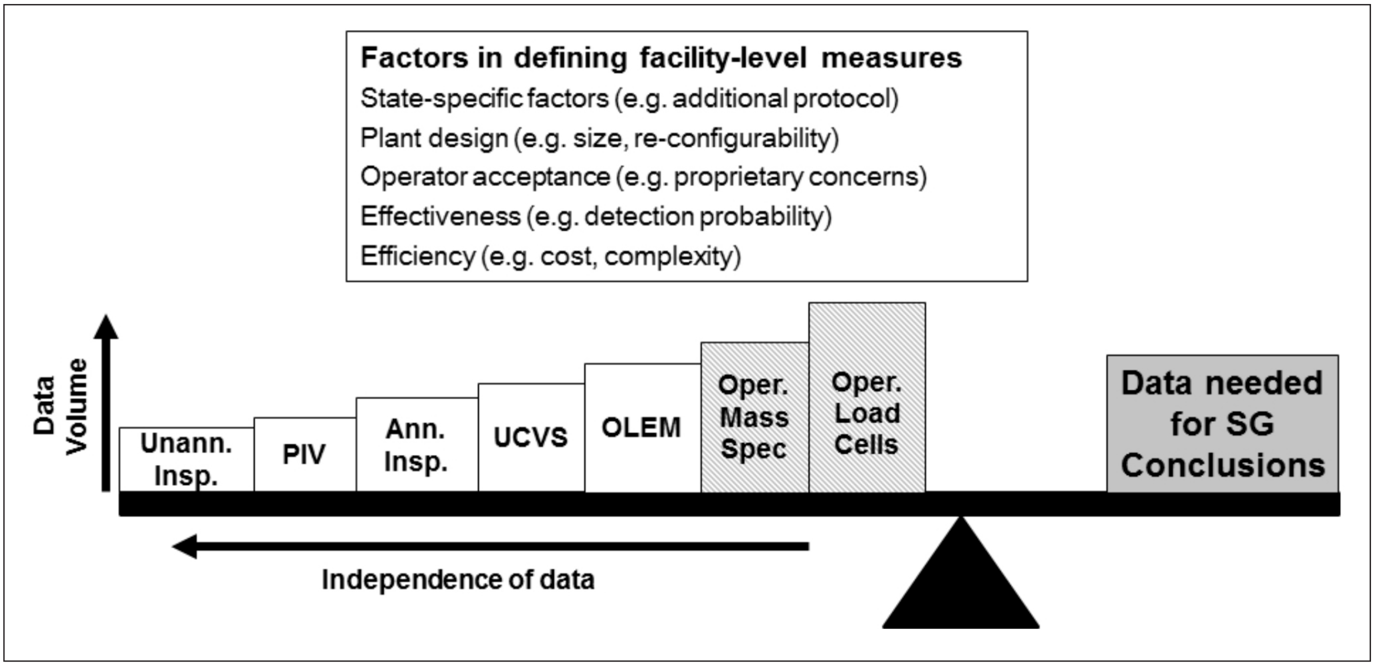
Assumed in this paper, though not discussed in detail, is the sharing of the operator's accountancy scale data. The high-accuracy accountancy scale data for each cylinder is a critical enabling data stream for optimal utilization of data from OLEM, UCVS and load cell monitoring concepts. For example, accountancy scale data would allow translation of relative enrichment measurements (from OLEM or UCVS) to absolute mass of ^{235}U in the cylinder, and for confidence-building in the authenticity of full- and empty-cylinder weights shared from the operator's load cells. Some potential methods for building confidence in the authenticity of shared accountancy scale data are mentioned, but development of data authentication measures for operator-owned weighing systems continues to be a development challenge for the IAEA; an exhaustive discussion of authentication methods is beyond the scope of this paper.

Though many development challenges remain before field implementation of these technologies will be considered by the IAEA, there are encouraging results and indications coming from development efforts in the safeguards community. For example, modeling- and measurement-based estimates of the achievable accuracy for online enrichment monitors and unattended cylinder NDA methods have helped to sharpen the viability picture for such instruments. Studies of how load cell data might be shared and authenticated for safeguards use have informed IAEA's considerations for shared weighing systems. Other studies have examined how the use of unattended systems might reduce the need for announced inspections, and sampling of in-process gas and cylinders.[6] This paper reflects on the safeguards community's recent progress at the instrument level, poses remaining development challenges from the IAEA perspective, and provides some qualitative and quantitative examples of how these instruments might work together to achieve the facility-level safeguards objectives under the IAEA's state-level approach to safeguards implementation.

Unattended Instrumentation in Context of the IAEA's State-level Concept

As global uranium enrichment capacity under international safeguards expands, the IAEA is challenged to develop effective safeguards approaches at gaseous centrifuge enrichment plants, particularly high-capacity plants, while working within resource limitations. New safeguards approaches should meet the high-level safeguards objectives for such facilities (i.e., timely detection of diversion from declared material, undeclared excess production, and production of higher-than-declared enrichment), but new approaches should also strive for efficiency advantages in implementation, for the IAEA, the state and the operator. Under the IAEA's state-level concept for defining safeguards approaches, the specific measures implemented at each facility will depend on a set of factors that include: state-specific characteristics (e.g., additional protocol in force); effectiveness in detecting and deterring the key diversion scenarios for that facility; plant design (e.g., size, re-configurability); operator acceptance (e.g., proprietary concerns); and efficiency (e.g., cost, complexity of safeguards

Figure 2. Depiction of how the IAEA might balance a toolbox of safeguards measures (left side of the fulcrum) including announced and unannounced inspection activities, a physical inventory verification (PIV) and unattended instrumentation, against the data needed to draw facility-level safeguards conclusions (right side of the fulcrum). Only selected measures on the left side of would be implemented at a given facility, depending on the data needed to draw safeguards conclusions under the state-level concept.



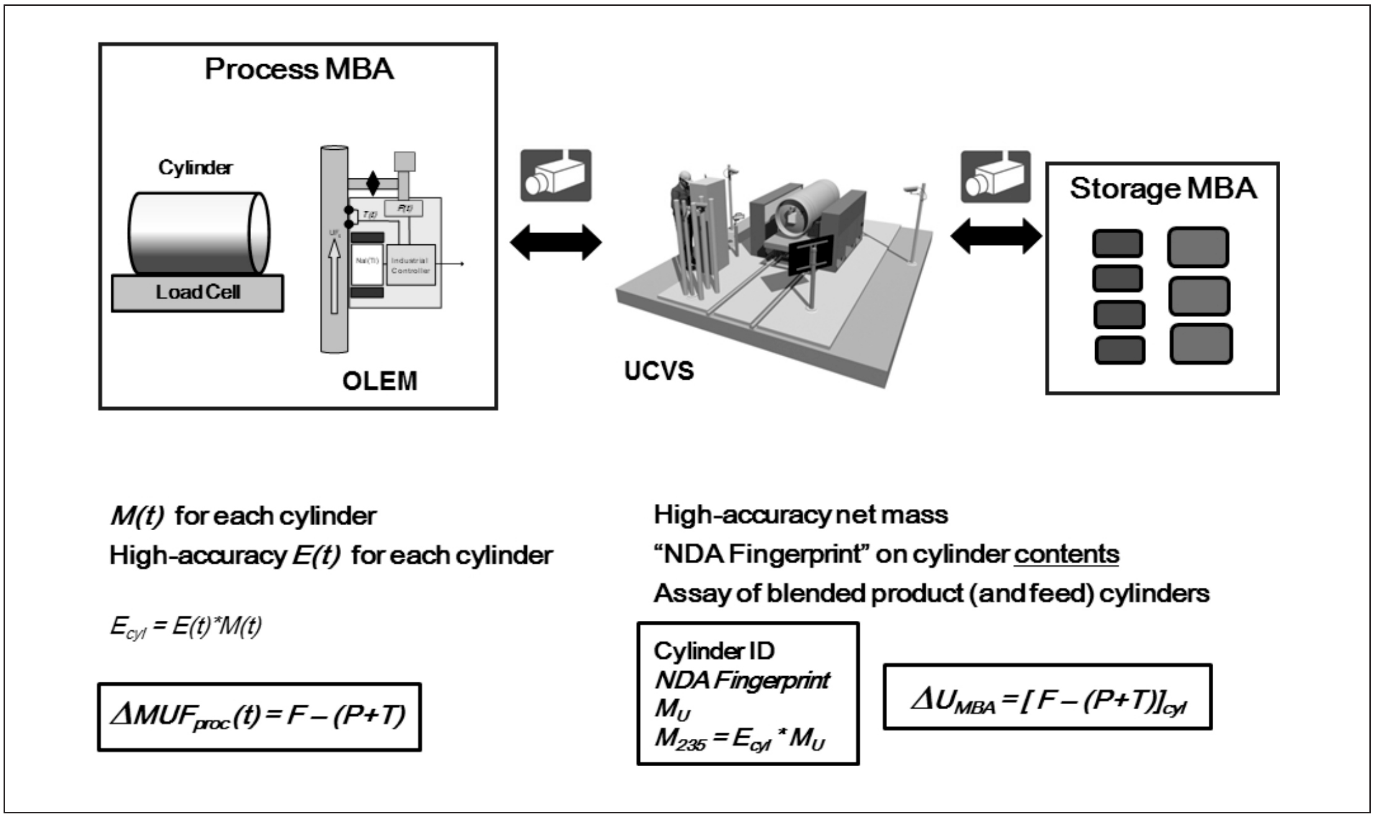
measures).[2] In order to optimize the efficacy and efficiency of safeguards measures at each different enrichment facility under safeguards, the IAEA needs a flexible toolbox of technologies (e.g., unattended and attended) and inspection options (e.g., announced and unannounced).

Improvements in safeguards effectiveness and enhancements in the efficiency of safeguards approaches are often in tension. To help relieve this tension, the IAEA's guiding philosophy is to rely on unattended instruments to perform routine, repetitive measurements, thereby unencumbering inspectors to do the investigative activities that rely on human intuition, tacit knowledge and decision making, such as design information verification or verifying the absence of indicators for undeclared activities. This implementation philosophy should lead to important operational advantages for all stakeholders, for example a significant reduction or elimination of announced inspections, reduction of material sampling activities during inspections, and the expediting of product-cylinder release for the operators.

Figure 2 provides a graphical representation of how the IAEA's inspection and technology tools (left side of the fulcrum) might be balanced against the data needed to draw safeguards conclusions at the facility level (right side of the fulcrum). For the tools on the left side of the fulcrum, the level of data independence increases from right to left. The potential volume of data derived from each measure during a given material balance period is depicted by the height of the box for each tool. For example, the volume of data derived from operator-owned and maintained load cells and mass spectrometers (boxes with grey hash) may be quite large, but this less-independent data would exert less force on the fulcrum arm than the same volume of more-independent data coming from IAEA-owned-and-operated instruments such as OLEM and UCVS. It is important to note that unattended instrumentation technology would always be accompanied and complemented by inspections (e.g., announced inspections, unannounced inspections and periodic physical inventories) that include investigative and data security activities.

As an example of how the State-level concept might be applied to enrichment plant safeguards, consider "Facility Y" located in a State with a comprehensive safeguards agreement and additional protocol in force, where integrated safeguards (e.g., including results from complementary access and open-source information analysis) has supported the broader conclusion that there are no undeclared nuclear material or activities in the State. Under these conditions, the importance of the excess production diversion scenario would be reduced, since the IAEA would have already concluded that there are no undeclared enrichment plants to further enrich undeclared low-enriched uranium product diverted from Facility Y. The measures implemented at Facility Y therefore, would be focused on detecting the higher-than declared production scenario, and verifying the declared material flows, as efficiently as possible. The safeguards measures implemented at this Facility Y are likely to be relatively limited compared to the measures implemented at Facility X, which is located in a State without an additional protocol in force, and where the provision

Figure 3. Schematic overview of how load-cell monitors, OLEM and UCVS might be integrated in a two-MBA plant similar to Facility X. Other containment and surveillance measures (e.g., cameras) in the facility would complement the unattended measurement systems.



of safeguards-relevant information to the IAEA has been more limited. For Facility X, the excess production scenario is of high importance because the IAEA is not able to draw the broader conclusion regarding undeclared enrichment facilities. In Facility X, the data needed to draw safeguards conclusions (right side of the fulcrum in Figure 2) will likely require a relatively *heavy* suite of safeguards measures (left side of the fulcrum).

