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JNMM Journal of Nuclear Materials Management

Fall 2005, Volume XXXIV, No. 1

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INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Global Best Practices: A Challenge to INMM

By Cathy D. Key
INMM President

We have successfully completed another INMM Annual Meeting. We wish to thank everyone that contributed to and attended the 46th Annual Meeting. Our meeting began with an outstanding Opening Plenary speaker, Charles Curtis, president of the Nuclear Threat Initiative (NTI). As you will read in his speech (see page 9) and in the Roundtable transcript (see page 13), Curtis presented a great challenge to the INMM as an organization.

As you may be aware, the INMM sponsored the first International Workshops on Global Best Practices in Materials Accountancy, Control, and Physical Protection in June 2004 in Prague, Czech Republic. The workshops were well-attended by representatives of several countries including Russia, Japan, United Kingdom, Finland, South Africa, Brazil, France, Korea, Canada, Australia, Czech Republic, Romania, Sweden, Mexico, Taiwan, Germany, Slovak Republic, Lithuania, and the United States. Curtis, in his presentation, challenges the INMM to work harder, stronger and faster in the area of best practices to assure cooperative and collective global action is present and effective in defending against nuclear terrorism.

The INMM takes Curtis' challenge very seriously. To date, we have submitted to the NTI a schedule for a proposed additional workshop to be held in 2006. Additional work is ongoing in the preparation of the workshop and a determination of who will attend. With the success of the 2004 workshop and implementation of the lessons learned from that experience, I feel confident that the 2006 workshop will be even more successful.

The INMM Fellows Committee met during the Annual Meeting and discussed the challenge presented to us by Curtis and NTI. The Fellows Committee has taken on the task of looking into how the INMM can further its involvement in the process of spreading best practices throughout the globe. We will keep our members informed of their progress.

This year's annual meeting had a record number of student participants. As we do every year, there was a competition for the best student presentation through the J. D. Williams Student Paper Award program. We had so many outstanding student presentations it became very difficult to pick just one winner. This award was given to two of the students. Their papers are presented in this issue. (See pages 23 and 32.) All of our student participants are winners in their own right. Our goal is to continue the growth of student participation in the INMM.

A First for INMM

This year the first INMM Student Chapter was created at Texas A & M University in College Station, Texas. Karen Miller is the president of the Student Chapter and can be reached via e-mail at karen_miller@tamu.edu. At the annual meeting we were honored to have a number of students from this new chapter. The INMM presented the Texas A & M Student Chapter with their official chapter banner at the Awards Banquet. An article on the formation of the Texas A & M Student Chapter appears in the September 2005 issue of the *INMM Communicator,* on the INMM Web site at www.inmm.org/members. Log in to learn more. We are extremely proud to have our first official student chapter. It was an honor and a privilege to meet multiple members of this organization. These students are our future and we will do everything within our abilities to assure they have opportunities in the nuclear management field. We hope to see continued growth in the area of student chapters.

Annual Meeting Highlights

The Closing Plenary session proves to be more interesting each year. This year it consisted of three very informative and interesting speakers. The summary of their discussions can be read on page 20. I wish to thank the Government Industry Liaison Committee headed by Amy Whitworth (amy.whitworth@nnsa.doe.gov) for the outstanding job they continue to do through their committee. This committee continues to outdo themselves.

I look forward to next year's annual meeting. Please make every effort to attend our 2006 Annual Meeting, which will be held in my home state of Tennessee, specifically Nashville, Tennessee. Mark your calendar now for the 2006 INMM Annual Meeting. The details are:

INMM 47th Annual Meeting
July 16–20, 2006
Nashville Convention Center
Renaissance Hotel
Nashville, Tennessee USA

INMM President Cathy D. Key may be reached by e-mail at cathykey@key-co.com.

"…to follow objectively where professional responsibility and logic lead"

By Dennis Mangan
Technical Editor

A February 4, 1973, article in *The New York Times* discussing the possibility of nuclear blackmail on a city, cites a May 15, 1970, Institute of Nuclear Materials Management study about the adequacy of the then Atomic Energy Commission's (AEC) safeguards of weapons-usable nuclear material. The study states that for various reasons the weakest AEC safeguards link is transportation. The *Times* article goes on to quote the INMM's summary which begins, "As a professional society, the Institute of Nuclear Materials Management can do no less than follow objectively where professional responsibility and logic lead."