Facilities X and Y are fictitious, created only to provide tangible examples of how the IAEA might define facility-specific safeguards measures under the State-level concept, using a flexible toolbox of unattended instruments and inspection authorities. In the remainder of this report, more details and discussion about each of the individual unattended instruments are provided, along with more thorough descriptions of how the data streams from such instruments might be integrated at the facility level. Facility X is used as an illustrative example in these discussions.

Potential Roles for Unattended Instrumentation at Facility X

The safeguards measures at Facility X include substantial utilization of unattended systems—load cell monitoring combined with OLEM, and UCVS. Consequently, this facility provides a convenient example for discussing how the data streams from these instruments could be integrated to allow the inspectorate to address the three relevant diversion scenarios: 1) diversion from declared, 2) excess production, and 3) higher-than-declared enrichment.

It is assumed in this discussion that Facility X contains two Material Balance Areas (MBAs, see Figure 3). The Process MBA includes the cascades, feed and withdrawal stations, weighing and sampling areas, and scrap and waste recovery. The Process MBA in Facility X includes the cylinder blending stations, though it is possible that the blending area could be a separate MBA, or even within the Storage MBA, in facilities under IAEA safeguards. Material forms in the Process MBA can be solid, liquid and gas and these materials could be either in-process or contained in cylinders. Therefore, the material accountancy measures in this MBA would be considered a mixture of 'bulk' and 'item' using IAEA nomenclature. The Storage MBA covers all of the cylinder storage areas and all material under safeguards in this MBA should be in solid form, contained in certified cylinder types. Generally speaking, only item accountancy measures are relevant to the Storage MBA.

The excess production scenario could be addressed by counting the cylinders introduced to the cascades to ensure that only declared cylinders are utilized, and via the continuous monitoring of the in-process UF_6 material balance ($MUF_{proc}(t)$ in Figure 3). This material balance would be based on the measured feed, product and tails mass flow rates (*F, P, T* respectively) in each enrichment unit (each of which might consist of 8-10 cascades), as determined from the sharing of operator load cell data from all of the feed and withdrawal stations in the unit. The time-dependent mass data, *M(t)* from the operator's load cells could be shared with the IAEA to determine the time periods during which specific cylinders are being filled (for product and tails stations) or are being withdrawn as plant feed. The material unaccounted for (*MUF*), would be calculated by the IAEA at time intervals negotiated with the operator, taking into consideration for example, the protection of operator's proprietary information. Under normal operation, the *MUF(t)* for total uranium calculated by the IAEA's sharing of the operator's load cells would be expected to be relatively small over short material balance periods, and consistent with mass decrements that are typical of normal operation for the plant (e.g., due to sampling, scrap, holdup). Unattended monitoring of the feed and withdrawal stations could also help to streamline inspection activities (e.g., to minimize cylinder switch-over activities).

The OLEMs on each unit header pipe would continuously measure the time-dependent relative uranium enrichment, *E(t),* in weight percent ^{235}U, of the gas filling or the gas being withdrawn from the cylinders. *E(t)* could be used in several ways. First, it could be combined with the *F, P,* and *T* total uranium mass flow rates recorded by feed and withdrawal station load cells, to calculate *MUF(t)* for ^{235}U. The IAEA then, could monitor for the excess production scenario using both the uranium and ^{235}U mass balances on the in-process gas.

OLEM data could also be used to calculate the average enrichment of the UF_6 in cylinders, E_{cyl}, by weighting the *E(t)* data for each cylinder time window by the *M(t)* for that same time window. By coupling the load cells and OLEMs in this way, a high-accuracy, independent measurement of E_{cyl} is produced. Alternatively, in cases where the sharing of load-cell signals is not acceptable or practicable, less-direct approaches to deriving mass-flow data could be considered. Such approaches may be viable, for example, in modern enrichment plants where the product enrichment level in each unit header is typically held as stable as possible for relatively long periods of time (e.g., 4.42% for several months). Under these assumptions, $E(t)$ = constant = E_{cyl} . *M(t)* could be assumed constant, or inferred from other plant variables.

Another important role of the OLEM units is the continuous monitoring of in-process gas for early detection of greater-than-declared enrichment levels. Because of the location of the OLEMs (see next section), a scenario involving cascade recycle and early takeoff inside the cascade halls is not precluded, but such a scenario is likely to require the operator to make undeclared facility modifications that would be prone to identification during unannounced inspections. Load-cell monitoring and other IAEA tools (e.g., environmental sampling during unannounced inspections) could also be used to address such early takeoff scenarios.

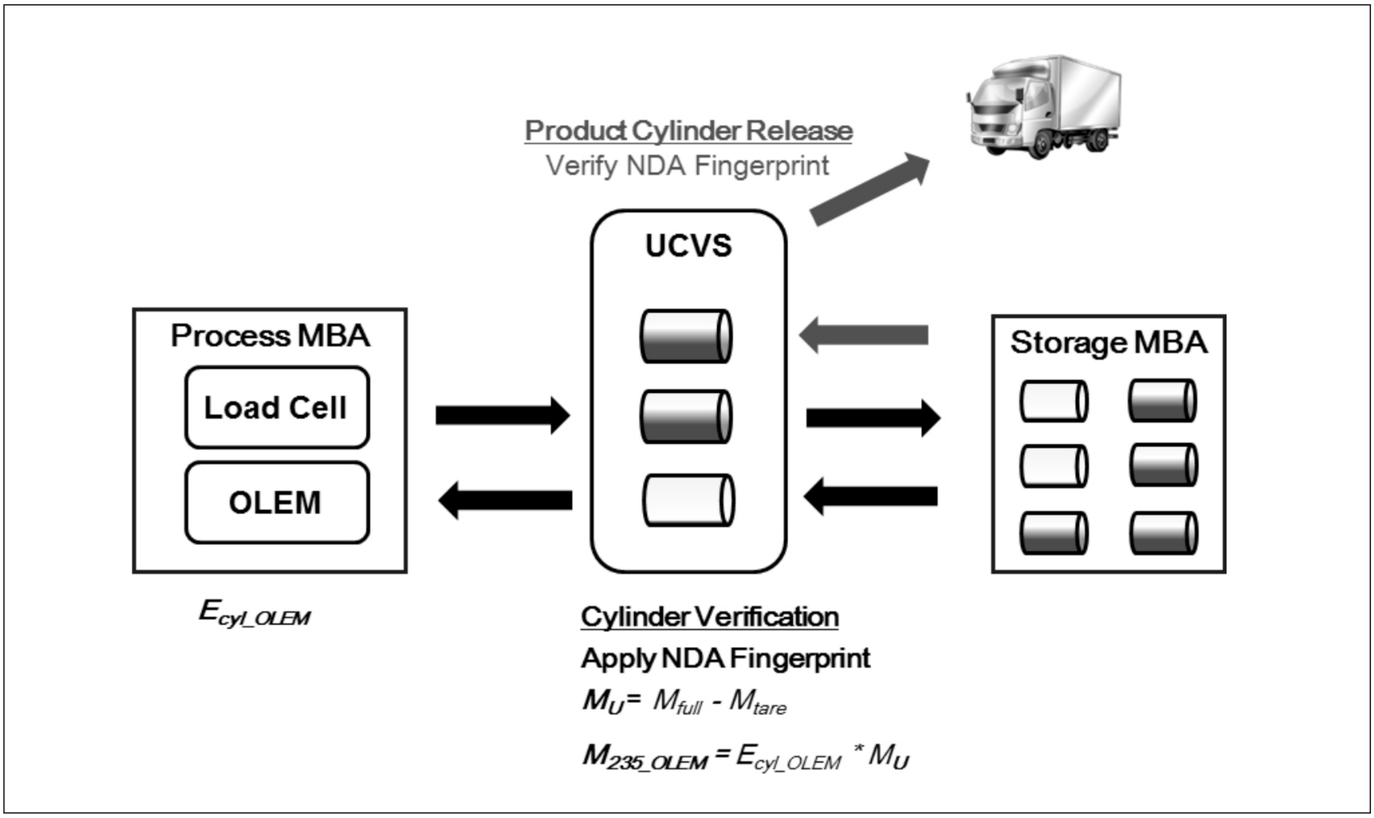
An extremely important piece of data for the facility-level instrumentation system at Facility X is the net uranium mass, M_U, in each cylinder. This mass would be based on the full and tare weights measured by the operator's accountancy scales, as reported through the sharing of the accountancy scale weight tickets. The UCVS, which would be built around the operator's accountancy scales in order to leverage the cylinder characterization opportunity presented by the facility's normal cylinder weighing operations, could be the interface for the collection and utilization of the scale weight tickets. Since $M_{235} = E_{cyl} \cdot M_U$, the combination of load cell, OLEM and UCVS data allows determination of ^{235}U mass for each unblended cylinder (blended cylinders are discussed later). Further, the accountancy scale weight values can be important as a confidence-building measure for the less-accurate tare and full weights reported from the load cells at the feed and withdrawal stations. Direct, independent assay of M_U using UCVS radiation signatures might also be a confidence-building measure on the authenticity of accountancy scale and load-cell data.

Once the value of M_{235} is established for each cylinder, it would be ideal that continuity of knowledge (CoK) on that cylinder and its contents would be maintained as long as the cylinder remains at the facility. This is a particular challenge in gaseous centrifuge enrichment plants since the traditional tool for CoK on nuclear material containers, metal or electronic seals, would require very frequent inspector presence to either emplace or remove seals; there exists no practical mechanism for unattended placement and removal of such seals. (There is a precedent for operators to either emplace or remove seals, but not both.) A new concept is needed to address this CoK challenge, and for that purpose, the concept of an "NDA Fingerprint" applied and verified by the UCVS is being investigated by the IAEA. This NDA Fingerprint is intended to compensate for the lack of traditional, continuous CoK on the verified cylinders, by providing a means to periodically confirm, in an unattended fashion, that the contents of the cylinder are unchanged.

The NDA Fingerprint is a collection of distinguishing attributes for the cylinder contents that could include, for example, total uranium mass, M_{235}, various isotopic ratios (e.g., M_{234} / M_{235} and M_{232} / M_{235}) and the spatial distribution of ^{235}U within the cylinder. The task of "setting" and verifying the NDA Fingerprint would be performed by the UCVS. A UCVS scan would occur each time a cylinder crosses an MBA boundary, to provide periodic re-verification of the cylinder contents, until the time the cylinder is shipped offsite. The UCVS and NDA Fingerprint concept could also be extended to facilities preceding the enrichment plant (e.g., for feed cylinders from the uranium conversion facility) and following the enrichment plant (e.g., receipt of the product cylinders at fuel fabrication plants), as a part of a state-level verification approach.

The UCVS units could play other important roles in Facility X, for example in terms of cylinder identification and tracking,

Figure 4. Conceptual overview of how an unblended product cylinder could be verified and released from the facility using a combination of load cell monitoring, OLEM and the UCVS. The empty cylinder would begin in the storage MBA at right, be characterized by the UCVS on its way into and out of the Process MBA. Data from load cells and OLEM (E_{cyl_OLEM}) would support high-accuracy calculation of M_{235_OLEM} in each cylinder. When the operator is ready to ship the cylinder off-site (grey arrows at top), the UCVS's NDA Fingerprint capability would be used to verify the constancy of the cylinder contents since production.



and for the verification of the UF_6 in blended cylinders for which there would be no associated OLEM-based measurement of E_{cyl}. Another potential benefit of the UCVS would be to ease and expedite the product cylinder release process for the operators. For example, product cylinders ready for shipment could be brought to the appropriate accountancy scale for final confirmation of M_U and verification, via the NDA Fingerprint collected by the UCVS, that the UF_6 inside the cylinder is unchanged since the cylinder was previously measured at the boundary of the Process MBA. A conceptual overview of how unblended product cylinders could be verified and released from the facility using unattended instrumentation is given in Figure 4.

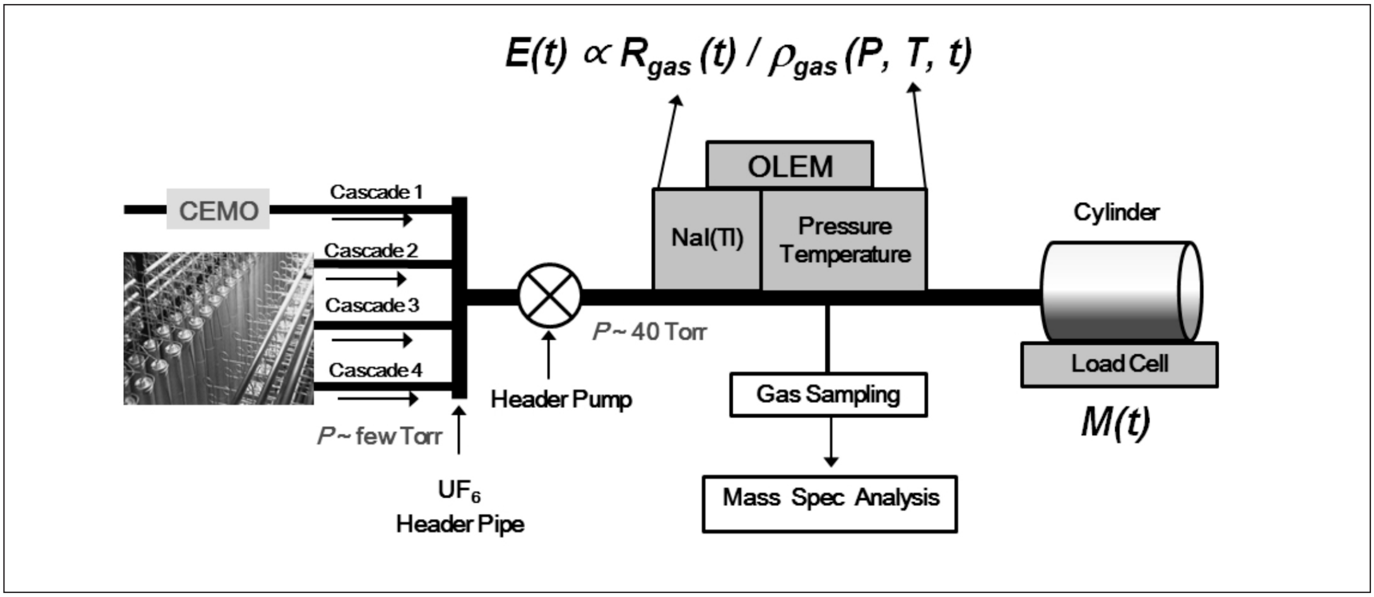
Online Enrichment Monitor

Online enrichment monitors are not a new concept in the safeguards community; the IAEA can draw on experience gained with a device called a Continuous Enrichment Monitor Online (CEMO).[7-10] CEMO was located on the output product stream of each individual cascade and consistent with the Hexapartite Safeguards Agreement developed in the early 1980s, the device's sole purpose was to provide indication of enrichment levels greater than 20 percent in a simple "Go/No-Go" fashion. For the IAEA's next generation of online enrichment monitor, considerably more is being asked. The IAEA sees two primary measurement objectives for OLEM:

1. Continuous monitoring of all declared gas flow to detect production of higher-than-declared enrichment;
2. High-accuracy quantification of gas enrichment as a function of time, *E(t)*, to support verification of ^{235}U flow in and out of cylinders.

The OLEM is expected to provide high-accuracy (less than a few percent relative uncertainty) monitoring of gas enrichment and the device must be practicably compatible with large modern centrifuge enrichment plants with a capacity of several thousand tonne SWU/year. Such a facility might have several units (e.g., 6-10), each consisting of multiple (e.g., 10) cascades. It is impractical to monitor the outputs of each cascade, as was done with CEMO, due to the large number of locations. Further, the CEMO location is unattractive for high-accuracy, quantitative gas monitoring because of the low gas pressure at those locations. The unit header pipes are advantageous loca-

Figure 5. Schematic of the OLEM concept that measures material streams from the multiple cascades comprising an enrichment unit, and at a location on the high-pressure side of the header pump. Pressure and temperature data are used to correct for gas density changes. Also shown are the locations where the IAEA's previous generation of online monitors (CEMO) were deployed (on the low-pressure side of the header pump, for each individual cascade).



tions for OLEM (Figure 5) because there the gas flow from multiple cascades is combined and a pump increases the gas pressure to a few tens of Torr, thereby producing a relatively strong gas signal compared to the background presented by, for example, wall deposits or nearby cylinders. Just as importantly, this location affords the opportunity for the IAEA to directly monitor the gas pressure, since there are fewer proprietary concerns from operators, compared to the low-pressure portions of the plant. Other challenges arise at this location, however, including significant gas pressure transients when cylinders are attached and removed from withdrawal stations.

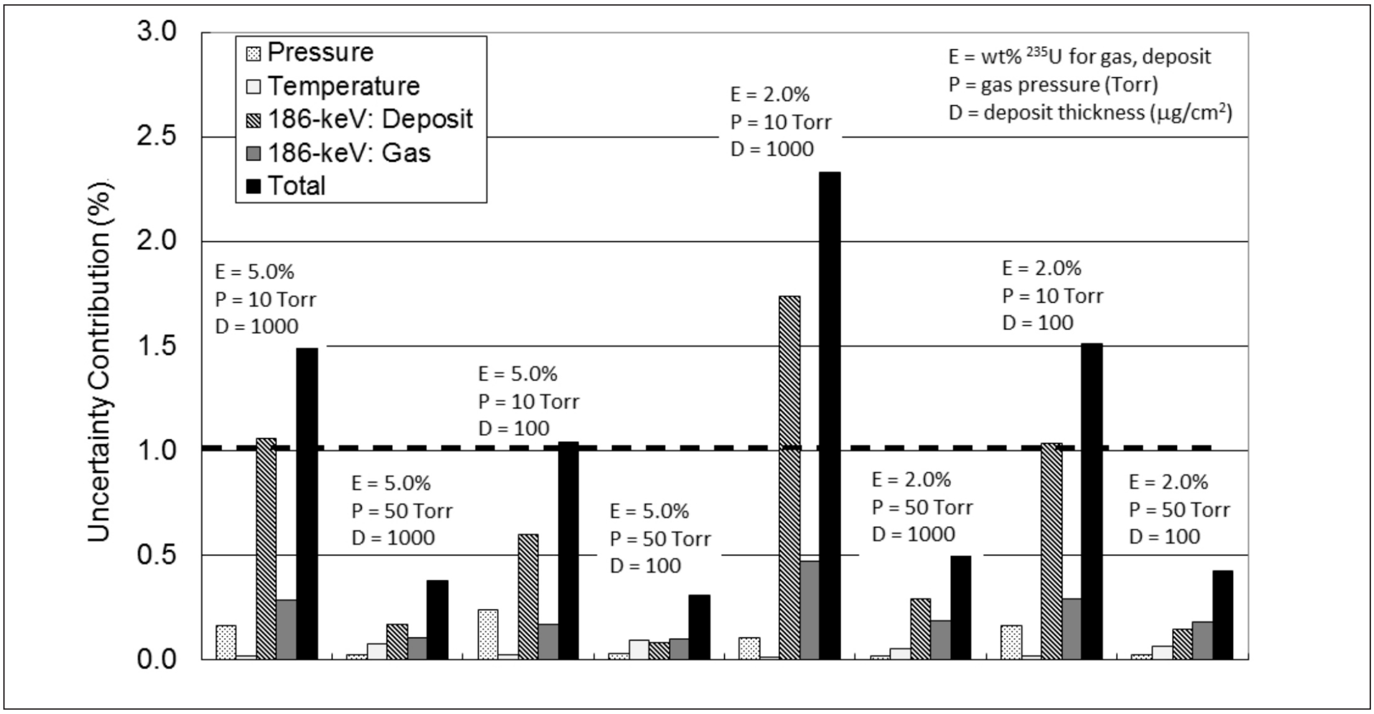
The OLEM design concept is based on NaI(Tl) gamma-ray spectrometers to collect $R_{gas}(t)$ (Figure 5), the net count rate specific to ^{235}U (e.g., the emission at 186 keV) in the gas flowing past the device. With properly designed collimation, the spectrometer can also collect other signatures that can be useful for calibration, for example a ^{234}Th emission at 63.3 keV derived from the deposits of uranium on the pipe walls. Options for measuring the UF_6 gas pressure ($P(t)$ in Figure 5) include a signal-sharing device installed on one of the operator's pressure gauges, or a dedicated IAEA pressure sensor. Temperature of the UF_6 gas inside the pipe ($T(t)$ in Figure 5) is inferred using temperature sensors (i.e., resistance temperature detectors) attached to the outside of the header pipe. Gas density corrections, based on the time-dependent pressure and temperature data streams, are applied to the gamma-ray spectrometry data in order to calculate the time-dependent enrichment, $E(t)$. The OLEM Collection Node will be housed in a tamper-indicating enclosure that can be attached to unit header pipes of various diameters. The OLEM hardware design utilizes modular, commercial components, plug-and-play extensibility to support phased deployment and plant expansion, and is intended to meet the IAEA's guidelines and requirements for unattended and remotely monitored safeguards systems. OLEM's software architecture has a modular design to facilitate maintenance, upgrades and the addition of new capabilities in the future. Specific data security requirements and approaches have been defined by the IAEA, to ensure that the OLEM can be a shared-use instrument (e.g., with operators and state regulatory bodies). OLEM development principles and requirements are documented in Reference 11.

The OLEM on each unit header pipe would continuously measure the time-dependent relative uranium enrichment, $E(t)$, in weight percent ^{235}U, of the gas filling or the gas being withdrawn from the cylinders. $E(t)$ could be used in several ways at the facility level, as described in the previous section. That discussion of OLEM roles assumed close coupling to the time-dependent load-cell data streams, $M(t)$, for each cylinder introduced to the process.

Development Status

Results from recent development work within the safeguards community have significantly clarified the viability picture for a practical OLEM device, including a better understanding of the uncertainties that might be achieved in realistic plant conditions. In a modeling study performed by the IAEA, simulated OLEM spectra for various combinations of enrichment, pressure and wall-deposit thickness were coupled to error-propagation methods to predict the components of the statistical uncertainty budget for a nominal OLEM design and enrichment analysis ap-

Figure 6. Predicted OLEM statistical uncertainty budgets for various combinations of (E)enrichment, (P)pressure (Torr) and (D)wall-deposit thickness (areal density, mg/cm^2), assuming product material at either 5.0% or 2.0% ^{235}U. The OLEM performance target for σ_E, 1% for product material, is shown in the dashed line for comparison. Figure from Reference 12.



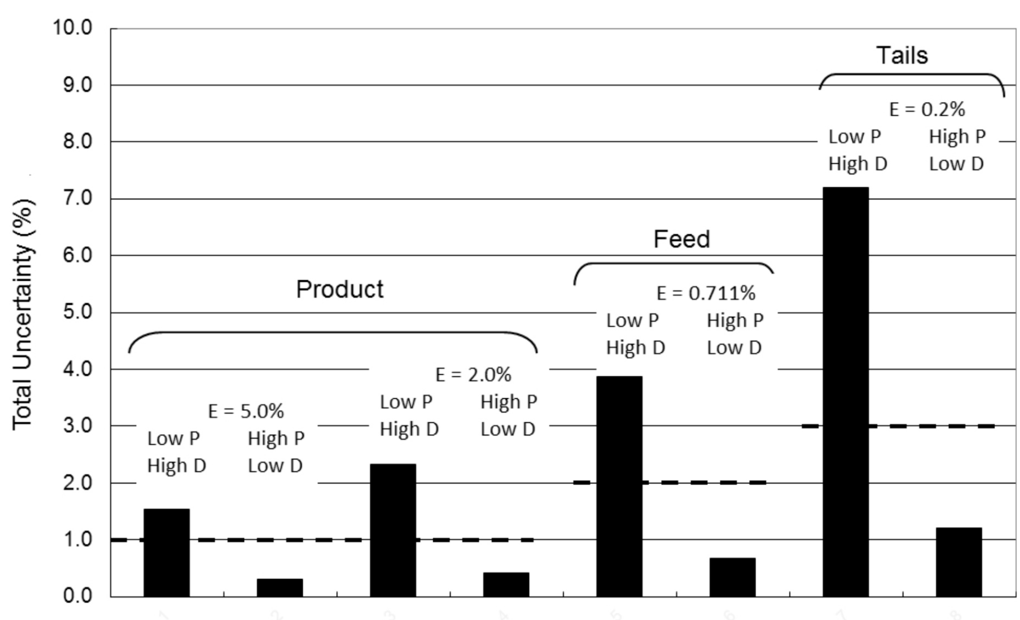
proach.[12] In that study, the nature of wall-deposit formation (e.g., expected range of areal density, in mg/cm^2), as well as various wall-deposit calibration approaches, were considered. A viability analysis based on statistical uncertainties was presented, assuming a wall-deposit correction method based on pressure transients, as proposed by others.[13]

Examples of the statistical 'uncertainty budget' results from the IAEA study are shown in Figure 6.[12] Here, the fraction of the total variance explained by each individual variance term is normalized to the total one-sigma uncertainty, σ_E. The broad ranges of pressure and wall-deposit thickness on the high-pressure side of the header pump lead to a range of behavior in the uncertainty budgets and in the predictions for total uncertainty. For scenarios with high gas pressure (~50 Torr), the deposit and gas uncertainty contributions are comparable in magnitude and particularly at lower gas enrichment values (e.g., 2 percent), somewhat larger than the uncertainties associated with the measurement of pressure and temperature. On the other extreme are the scenarios with low (~10 Torr) and high wall-deposit levels (1000 mg/cm^2). The deposit uncertainty, which must be extrapolated from the pressure-transient data, dominates the uncertainty budget in these scenarios.