These words were echoed back to us in Charles Curtis' challenge to the INMM during his presentation at our plenary session at the recently held Annual Meeting (see page 9). His challenge is for the INMM to, "…play a larger role in the world's number one security imperative — keeping nuclear weapons out of terrorist hands." He says that "…two indispensable elements of nuclear materials security are missing:

- The first element: Identify the world's best practices in nuclear materials security and accounting.
- The second element: Create the institutional infrastructure to put these best practices in place in every nuclear materials facility in the world."

Curtis then goes on about his vision of the role of INMM: "We need your professional credibility to make the case for such an initiative, and we need your judgment and expertise to develop the right institutional infrastructure to carry it forward."

In my opinion, this is a challenge made to a superb technical professional society worthy of the challenge, and an organization in some respects that is a well-oiled machine capable of executing a strong response to the challenge. As INMM President Cathy Key notes in her message in this issue, the challenge to develop a response to Curtis' challenge was given to the Fellows Committee, chaired by Obie Amacker. Amacker formed an ad hoc committee under the leadership of Immediate Past President John Matter to generate the response. (Other members of the ad hoc committee are Paul Ebel, Joe Indusi, Ed Johnson, Dennis Mangan, Tom Shea, and Jim Tape.) The ad hoc committee has generated a draft proposal which is being reviewed by the entire Fellows Committee. It is hoped that this proposal (or a modified version thereof) will be shared with the Institute's Executive Committee at its November meeting. Hopefully INMM's response will be shared with all in the winter issue of *JNMM.*

The fall issue of the *Journal* is generally my favorite issue because it focuses on our important annual meeting. In this issue, Charles Pietri, the chair of our Technical Program Committee, provides an excellent overview of our 46th. We include Curtis' plenary address, along with the interesting Roundtable interview with Curtis, which followed his speech. We include a summary of the closing plenary session, and in addition, we have the two student papers that received the J. D. Williams Student Paper Award at the meeting, one, *Forward Model Calculations for Determing Isotopic Compositions of Materials Used in a Radiological Dispersal Device,* by David Burk and his colleagues from Texas A&M University, and the other, *Detection of Highly Enriched Uranium Using a Pulsed Inertial Electrostatic Confinement D-D Fusion Device,* by Ross Radel of the Fusion Technology Institute of the University of Wisconsin. I remember when I made my first presentation at an American Nuclear Society meeting, and I certainly did not have the poise that these two demonstrated.

Also in the issue are two topical papers. The first one, *Toward the Simulation of Photofission for Nuclear Material Identification,* by Maura Monville of Washington University, Enrico Padovani of Politecnico Milano, and Sara Pozzi and John Mihalczo of Oak Ridge National Laboratory, addresses a technique that could be used to analyze cargo containers to detect clandestine fissile material. The second paper, *A Concise Algorithm for Determining Sample Sizes for Inspections,* is authored by Ming-Shih Lu and Robert Kennett of Brookhaven National Laboratory. This paper underwent an interesting peer review inasmuch as it created mixed positions among the reviewers. The main issue: One reviewer raised a point about the authors not including false alarms and asserted that the authors needed to allow for these for their results to be meaningful. The authors held firm that this should not be an issue, and another reviewer agreed. We then decided to publish the paper.

In closing, I would like to acknowledge a "thankless" job—the oversight of the INMM Annual Meeting by the INMM vice president. Nancy Jo Nicholas put forth a commendable effort this year.

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

JNMM *Technical Editor Dennis Mangan may be reached by e-mail at dennismangan@comcast.net.*

Report of the 46th INMM Annual Meeting: If Not INMM—*Then, Who?*

That's the question Charles Curtis, president of Nuclear Threat Initiative (NTI), posed to the participants during the 46th INMM Annual Meeting at the Marriott Desert Ridge Hotel and Resort in Phoenix. Curtis, this year's plenary speaker, had just challenged the INMM to consider a potential institutional model for promulgating best practices for nuclear materials security by building an operational capacity within INMM to provide such best practices support globally on a full-time basis! It was an astounding challenge to INMM and the meeting participants—and it caught most of us by surprise. But, yes, what other organization except INMM—the world's premier professional forum for the exchange of technical information, policy matters, and new ideas and initiatives in the international nuclear safeguards community—could be successful in such a venture! Plans are in the works by the Fellows Committee to address this challenge and provide the INMM Executive Committee with recommendations. (And you all thought INMM was really challenged by the imaginary scorpion scare in Phoenix two years ago followed by the trauma in 2004 when forty-three papers were cancelled a day before the meeting! We handled those superbly. Charlie Curtis and NTI have outdone those trials and I'm sure INMM will meet this test once again.)