Figure 7, also taken from the IAEA's viability study, shows how σ_E varies for product, feed and tails material under the bounding plant conditions considered in this study.[12] For plants with particularly high wall-deposit levels, the accuracy of the OLEM measurement is degraded, particularly during low-pressure periods of the cylinder filling process. For relatively new or clean plants (i.e. with low deposit levels) and during periods of higher-pressure operation, OLEM statistical uncertainty is significantly improved. Concurrent and subsequent modeling and analysis performed by others have helped to support the uncertainty budget predictions in Figure 7, for example in independent modeling and analysis performed by Oak Ridge National Laboratory (ORNL).[14]

The modeling-based viability analysis described above is significantly simplified and other factors in the actual implementation of OLEM will influence the uncertainty of *E(t)* (e.g., additional sources of uncertainty in gamma-ray spectral analysis, time-segmentation approaches, systematic calibration errors, and the validity of assumptions used in a wall-deposit correction method based on pressure transients). Even still, such analysis was fundamental to the IAEA in understanding the strengths and limitations of technologies under development in the safeguards community, and to developing performance targets for OLEM: s_P = 1%, σ_F = 2% and s_T = 3 percent for product, feed and tails gas streams, respectively. These performance targets were documented in the IAEA's user requirements for OLEM[11] that are now guiding the OLEM development project[14] being performed under the auspices of the United States Support Program to the IAEA, by a collaboration between Oak Ridge National Laboratory (ORNL) and Los Alamos National Laboratory (LANL). The uncertainty budgets and predicted performance for OLEM have

Figure 7. Summary of OLEM total statistical uncertainty predictions for bounding plant conditions on pressure ('Low P' = 10 Torr and 'High P' = 50 Torr), wall deposit areal density ('Low D' = 100 mg/cm^2 and 'High D' = 1000 mg/cm^2), and enrichment. Performance targets for σ_E (1 percent for product, 2 percent for feed and 3 percent for tails) are shown in dashed lines for comparison. Figure from Reference 12.



also been utilized in facility-level analyses of how various unattended instruments might integrate to meet safeguards objectives, a topic described later in this paper.

A collaborative field measurement campaign performed by LANL and Urenco at Urenco's Capenhurst (England) facility provided invaluable experience and empirical support for the viability of OLEM.[15] LANL's field tests in Capenhurst extended the community's understanding of how pressure transients can be used for wall-deposit calibration, and confirmed that measured uncertainties on product-gas enrichment are consistent with IAEA's modeling-based performance targets. For example, assuming measurement conditions consistent with those used in IAEA's modeling (e.g., NaI spectrometer size and pipe location, ranges of operating pressures, pressure transient behavior, time segmentation, estimated wall deposits), the total relative uncertainty measured by LANL was approximately 0.6 percent for gas at E = 4.8 percent, over a time period of approximately three weeks. This measured uncertainty (systematic + statistical), corresponding to a range of operating gas pressures between 15 and 45 Torr, is bracketed by IAEA's predictions for statistical uncertainty under similar conditions: ~1.0 percent total uncertainty at 10 Torr and E = 5.0 percent; ~0.3 percent total uncertainty at 50 Torr, E = 5.0 percent. These comparisons suggest that for a well-calibrated instrument on a product header pipe, systematic contributions to uncertainty can be sufficiently minimized to meet OLEM performance targets.

Requirements, Development Questions and Operator Impacts

OLEM development is relatively mature. Previous CEMO experience, recent modeling-based studies, and proof-of-principle testing on a product header pipe in an operational enrichment plant have infused confidence into the OLEM development path. IAEA's user requirements, which are guiding that development path, are documented in Reference 11; a subset of key requirements is given here:

- Accuracy targets: s_P = 1 percent; σ_F = 2 percent; s_T = 3 percent;
- Quasi-continuous, self-contained wall-deposit calibration method(s) that do not require operator information (e.g., mass spectrometry data from gas sampling);
- To protect the operator's proprietary information, no (routine) raw data transmission (e.g., time dependent pressure and temperature data) from the collection node. Computations of *E(t)* must be performed internal to each OLEM node;
- Data security provisions that allow data sharing with operators and other stakeholders;
- Resistance to spoofing scenarios.

Development questions yet to be addressed in development projects related to OLEM include:

- Empirical uncertainties achievable in realistic plant settings, including systematic errors over long periods of operation, on product, tails and feed pipes, and for pipe designs different than those studied to date (e.g., steel pipes);

- Accuracy of quasi-continuous wall-deposit calibration techniques, particularly for the feed header pipe where a pressure-transient method may not be viable;
- Vulnerabilities related to the measured data streams, for example the potential for manipulation of pressure, temperature or gamma-ray signatures measured by the OLEM, and potential methods to address or to at least flag such anomalies;
- Cost, reliability, data security provisions and maintainability.

Operators' views of the OLEM to date have been generally positive[16] for several reasons. For example, proof-of-principle field testing on a product header pipe at Urenco's Capenhurst indicated that accuracy below 1 percent could be expected in a field device, and a device with that level of accuracy could be used by the operator for process control, potentially reducing the need for expensive and time-consuming gas sampling and mass spectrometry analysis. OLEM data sharing could also assist the operator in addressing criticality control requirements, or material accountancy requirements from regional or State authorities.

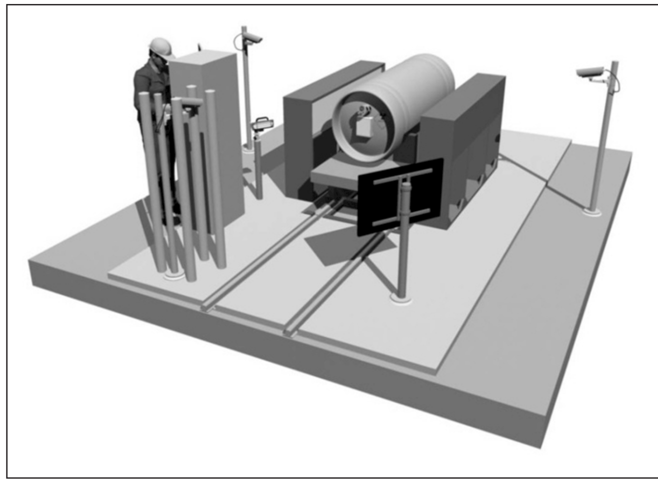
Unattended Cylinder Verification Station

The concept of an unattended cylinder verification station has been under consideration by the IAEA for several years.[4] A notional UCVS is illustrated in Figure 8, where a facility operator's trolley brings the cylinder to the operator's accountancy scale (cranes may serve the same purpose in some facilities), around which the IAEA's UCVS is built. The UCVS would include technologies for cylinder identification (e.g., using laser-based technologies[17] or a future industry-standard barcode[18, 19]), sharing of the accountancy scale data,[20, 21] video surveillance using the IAEA's new generation of cameras,[22] and nondestructive assay of the cylinder contents. Additional discussion of candidate technologies and integration approaches for identification, accountancy-scale sharing, and surveillance is provided in the aforementioned references and Reference 23. In this paper, we focus on the roles and candidate technologies/methodologies for the unattended NDA function of the UCVS. The IAEA envisions several possible measurement objectives for the NDA components of a UCVS:

1. Unattended, independent assay of E_{cyl} and M_{235} for product, feed and tail cylinders;
2. Independent assay of M_U as a confidence-building measure on the authenticity of shared signals from operator weighing systems;
3. Unattended application and re-verification of an NDA Fingerprint to maintain the verification pedigree of the cylinder contents during the cylinder's life at the facility.

NDA signatures that might be utilized to meet these measurement objectives are described in this section. Though others have explored active interrogation methods for the NDA of cylinder contents,[24, 25] only passively collected signatures are considered here because passive unattended instruments have important practical advantages for the IAEA, for example in terms of simplicity, maintainability, operator acceptance and facility safety requirements. In these discussions, it is assumed that the feed material for the plant is natural (not recycled) uranium so that the isotopic ratios of that feed, (e.g., $^{234}U/^{235}U$) are known to within natural variations.

Figure 8. Conceptual design of an integrated UF_6 cylinder verification station (UCVS) that is built around a the operator's accountancy scale and includes unattended NDA instrumentation (blue panels), camera surveillance and cylinder identification technology. Figure from Reference 23.



Traditional Enrichment Meter Method as Direct Measure of E_{cyl}

The 'traditional' 186-keV emission from ^{235}U, which is the sole signature used by the IAEA in today's cylinder verification measurements with handheld spectrometers, is well-documented. The traditional 186-keV analysis provides a direct measure of ^{235}U, but due to self-attenuation in the UF_6, the measurement is very localized. Typical uncertainties achievable with handheld devices on product, feed and tail cylinders are known from IAEA's long history of verification measurements, and are reflected in the International Target Values for verification of UF_6 cylinders.[26]

Total Neutron Count Rate as Indirect Measure of M_{235}

The potential use of total neutron count rate as a means of determining M_{235} is based on the production of neutrons in $^{19}F(\alpha,n)$ reactions, with the dominant alpha emitter being ^{234}U for all enrichments above natural[27, 7, 28]. The highly penetrating nature of this signature allows full-volume interrogation of the cylinder, and therefore, absolute measurement of uranium isotopic mass. However, because this signature is driven by ^{234}U, it requires knowledge of the $^{234}U/^{235}U$ ratio as a function of enrichment in order to infer M_{235}. A 'facility-specific' calibration for a UCVS instrument would incorporate knowledge about how the $^{234}U/^{235}U$ ratio changes as a function of enrichment in each unit/facility. This calibration could be informed, for example, by IAEA's archival data of uranium isotopic ratios from destructive analysis on UF_6 samples drawn from the process or cylinders, and/or from environmental sampling at each specific facility.[29, 30]

High-Energy Gamma-Ray Region as Indirect Measure of M_{235}

The neutrons produced in the UF_6, primarily from $^{19}F(\alpha,n)$ reactions, interact in the UF_6 itself and surrounding materials and those interactions (e.g., inelastic scatter and neutron capture) can induce high-energy gamma-ray signatures that extend to energies greater than 10 MeV. Prominent among these are the 7.631-MeV and 7.645-MeV lines from neutron capture reactions on ^{56}Fe in steel. Steel volumes included in the design of the collimators for the gamma-ray spectrometers, the steel in the wall of the cylinder, and the gamma-ray spectrometer crystal itself, serve as neutron-to-gamma-ray converters.[31, 32]

Induced Fission Neutrons as Direct Measure of E_{cyl}

The coincident neutrons produced from fission in ^{235}U can be used to directly determine E_{cyl} in the cylinder. Though active interrogation is a possibility, only passive methods (e.g., from reflected (α,n) neutrons) are considered here. In the passive mode, the primary source of interrogating neutrons are those from $^{19}F(\alpha,n)$ produced in the cylinder, which are then moderated in the surrounding environment (e.g., concrete floor or polyethylene designed into the measurement system) before reflecting back into the UF_6 in the cylinder.[33, 34, 35] The induced reactions, due to the energy dependence of the ^{235}U fission cross-section, arise primarily from the reflected neutrons that have been moderated to thermal or near-thermal energies. The penetration of these neutrons back into the cylinder is limited, and therefore the assay volume for the determination of E_{cyl} is somewhat localized.

Multiple Signatures for Indirect Measurement of M_U

In the discussion above, the ability to independently determine three different parameters was discussed: E_{cyl} , the enrichment of the cylinder (via gamma-spectroscopy or induced coincident neutron); M_{234}, the mass of the ^{234}U in the cylinder (via the total neutron signature); $R_{234\_235}(E)$, the expected behavior in the $^{234}U/^{235}U$ ratio as a function of enrichment in a specific facility (via archives of environmental sampling or destructive analysis of UF_6 samples from that facility). Using this combination of measured parameters, it is possible to independently calculate the total mass of uranium in each cylinder where $M_U \propto M_{234} / (R_{234\_235}(E_{cyl}) * E_{cyl})$. The absolute value of M_U, and its repeatability over multiple cylinder measurements, could offer a confidence-building measure for the authenticity of the shared data from operator weighing systems about each cylinder. A key characteristic of a total uranium mass calculated using UCVS signatures is independence—no operator declared information is needed to verify the declared net weight from scale data (either load cells or accountancy scales) shared from the operator.

Development Status

For the direct assay of E_{cyl}, M_{235} and M_U, the nominal measurement scenario is a one-time assay of an unknown cylinder, and comparison of the measured E_{cyl} , M_{235} and M_U values to the operator's declaration. Past and ongoing technology development projects have been quite informative as to the use of various NDA signatures for the measurement of E_{cyl} and M_{235}; a summary of recent work is provided below.

Pacific Northwest National Laboratory (PNNL) has developed a hybrid cylinder assay technique that utilizes an array of NaI(Tl) spectrometers to simultaneously measure the direct 186-keV signature from ^{235}U and via high-energy gamma rays induced by neutrons in ^{56}Fe and the NaI(Tl) itself, the total neutron emission rate from the cylinder. The 186-keV signature provides an unambiguous measure of E_{cyl}. Under assumptions of known $^{234}U/^{235}U$ behavior in the plant, the total neutron signal can be calibrated to total M_{235} in the cylinder.[31, 36] Over several field campaigns using PNNL's Hybrid Enrichment Verification Array (HEVA) prototype for the assay of Type 30B cylinders with enrichments ranging from 2.0 percent to 5.0 percent, relative uncertainties of approximately 3% for E_{cyl} and 4% for M_{235} were reported. For a small population of Type 30B cylinders with natural enrichment levels (0.711%) typical of feed cylinders, the relative uncertainties for E_{cyl} and M_{235} were approximately 6 percent and 8 percent, respectively.[32, 37] Measurement times were approximately 5 minutes per cylinder. These uncertainties were dominated by systematic effects (e.g., wall-thickness variation and variation in the $^{234}U/^{235}U$ ratio); statistical counting uncertainty was relatively low. The PNNL studies, to date, have not explicitly addressed the assay of M_U or the partial defect sensitivity of the method.

Another cylinder assay method under development is LANL's Passive Neutron Enrichment Monitor (PNEM).[33, 34, 35] PNEM employs moderated ^3He modules to measure the singles and doubles neutron emission rates from the cylinder. The singles emissions come primarily from the ^{234}U, which under an assumption of known $^{234}U/^{235}U$ behavior allows determination of ^{235}U mass (analogous to the indirect neutron signature in PNNL's gamma-ray method). This portion of the PNEM methodology is also similar to that utilized by UCAS, a system deployed by the operator at an enrichment plant in Japan.[28] PNEM extends beyond singles neutron counting, however, to include the coincidence (i.e. doubles) neutron signature that arises from fission in ^{235}U. The coincident neutron signal also includes the spontaneous fission from the ^{238}U in the cylinder. The singles to doubles ratio allows calculation of the cylinder enrichment level. A field campaign using a PNEM prototype included the assay of Type 30B cylinders with enrichments ranging from 2.0 percent to 5.0 percent, and measurement times of approximately 20 minutes.[35] Relative uncertainties for E_{cyl} and M_{235} over the measured cylinder population have not been published. The LANL studies, to date, have not explicitly addressed the assay of M_U or the partial defect sensitivity of the method.

The European Commission's Joint Research Centre (JRC) at Ispra has also studied potential NDA methods for cylinders, and provided both qualitative and quantitative assessment of the systematic and statistical uncertainties that arise when utilizing various radiation signatures to assay cylinder contents.[25, 38] Via Monte Carlo modeling, this work provided numerous insights into the impact of UF_6 geometry inside the cylinder (e.g., due to different cylinder filling methods and handling practices) and sensitivity of measured neutron signatures with detector location. Modeling was also used to explore, preliminarily, the ability to detect partial defects from a cylinder. The study highlighted the value of the ^{234}U-based totals neutron signature for its full-volume-interrogation capabilities.

All published work to date was focused on the assay of E_{cyl} and M_{235}. Another important potential role of the UCVS, however, is the application and re-verification of an NDA Fingerprint. In this role, the measurement scenario is repeated measurements of the same filled cylinder during the cylinder's lifespan at the facility. The NDA Fingerprint concept, as described earlier, could help solve the continuity of knowledge challenge that follows the original assay of E_{cyl} , M_{235} and M_U, whether those initial value comes from OLEM (for unblended cylinders), UCVS (for unblended or blended cylinders) or some combination thereof. There are a number of observable signatures that could be used in the creation of the NDA Fingerprint attributes, and generally speaking, they are the same neutron and gamma-ray signatures described previously for direct NDA of E_{cyl} and M_{235}. Potential attributes, to include in an NDA Fingerprint are E_{cyl}, M_{235}, M_U, isotopic ratios such as $^{234}U/^{235}U$ or $^{232}U/^{235}U$ (in the case of recycled uranium feed), and potentially, the spatial distribution of each of these attributes, throughout the cylinder. The key metric for an NDA Fingerprint, therefore, is constancy and reproducibility of repeated measurements on the same cylinder, including when successive measurements are made by different UCVS units (e.g., at two different locations in a large enrichment plant, or at an enrichment plant and a fuel fabrication plant elsewhere in the world).

Preliminary Requirements, Development Questions and Operator Impacts

IAEA requirements for an unattended cylinder verification station are evolving and some new UCVS roles, for example the viability of an NDA Fingerprint and the direct assay of M_U, need more study before quantitative requirements can be defined. Listed below, however, are some preliminary requirements for the NDA-related functions of a UCVS:

- Accuracy targets for E_{cyl} and M_{235}: s_P = 3 percent; σ_F = 6 percent; s_T = 9 percent;
- Accuracy targets for M_U: s_P = 5 percent; σ_F = 10 percent; s_T = 15 percent;
- NDA Fingerprint reproducibility targets: to be determined through continued study;
- Partial defect targets: to be determined through continued study;
- Potential for direct assay of M_U as confidence building measure on the authenticity of cylinder weight tickets shared from operator's accountancy scales;
- Data security provisions that allow data sharing with operators and other stakeholders;
- Resistance to spoofing scenarios.

Development questions yet to be addressed for the NDA-related functions:

- Direct NDA of E_{cyl} , M_{235} and M_U: Uncertainty budget and total uncertainty in realistic plant settings, including systematic errors and over long periods of operation, on product, tails and feed cylinders;
- NDA Fingerprint: Candidate signatures and attributes, and reproducibility of the NDA Fingerprint for verification and re-verification under realistic plant conditions (e.g., cylinder position/rotation in UCVS gantry, variable backgrounds, cylinder age, handling);
- Partial defect sensitivity for both the direct NDA and the NDA Fingerprint roles;
- Applicability of the NDA methods in the case of non-natural feed materials, for example re-enriched tails or recycled uranium;
- Potential integration or combination of signatures from the candidate methods (e.g., HEVA and PNEM) to achieve benefits that neither can deliver independently;
- Vulnerabilities related to the measured data streams, for example, the potential for manipulation of the gamma-ray or neutron signatures measured by UCVS, variations in U^{234}/U^{235} ratios, and potential methods to address or to at least flag such anomalies;
- Value of an independent, directly assayed value of M_U from the UCVS as a confidence-building measure on the authenticity of shared signals from operator weighing systems;
- Cost, reliability, data security provisions and maintainability.

Compared to OLEM and load-cell monitoring, there has been relatively little feedback from operators regarding the impact and/or utility of UCVS in plants, at least in part due to the relative immaturity of methods and technologies therein. The installation of UCVS components (e.g., for cylinder identification, surveillance and NDA) around the plant's accountancy scales may be viewed as a negative impact by operators, but the potential for an automated cylinder tracking infrastructure and the opportunity for automated and expedited product cylinder release are potential benefits. Other potential benefits of sharing UCVS data could be the operator's criticality control obligations and the satisfaction of accountancy requirements from regional or State authorities.

Load Cell Monitoring

The monitoring of feed and withdrawal stations is of interest to the IAEA because of its potential for the direct and continuous detection and deterrence of the excess production scenario, a capability that other unattended systems such as the OLEM and UCVS can address only indirectly. The utility of load cell data to the IAEA can be categorized into the following roles:

1. Counting of cylinders introduced to the process, to verify that only declared cylinders are utilized;
2. Quantitative monitoring of uranium mass flow to support periodic mass balance calculations for in-process material.

Mass-flow monitoring is central to the IAEA's ability to independently close the facility mass balance and therefore, to detect the excess production scenario. A number of technologies and combinations thereof have been proposed for mass-flow monitoring, for example the use of active interrogation techniques to determine the flow rate of gas moving through unit header pipes. The Blend-Down Monitoring Station in Russia provides a fielded example of such a technology that supports treaty verification at a facility not under IAEA safeguards.[39] For IAEA safeguards, in contrast, the current emphasis is on a mass-flow approach that does not require additional technology to be installed in the plant: sharing of the data streams from operator's load cells at the feed and withdrawal stations.

If the mass flow rate signals from all of the occupied feed and withdrawal stations are monitored, the IAEA could periodically calculate the material unaccounted for, *MUF*, for the in-process flows of each enrichment unit: $MUF(t) = F - (P + T)$ where F, P and T are the mass flow rates (kg/hour) of uranium as recorded by the load cells at all feed and withdrawal stations at time t. The uncertainties, both statistical and systematic, associated with the measurement of cylinder mass at each active feed and withdrawal station would propagate through the unit- or facility-level versions of the *MUF* equation above. The IAEA's ability to detect excess production scenarios using load-cell monitoring is dependent on the uncertainty associated with the $MUF(t)$ calculation.

As described earlier, the load cell data streams can be integrated with the other unattended instruments to support the detection of other diversion scenarios. For example, monitoring the load cell signals could provide the time-dependent mass flow data, $M(t)$,corresponding to withdrawal or filling of each cylinder in the Process MBA. This data, along with the start and end times associated with the filling or withdrawal process could be combined with the OLEM $E(t)$ data from the same time period to support the calculation of E_{cyl}. Monitoring of the filling or withdrawal profile characteristics could also provide indication of operational anomalies that might warrant further investigation for facility misuse.[20]

Development Status

An important early development challenge for flow monitoring concepts is a full understanding of the uncertainty budgets and total uncertainty associated with a near-real-time material balance based on the simultaneous monitoring of multiple feed and withdrawal stations. For example, if the relative uncertainty for each of the four load cells in each feed/withdrawal station is estimated to be 0.5 percent, what is the absolute uncertainty of a mass balance during a time period in which two feed stations, three product stations and two tails stations are in operation? What role do biases from hoses attached and detached from the load cells present? How do the venting of light gases, ice collecting on the outside of cylinders, or scrap and waste removed from the process by the operator impact σ_{MUF}? Similar to the studies of the OLEM uncertainty budget (see section on OLEM), the nature and magnitude of uncertainties related to each individual feed/withdrawal station need to be understood. Then, those station uncertainties can be propagated through *MUF* calculations at the enrichment unit level, as a function of material balance period (e.g., daily, weekly, monthly).

Another important issue to address early in the development of the load-cell concept, which is founded on an operator-owned instrument, is vulnerability to spoofing. Prominent vulnerabilities at the instrument and enrichment unit levels should be identified and addressed, to the extent practicable. The spoofing capabilities of an operator with thorough knowledge of the plant's operational characteristics should be considered. Also important to consider is the fact that load-cell monitoring is an 'all or nothing' proposition in that all stations occupied by cylinders must be monitored, at all times, in order to faithfully verify the number of cylinders introduced to the process and to calculate the in-process mass balance. If even one station fails or gives spurious results, the IAEA's ability to detect undeclared excess production is immediately impacted, and the IAEA reverts back to traditional safeguards measures for the detection of excess production scenarios during that time period. This is to be contrasted with the OLEM and UCVS, where instrument failure translates to a time during which unattended verification of the operator's declared activities drop below 100 percent, but the fraction of the facility flow still being verified would remain a considerable improvement on what is now being done under traditional safeguards.

In addition to study of the uncertainty budgets and the resulting efficacy for detection of excess production scenarios, work is also needed to develop and assess hardware and software approaches for data sharing. Ongoing studies by the European Commission's JRC at Ispra, in an operating enrichment plant in France, will aid the community's understanding of hardware, data collection methods, and operator tolerance for the sharing of near-continuously produced process control data that is often considered proprietary. A key question, for example, is the frequency with which an operator will allow data to be collected for safeguards purposes.

Another key development issue for load-cell sharing is the development of a suite of methods that build confidence in the authenticity of the shared data streams. Some candidate methods proposed previously include correlation of the empty and full load cell values to the weight tickets from accountancy scales, monitoring of the fill-rate profiles for anomalies, and the use of historical data on normal plant operation to train algorithms intended to detect anomalous conditions that might indicate plant misuse.[40, 20] Independent measurement of M_U using NDA signatures from the UCVS could also provide confidence-building measures for the shared load cells, as well as the shared accountancy scale. Calibration activities, for example using known weight standards, during unannounced inspections, represent other possibilities.

Requirements, Development Questions and Operator Impacts

The IAEA has not finalized requirements for the sharing of load cells signals with the operator, and significant development and analysis is needed before such a step could be completed. Listed below, are some preliminary requirements to be considered by the development community:

- Reliably detect the introduction and removal of all cylinders at the feed and withdrawal stations;
- Provide a quasi-continuous uranium mass balance (i.e., independent *MUF* calculation) for in-process material in each enrichment unit;
- Realize *MUF* uncertainties, at the enrichment-unit level, low enough to address plausible excess production scenarios defined by the IAEA, in terms of both detection probability and a false alarm rate tolerable to the operator;
- Incorporate confidence-building measures and data security provisions to detect and deter spoofing scenarios.

Development questions to be addressed by development projects related to load-cell monitoring include:

- Uncertainty budgets, including statistical and systematic uncertainties, for individual cylinder station weight measurements;
- Propagation of cylinder station uncertainties to unit- and facility-level *MUF* calculations over a range of data collection frequencies and material balance periods, and evaluation of those uncertainties in the context of plausible excess production scenarios;
- Vulnerabilities related to the measured data streams, for example the potential for manipulation of individual cylinder station weight profiles, manipulation of the data streams from all active stations, or off-normal plant conditions that could disguise diversion scenarios;
- Operator's willingness to share process control data (e.g., frequency and content of the shared data stream), and assuming those constraints, the ability of the IAEA to count cylinders and periodically calculate the material balance at the unit or facility level;
- Identification and exploration of a suite of inspector activities and confidence-building measures meant to elevate the confidence level on the integrity of the data shared from operator instruments;
- Field testing and evaluation over extended time periods to build an understanding of how load-cell uncertainty and reliability interplays with the 'all-or-nothing' nature of load cell monitoring for the excess production scenario;
- Cost, reliability, data security provisions, and maintainability.

In terms of operator impacts, the concept of load-cell monitoring differs from OLEM and UCVS, since the load cells are owned and maintained by the operator. While no additional large instruments must be installed at the facility, installation of the signal-splitting technology and cabling required to instrument 100 or more load cells may be problematic and resource-intensive. Operators have also expressed concerns about the intrusiveness of this monitoring approach, from the perspective of revealing proprietary information about feed and withdrawal techniques. A potential advantage for operators is the prospect for streamlining inspection activities, for example by minimizing the need for cylinder switchover activities during the annual physical inventory verification.

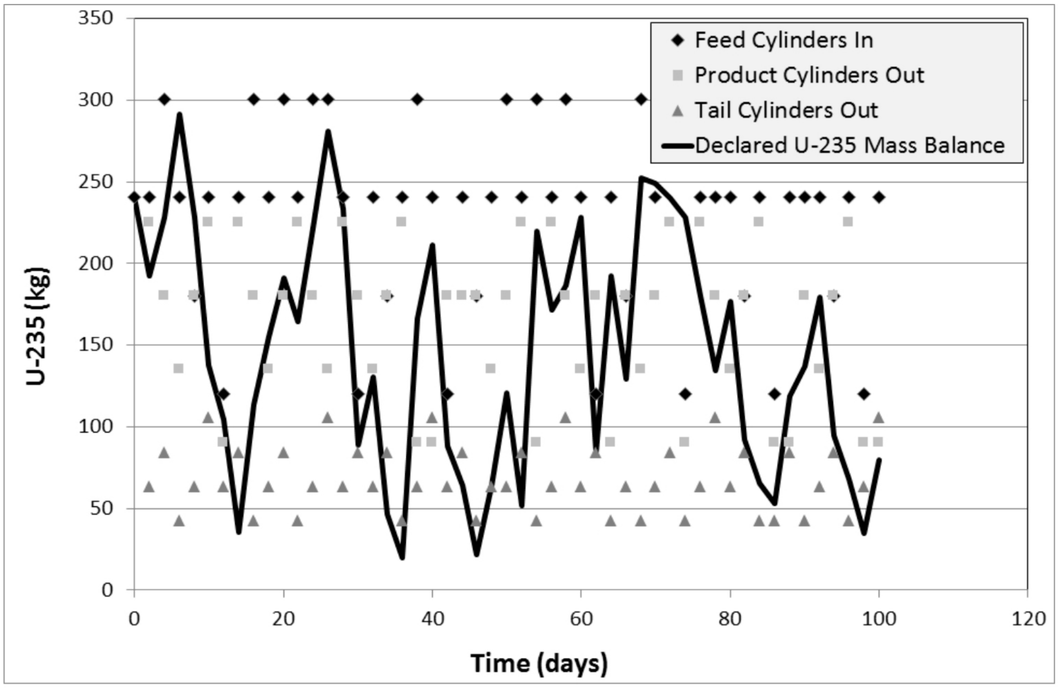
Example Case Study: Near-Real Time Verification of Cylinder Flow in Process MBA at Facility X

In the previous sections, the potential roles of each individual unattended monitoring technology were described, and qualitative discussion of how the data from those instruments might be integrated was presented. In this case study of notional Facility X, the potential benefits of utilizing these unattended instruments, both in terms of efficacy and efficiency, are explored quantitatively.

Facility X has a capacity of 4,000 tonne SWU/year and is located in a state without an additional protocol in force. The unattended measures to be implemented by the IAEA at Facility X include sharing of the data streams from the operator's feed and withdrawal weighing stations (total of ~200 in the plant) to determine the number and timing of cylinders introduced to the process, and to monitor the in-process total uranium balance. Also deployed are OLEM units (total of sixteen in the plant) on the product and tails header pipes, and UCVS units (three or less) around the accountancy scales.

OLEM and UCVS measurement uncertainties used in this case study were based on published data from modeling studies and proof-of-principle field campaigns, as described earlier. For OLEM, gas enrichment uncertainties are s_P = 1 percent and s_T = 3 percent for product and tails gas streams, respectively. For UCVS, the uncertainty of enrichment assay for blended product cylinders, s_P, is 3 percent; the application and subsequent verification

Figure 9. Declared ^{235}U mass balance in the Process MBA of Facility X, as tallied from the facility's Inventory Change Report for the Process MBA. The ^{235}U mass entering (feed cylinders) or leaving (product or tails cylinders), summed over two-day intervals, is depicted by the data markers. These values assume full cylinders at the enrichment levels described in the assumptions (i.e. 0.711 percent, 3.0 percent and 0.25 percent for feed, product, and tails respectively).



of the NDA Fingerprint on each cylinder ensures that: a) all feed cylinders match the profile of natural feed material from conversion plants typically utilized by Facility X, and b) verification knowledge on each cylinder is maintained through its life in the facility using an NDA Fingerprint. The accountancy scale data is also shared, and validated by IAEA's confidence building measures for data integrity. The relative accuracy of the accountancy scale is assumed to be 0.1 percent, negligible compared to other measurements uncertainties.

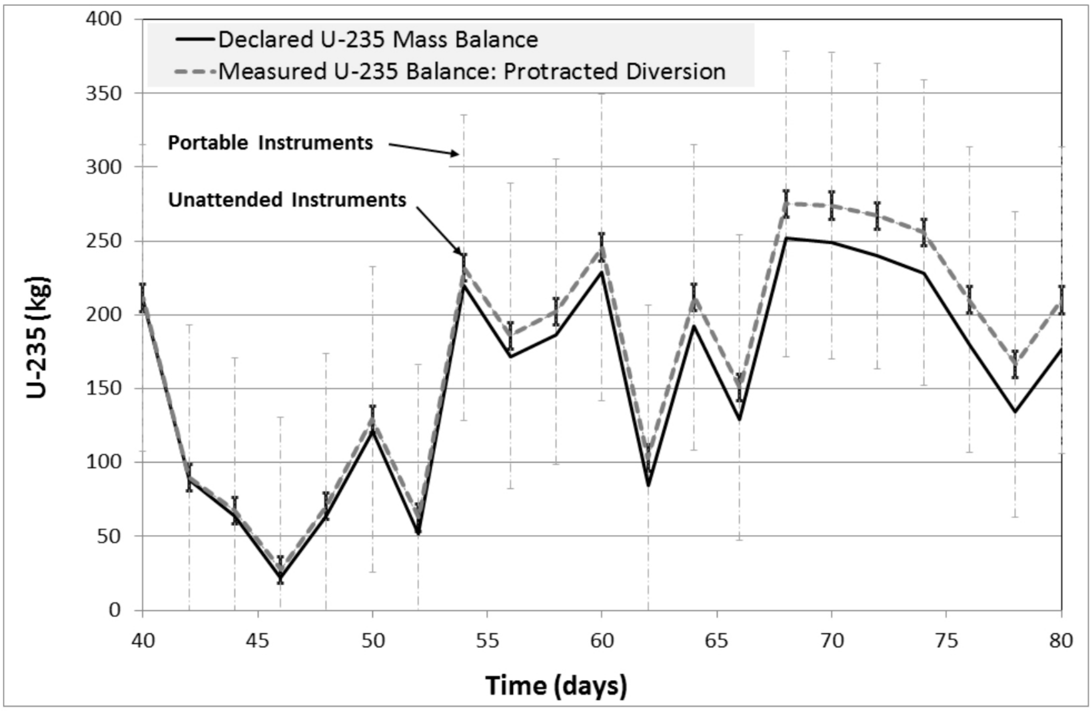
Inspection activities at Facility X would be defined to complement the capabilities of the unattended monitoring systems. Such activities might include environmental sampling, UF_6 sample collection for subsequent laboratory destructive analysis, and data authentication measures (e.g., use of calibrated weight standards on operating weighing systems).

Shown in Figure 9 is the flow of cylinders in and out of the Process MBA for Facility X over a 100-day period of plant operation, and the resulting declaration for ^{235}U mass balance. The ^{235}U mass entering (Type 48 feed cylinders) or leaving (Type 30B product and Type 48 tails cylinders) assumes full cylinders at enrichment levels of 0.711 percent, 3.0 percent and 0.25 percent for feed, product, and tails respectively. The declared ^{235}U mass balance at the perimeter of the Process MBA could be provided by the Operator's Inventory Change Report (ICR) which includes, for each cylinder: date and time of MBA boundary crossing; total uranium mass in cylinder; and the enrichment level as declared by the operator (e.g., from gas sampling and mass spectrometry weighted by mass-flow monitoring for product cylinders). Note that the ^{235}U mass balance, as measured at the boundary of the Process MBA, is always positive due to in-process gas in the cascades, the time required for homogenization of product cylinders, and the time required for cylinder blending activities.

Figure 10 is a graphical comparison of the IAEA independent measurement of ^{235}U mass balance using a combination of load-cell monitoring, OLEM and UCVS. Load-cell monitoring ensures that only the declared number of cylinders is introduced to the process, and the OLEM and UCVS measurements verify the contents of those cylinders. The operator's declared ^{235}U mass balance (black curve) for the process MBA is compared to the IAEA's measured mass balance (grey dashed curve). This measured mass balance reflects a protracted diversion scenario that assumes one significant quantity of ^{235}U (75 kg of low-enriched uranium[1]) is diverted over the course of 90 days, with a constant rate beginning on approximately day 40.

The error bars on the IAEA's independent measurement of the actual mass balance are calculated in two ways: a) OLEM and UCVS for cylinder assay, assuming published values for instrument uncertainties as described above, and b) today's handheld

Figure 10. Comparison of operator's declared ^{235}U mass balance (black curve) for the process MBA of Facility X, and the true mass balance (grey dashed curve) under a protracted diversion scenario. Two different error bars are shown for the IAEA's independently measured mass balance: a) OLEM and UCVS for cylinder assay (solid black bars), assuming published values for instrument uncertainties, and b) today's handheld NDA methods for cylinder assay (grey dashed bars), assuming International Target Values for uncertainty.



NDA methods for cylinder assay, assuming International Target Values for uncertainty (s_p = 5.8 percent, σ_F = 10 percent and s_T = 22 percent).[26] These uncertainty calculations assume 100 percent of the cylinders moving in and out of the process MBA are verified, and 1-week material balance periods (recalculated every two days in a rolling fashion).

Nominally, the one-sigma absolute uncertainty of the weekly mass balance using the unattended instrumentation (black solid error bars) is 9 kg of ^{235}U, while the one-sigma uncertainty using today's technologies (grey dashed error bars) is over 100 kg of ^{235}U. This means that with the unattended instrumentation, the protracted diversion scenario could be detected long before a significant quantity is diverted. Such early detection is not possible with today's technologies, as the total uncertainty is significantly higher than one significant quantity.

The key message from Figure 10 is that unattended instruments are not only capable of measuring 100 percent of the declared flow in an efficient manner, but they are also capable of providing substantially improved accuracy for the assay of E_{cyl} and M_{235}, compared to what is possible with today's portable devices. The much-improved uncertainties offered by the individual unattended instruments, and the capability to fingerprint feed cylinders, translates to a facility-level mass balance that is over an order of magnitude more accurate than would be possible with today's NDA techniques, even if each and every cylinder was measured with those devices (which is practicably impossible). This analysis suggests that an appropriate suite of unattended instruments could address one of the significant effectiveness shortcomings of traditional safeguards: "for large plants the uncertainty of D [difference between operator's declaration and inspector's measured value] for ^{235}U is large, leading to low diversion detection probability due to the limitations of available [portable] NDA techniques".[1]

In addition to efficacy improvements, the IAEA also seeks efficiency improvements. The potential efficiency improvements of the unattended measures at Facility X, as compared to traditional safeguards approaches, include the reduction of announced inspections and cylinder verification measurements during inspections, potentially reducing inspection days by as much as 40 percent compared to traditional safeguards. In addition, the need for sampling of in-process gas and head space in cylinders could be significantly reduced, since continuous monitoring of these materials is provided (though environmental sampling would still be important part of unannounced inspections). The unattended measures at Facility X would also provide efficiency benefits to the operator. For example, the product cylinder release process would be eased and expedited, and the operator would have the benefit of OLEM and UCVS data to support process control, criticality safety and cylinder tracking.

The case study also helps to illustrate how instrument-level measurement uncertainties could be utilized by the IAEA to assess the value of unattended instrumentation for detecting diversion scenarios. The need for technology development projects to address uncertainty budgets, over a representative range of plant conditions, was a recurring development theme in this paper.

Summary and Conclusions

This paper builds on the IAEA's previously defined vision and objectives for advanced safeguards approaches, but focuses on the potential roles and development status of three unattended measurement systems: an Online Enrichment Monitor (OLEM), an Unattended Cylinder Verification Station (UCVS), and sharing of the operator's load cell signals.

The OLEM could provide continuous measurement of 100 percent of the declared gas flowing through unit header pipes, a key capability for the detection of the higher-than-declared production and diversion-from-declared scenarios. In a large-capacity enrichment plant, approximately twenty OLEM units would be required. OLEM would likely be owned and operated by the IAEA, but the data streams could be shared with the operator (e.g., for process control and criticality control purposes). OLEM is the most mature, in terms of development, of the three candidate technologies. Modeling-based viability studies and proof-of-principle measurements in an operational enrichment facility have established the expected range of measurement uncertainties in operational settings, data analysis methods are largely understood, and field prototypes based on IAEA user requirements are now under development.

The UCVS could provide unattended verification of the declared uranium mass and enrichment of 100 percent of the cylinders moving through the plant, but also apply and verify an NDA Fingerprint to preserve verification knowledge on the contents of each cylinder throughout its life in the facility. The UCVS would be built around the operator's accountancy scales, so that two or three UCVS units might be utilized in each plant. UCVS would be owned and operated by the IAEA, but the data streams could be shared with the operator (e.g., for cylinder tracking and process control). Modeling-based viability studies have been performed, the strengths and limitations of two different cylinder assay methods are currently being studied, and proof-of-principle field measurements have been performed on Type 30B cylinders at fuel fabrication plants for both methods. The expected measurement uncertainties, in realistic enrichment plant operation on Type 30B and Type 48 cylinders, for the assay of cylinder enrichment and ^{235}U mass are not yet fully understood, nor has the viability of the NDA Fingerprint, or the direct assay of total uranium mass, been explored.

Sharing of the operator's load cell signals from feed and withdrawal stations has the potential to count all cylinders introduced to the process and to provide periodic monitoring of the uranium mass balance for the in-process material at the plant, thereby enabling the detection and deterrence of excess production and protracted diversion scenarios in a way that other unattended instrumentation cannot. In a large-capacity enrichment plant, over 100 feed and withdrawal stations would need to be instrumented to facilitate data sharing with the IAEA. Though there are no new developments needed in terms of the weighing technologies themselves, there remain a number of unanswered questions about the statistical and systematic uncertainties associated with operator load cells, how those uncertainties propagate through a facility-level mass balance, and the effectiveness for detecting excess production scenarios using a mass balance with those uncertainties. Candidate hardware and data acquisition software is being explored in field campaigns now underway, and innovative techniques for building confidence in the integrity and completeness of the load-cell data need further exploration. Operator acceptance of load-cell data sharing, and the frequency with which the data could be shared, remain important topics for discussion.

The key themes and conclusions from this report are summarized here:

Potential for unattended instruments to substantially improve effectiveness and efficiency: Creative integration of unattended instrumentation and coupling to unannounced inspections has the potential to achieve significant improvements in the timely detection and deterrence of diversion from declared material, undeclared excess production, and production of higher-than-declared enrichment. In the case study of Facility X presented here, the major improvement in cylinder assay accuracy offered by the integration of load-cell monitoring, OLEM and UCVS opens the possibility of near-real time verification of the declared ^{235}U mass balance at the perimeter of the process MBA. This capability was never before available to the IAEA, due to the limited sampling of cylinders during interim inspections and the relatively poor measurement accuracy of the portable devices used for cylinder verification measurements. Such unattended instrumentation combinations would also lead to substantial efficiency improvements, for example the elimination or significant reduction of announced inspections, and a reduction in sampling of gas and cylinders during inspections. More diversion-scenario analysis, similar to the Facility X case study, is needed to more fully understand the strengths and limitations of the IAEA's toolbox of instrumentation and inspections, but such analyses requires instrumental-level uncertainties as input.

Need to characterize and quantify instrument measurement uncertainties: A solid understanding of the achievable measurement uncertainties in realistic plant environs, and the corresponding uncertainty budgets (i.e., the relative contributions of random and systematic errors), for each of the candidate unattended technologies is invaluable to the IAEA to help guide and refine the development of user requirements, and also to support the analysis of facility-level diversion scenarios. These instrument-level uncertainty studies are more advanced for OLEM and UCVS than for load-cell monitoring, but further investigation is needed for all three unattended instruments.

Need to characterize potential vulnerabilities and data security challenges: Instrument development activities should address, at least in the preliminary sense, key vulnerabilities or spoofing possibilities, since vulnerabilities could ultimately define whether the technology could be adopted by the IAEA. The same could be said for data security measures and whether those measures are sufficient to meet IAEA's requirement to draw independent safeguards conclusions, while at the same time facilitating the sharing of instrument data with operators and other stakeholders.

Need to identify and pursue long-term field testing opportunities: Previous and ongoing projects in the safeguards community have begun building a body of knowledge on the viability of unattended instruments, via modeling and proof-of-principle field tests with early prototype instrumentation. However, in order to build confidence in the lifecycle viability of these technologies, long-term field testing in representative facilities with field prototypes meeting IAEA's user requirements is needed. Developing flexible testing agreements that include tolerance for instrument "learning periods" and down-time for revision or troubleshooting is critical. The IAEA will continue to engage member states and facility operators to identify suitable testing opportunities.

Need to consider instrument lifecycle costs in context of facility-level approach: Once the technical viability of instruments has been established, the instrument lifecycle cost needs to be estimated. The IAEA can then incorporate the individual instrument cost estimates in the aggregate cost of the facility-level approach. For example, how does the lifecycle cost of a UCVS help to reduce the cost of other measures (e.g., announced inspections)?

Need to explore "win-win" opportunities for IAEA and operators: Discussions between the IAEA and operators have suggested that IAEA's unattended instruments may have notable benefits for facility operators, for example for process control, criticality safety, or meeting requirements from state authorities. Such opportunities should be identified and pursued as early as possible, so that the necessary hardware and software capabilities (e.g., sensor duplication, data branching methods, and data security hardware/software) can be integrated efficiently, rather than as an afterthought.

Need to continue development of inspection methods and portable instrumentation that complement a new generation of unattended instrumentation: Though the role of unattended instrumentation was the focus of this paper, efforts continue to integrate and improve other key safeguards measures in the IAEA's toolbox, including for example, activities during unannounced inspections. These activities may include environmental sampling, UF_6 sample collection for subsequent laboratory destructive analysis, and data authentication measures (e.g., use of calibrated weight standards on operating weighing systems).

The case study and the other concepts presented in this paper should not be considered a comprehensive study of all implementation options being considered by the IAEA, nor should the preliminary requirements be considered binding. The analysis and discussion presented here are intended as a starting point for discussions regarding the potential of, and challenges associated with, the use of unattended measurement systems at enrichment plants. It remains to be seen whether any of these technologies described in this paper, or combinations thereof, will be deployed in field operations. Ultimately, deployment decisions will be based on a combination of factors that include efficacy, lifecycle cost, and operator acceptance.

Acknowledgements

The authors recognize the cooperation of Urenco Limited, Euratom, and the U.S. Department of Energy in discussions regarding instrumentation concepts for enrichment plants. The authors are especially appreciative to Peter Friend from Urenco, Kiril Ianakiev from Los Alamos National Laboratory and Jose March-Leuba from Oak Ridge National Laboratory for sharing their insights and experimental experience with online gas measurement techniques. On the topic of cylinder NDA methods, information sharing and discussion with David Jordan of Pacific Northwest National Laboratory and Karen Miller of Los Alamos National Laboratory are appreciated. We would also like to thank Peter Schwalbach, who has provided helpful Euratom perspectives about enrichment plant safeguards objectives and potential instrumentation approaches. From within the IAEA, the authors are grateful to Jill Cooley, Sergey Zykov, Cesare Liguori, and David Beddingfield for informative discussions and perspectives regarding the role of safeguards technologies, and emerging priorities under the State-level concept.

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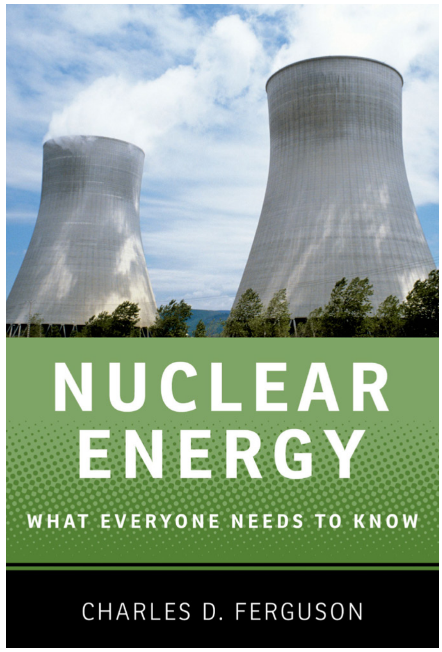
Nuclear Energy – What Everyone Needs to Know

Charles D. Ferguson

Softcover, 222 pages
ISBN 978-0-19-975946-0,
Oxford University Press, Inc., 2011
Review by Mark L. Maiello, Ph.D.

Writing a book for general consumption is one of the most difficult assignments an author of technical material can take on. Charles Ferguson, current president of the Federation of American Scientists, not only assumes this challenge but also attempts what I consider to be a non-traditional marriage of nuclear technology to proliferation issues in another volume of the long-running "What Everyone Needs to Know" series of Cambridge University Press. It might be enough for most authors to stick to a discussion of nuclear power and its infrastructure, past accidents, regulations and its continuing economic problems, but predictably and, I suspect, refreshingly for those students and general readers interested in the subject, the author included more than thirty pages on proliferation concerns. He broadened the discussion still further by including energy security, climate change and sustainable energy. As such, the book is a new, updated approach to the subject of nuclear energy that even manages to include what was known at the time of publication about the condition of the Fukushima reactors.

Written primarily for the general public, the book will also find use with undergraduates and graduate students who need a quick introduction to the field. It follows the question-and-answer format of the series, not a serious detriment for lay readers but perhaps a bit too structured for some. Certainly for the general reader, this format presents what some may consider difficult material in bite-sized increments that are easier to digest. However stilted the format may be, it makes looking up answers to particular questions fairly easy.



Ferguson tackles the questions head-on with factual responses. With characteristic ability, he successfully elucidates for his intended audience while leaving out the more elaborate language found in his professional publications and lectures. His style may be a tad on the dry side, but the retorts to the wide-ranging questions are clear. And the questions *are* wide ranging. They cover the current, prevalent issues that beset and define nuclear power. In Section 2, questions about the costs of nuclear plants are considered along with considerations of energy security. Ferguson then addresses the greenhouse effect and whether nuclear power can be of aid in the long struggle against climate change. Proliferation questions range from the pedestrian (though for the general reader fundamental), "what is the nuclear suppliers group?" to the interesting, "what are nuclear safeguards?" Questions about Three Mile Island, Chernobyl, and Fukushima cover the expected ground with some fascinating tidbits added in: "what happened to Soviet designed reactors after Chernobyl?" and "what are the concerns about nuclear safety culture in Japan?" Physical security questions consider who might attack a nuclear reactor and have there been nuclear attacks on reactors in the past? Questions concerning the countries closest to operating permanent radioactive waste repositories and whether reprocessing reduces waste volumes are covered in Section 7 on radioactive waste. The shortest section, number 8, reviews questions about sustainable energy.

The author was not shy about taking on issues that do not have short, black and white, or definitive answers. His response to the question "Can the nuclear industry survive if another major accident occurs?" is one of these challenging questions. Given that the Fukushima incident had occurred just before publication, the author and his editor are commended for even posing the question. No one can predict the correct answer to this with any certainty. Nonetheless, Ferguson takes it on explaining perceptions of risk and how some risky activities like automobile travel are tolerated while potential releases of ionizing radiation from a nuclear accident—a risk not in the control of the public nor perceived as such—are not. That is not a novel answer but it is a courageous response albeit a bit indirect.

Because Ferguson chose the material he did, a general readership, possibly predisposed by former publications—perhaps even by the Oxford University Press "A Very Short Introduction" series—may find disappointment in the lack of illustrations (only two are presented). It's just not possible to provide *informative* illustrations about the Nonproliferation Treaty or the Nuclear Suppliers Group. Therefore, general readers of this book ought to be genuinely interested in the content of this 222 page effort before they purchase it (only about sixty pages longer than a typical book in the "A Very Short Introduction" series).

This is a book you can recommend to non-technical readers who are interested in what you do for a living. It may even find use as college-level supplementary reading for a political science or science for non-science majors course. Teachers of health and nuclear physics and nuclear engineering at all levels ought to read the book if they are not familiar with its content. Students of these subjects certainly should be aware or made aware of the associated nonproliferation and environmental issues. It's a quick read at this level of education.

As part of his professional campaign to educate the public, Ferguson has again made a significant contribution. This one is a bit unique having chosen to address such current issues that rarely find themselves bound between the covers of the same book. Therein lies this book's value. It's a book that the public has needed—whether the public knew that or not. It brings together what nonproliferation professionals consider natural bed fellows as opposed to what nuclear engineers and the public might not: nuclear proliferation, energy sustainability, physical security, and international control of nuclear technology. It does so in a format that ought to inform if not satisfy—at least at an introductory level.

If there is any deficiency to the publication, it is indirect. The perception of this reviewer is that the accessibility to the book in the traditional manner (via bookstore), might make it difficult to find serendipitously. Oxford University Press does an excellent job pushing its "A Very Short Introduction" series and may in fact be as successful with its "What Everyone Needs to Know" editions. However, long gone are the days when such inexpensive series as Golden Guides were to be found literally everywhere—from book sellers to supermarkets. Science was a mere impulse-buy away. To the general reader, such accessibility is important. But certainly online availability will favor sales to industrious purchasers who will take the time to seek out Ferguson's fine book.

Taking the Long View in a Time of Great Uncertainty Working Toward Solutions

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

As we all recover from another successful Annual Meeting, the Institute's 54th, held in Palm Desert, California, it is important for us to reflect on the events that have impacted the Institute in the past year, and how we have responded to the resulting challenges, and what our strategic objectives are as we head into another year of great uncertainty.

Despite the reduced attendance this year, the Annual Meeting was still a nonstop whirlwind of information exchanges, great presentations, meetings, hallway discussions, a well-attended awards dinner and many activities with student participation. We also had a great J. D. Williams Student Paper competition, with thirty-nine papers eligible for review as well as several qualified applicants for the Sorenson scholarship. Overall, it was encouraging to see that the strategic initiative taken by Institute more than a decade to encourage participation by the younger generation is coming to fruition. Kudos should go to Steve Ward, the Student Activities Committee Chair, who coordinated student registration; welcomed the students as they arrived (he was in the lobby of the hotel on Friday and Saturday afternoon); mentored them during the week; and was back in the lobby on Thursday afternoon and Friday morning to make sure they checked out and were safely on their way back home after the meeting—great job Steve!

Also, with the help of Jim Larrimore, we were able to open the door to another important objective of engaging the international community more directly in our strategic discussions. Jim turned over the

gavel as the chair of the International Safeguards Technical Division (ISD) to Mike Whitaker on Sunday afternoon at the ISD Technical Division (pictured with INMM president, Ken Sorenson and INMM Vice President Larry Satkowiak) after thirteen years of leading the division into the 21st Century. In email exchanges prior to the Annual Meeting, Jim had suggested that we hold a special joint meeting with the Strategic Planning Committee (SPC) and representatives of the ISD to discuss how the Institute should be responding to worldwide events.[1] More on this later…

The Challenges of 2012-2013

In addition to the usual challenges of keeping our student chapters engaged and vibrant, our regular chapters active and contributing, and meeting our mission responsibilities in response to an ever changing nuclear landscape worldwide… we were also faced this year, as were many professional organizations here in the United States, with growing restrictions in federal participation at conferences imposed by the U.S. government. These restrictions not only applied to federal agency staff attending technical conferences such as our Annual Meeting, but also extended to contractor personnel who support those agencies, and in some situations, even international participants who have been supported by U.S. government program offices. This situation has diminished the vital scientific and technical collaborations that are the lifeblood of our Institute. These collaborations are not only vital to the continued advancement of science, technology and policy in the nuclear materials management discipline, but also contribute in many different ways to global security. The Executive Committee (EC) worked throughout the past year to obtain an "Agency Waiver" from the U.S. Department of Energy, and encouraged non-traditional attendees to register for the Annual Meeting. These efforts and other actions taken by the EC and INMM headquarters helped to minimize the impact, but nonetheless, our attendance dropped by more than 30 percent from last year, to below 600. The situation was further exacerbated by the current global fiscal malaise that has evidenced itself here in the United States through the debt crisis and Sequestration, as agency and laboratory budgets continue to be reduced.

While all of this attention was focused inwardly to sustain the Institute, the rest of the world did not stop spinning…

Emerging From the Dark Side

In my summer column, "As the World Turns…Toward a More Dangerous Place,"[2] I spoke about the external events in our world today that are indicators leading us to a more dangerous future. Since that article was written we have seen growing turmoil in Egypt; rising tensions between the United States and Russia, and little progress resolving the international concerns associated with the nuclear programs of Iran and North Korea. Many of these events, which we have previously called "externalities" in our Strategic Planning parlance, impact the environment and work of our Institute members and their organizations—particularly when the issues are associated with "things nuclear."

As I have mentioned before, the art of scenario planning, one tool in the planning kit of forward thinking organizations and management teams, requires consideration of uncomfortable futures, stories that, when contemplated and discussed, can create new thinking and strategies that not only help organizations prepare for those uncertainties, but can even contribute to changing paths to the future. The strategic discussions that result from scenario planning help to prepare organizations and their management for "any eventuality," giving them not only renewed confidence to address critical events when they occur, but to prepare in advance for even the most unlikely situations.

It was in the light of this examination of uncomfortable futures and the events that might lead to them that Jim Larrimore suggested we should perhaps approach the events being presented in this column not from a negative perspective, but rather from the perspective of how the Institute and its technical and scientific expertise can be applied to help leaders and policy makers make more informed decisions, keeping the Institute *above* the politics.

At Jim's suggestion we held a joint SPC and ISD discussion this year on Tuesday afternoon (pictured above). With 21 attendees, including six members of the SPC, we had a lively discussion that was facilitated by INMM president, Ken Sorenson. Some perspectives from that meeting include:

- It was agreed that INMM should not take a "political stand" on controversial issues. Examples of such issues are the difficult situations that exist in Iran and DPRK today; continuing unrest and political conflict in the Middle East; U.S.-Russian relations; and other international tensions.
- When international events present challenges to the world, it was agreed that the primary focus for the Institute, and the tenor of this column, should be "how can we lend our expertise" to help solve the technical and scientific issues that will facilitate decisions and actions by leaders and policy makers to solve these challenges. Two examples that were discussed are:
  - With respect to the recent nuclear test by North Korea in February, the challenge to the international community was to determine if the test was a plutonium or highly enriched uranium device. If the latter, there was concern that North Korea could produce more useable materials for additional weapons. At issue was whether the international community had the technical means to make that determination, which proved to be elusive. A challenge to the Institute would be to bring together the technical expertise of the membership to enhance technical monitoring capabilities so that such a determination in the future is more likely.
  - With respect to Iran, one suggestion was that a more appropriate question the Institute could address would be "Why does Iran pursue the path they are on?" Is there research that could be done to better understand the current relationships among nations, or technical breakthroughs that would improve the trust needed for diplomats to do their work?
- It was agreed that future columns would include reviews by volunteers from the ISD to ensure that issues raised are given an international perspective and voice.
- We also agreed that we would continue to encourage members of the international community to participate in our strategic discussions, as well as our student chapters and younger generation members.

The hour and half meeting went fast, and detailed discussions on some issues were left for future gatherings; however, the exchange proved valuable in that it opened an important discussion and engagement with our international membership that we had been seeking since the formation of the Strategic Planning Committee.[3] We hope to continue this dialogue as the Institute addresses a challenging external environment and continues to contribute to global security, science and technology.

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. Larrimore had previously suggested that we recast the strategic questions posed in the first column of "Taking the Long View" into meaningful challenges the Institute could pursue. See Jekowski, J. 2011. "Taking the Long View in a Time of Great Uncertainty: Preparing for Social Chain Reactions." *Journal of Nuclear Materials Management*, Volume 39, No. 3, 28-29 for examples suggested by Jim at that time.
2. Jekowski, J. 2012. "Taking the Long View in a Time of Great Uncertainty: As the World Turns…Toward a More Dangerous Place." *Journal of Nuclear Materials Management*, Volume 40, No. 4, 111-113.
3. See discussion of the Changing Face of the INMM, Jekowski, J. 2011. "Taking the Long View in a Time of Great Uncertainty: The Changing Face of INMM at the 52nd Annual Meeting." *Journal of Nuclear Materials Management*, Volume 40, No. 1, 56-57.

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Thank You to the Members of the INMM from the Family of Ed Johnson

Thank you for honoring Ed at the 2013 INMM Annual Meeting. Ed loved the INMM organization and worked tirelessly for its success. I know that Ed could be very difficult at many of the Executive Committee meetings but he was always well-intentioned.

Our children grew up knowing that there would be at least one great trip every year because their Dad would be attending the INMM Annual Meeting, and later, when they had their own families we would bring their children to the meetings. Over the years we made many wonderful and lasting friendships through the INMM.

There are many of you we will not have the privilege of meeting again, but to all of those involved in the INMM, we thank you for the many memories we shall cherish.

Sincerely,

Jerry Johnson

Jerry Johnson
(Mrs. Edway R. Johnson)

Jerry and Edway R. Johnson at the 50th INMM Annual Meeting.

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Calendar

January 13–15, 2014
INMM 29th Spent Fuel Seminar
Crystal Gateway Marriott Hotel
Arlington, Virginia USA
Contact: +1-847-480-9573
inmm@inmm.org
Website:
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February 11–12, 2014
Risk Informed Security Workshop
Stone Mountain Inn
Stone Mountain, Georgia USA
Website:
www.inmm.org/riskworkshop

May 12–14, 2014
Third International Conference on Physics and Technology of Reactors and Applications
Tetouan, Morocco
Website:
www.gmtr-association.com/phytra3/

July 20–24, 2014
INMM 55th Annual Meeting
Atlanta Marriott Marquis
Atlanta, Georgia USA
Website:
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