At the conclusion of the Opening Plenary Session, a luncheon interview of Curtis, was conducted at the INMM Roundtable by our *Journal's* Technical Editor Dennis Mangan. A lively discussion about several topics including INMM's potential role in global best practices followed. Curtis' speech and a transcript of the Roundtable are published in this issue of the *Journal.* (See pages 9 and 13.) The speech also will be found in the *Proceedings of the INMM 46th Annual Meeting, on CD-ROM.*

As a fitting finale to Curtis' visit with INMM he was awarded an Honorary INMM Membership for his interest and work in the nuclear materials management and nonproliferation areas. He was especially pleased with this honor.

Dr. Charles Curtis Receiving Honorary INMM Membership; Key(r); Nicholas(l)

Moving on to meeting details, we note that there were no significant (or even noticeable) concerns at this meeting. (Remember the wholesale withdrawal last year of the forty-three papers due to one facility's administrative issues and, a few years earlier, the last minute withdrawal of papers from some of our overseas colleagues for similar reasons?)

We hear that the 46th Annual Meeting was a success to add to our list of successes. Some innovations this year included greater student participation in terms of attendance and presentation of papers and the widespread and nearly flawless use of PowerPoint LCD projection for presentations—more about these events later. We even recruited the Marriott's conference manager to display our new INMM podium banners—did you notice them?

And how would we ever survive much less thrive without Glenda Ackerman and her well-tuned Registration Committee.

New INMM Podium Banner Presented by the Marriott Hotel Conference Manager Edith Ambrester

Registration Chair Glenda Ackerman and Technical Program Committee Chair Charles Pietri. All smiles just before registration began!

The INMM headquarters staff consisted of Leah McCrackin, our executive director, now a veteran with two annual meetings to her credit; Lyn Maddox, our meetings and exhibition manager (a.k.a. Ms. Fixit, who works her magic with the hotel staff and facilities to keep us happy); Madhuri Carson, our cool conference administrator who always knows what's going on; Patricia Sullivan, the *Journal* managing editor, who facilitates the Roundtable and *JNMM* associate editors' meeting; and our new administrator Kesha Bunting (a novice when the meeting began but an expert in her area after a few days)—worked diligently (many times behind the scene) to keep the program rolling and helped to correct the few issues that arose. (We won't tell you about those!)

There were 816 total attendees including 102 companions; 287 papers presented including twenty posters (a total of 337 abstracts were submitted with fifty withdrawals or a net 287 papers available for presentations), and forty-one sessions. (For comparison, in 2004 we had 848 total attendees including eighty-four companions, 289 papers including thirteen posters, and forty-nine sessions.)

Sunday afternoon is the long-established time for the six INMM Technical Divisions to meet and discuss issues and topics of importance with colleagues that are not ordinarily able to meet in such a forum—another advantage of the INMM Annual Meeting where the most knowledgeable professionals in the nuclear materials management community are assembled. All meetings were well attended and, from what I hear, much useful work accomplished.

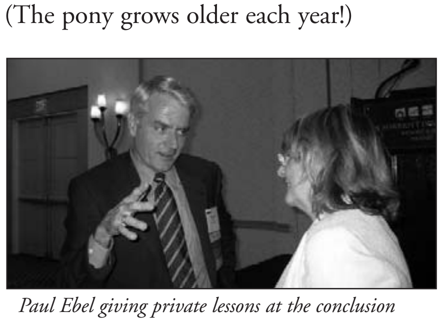
The exhibitors at our meeting deserve a lot of recognition for the way they spend a few days of their lives setting up displays and meeting with interested individuals who gain some insight into the practical applications and the innovative technology available for use. We try to plan events, such as the President's Reception and coffee breaks, in locations that give visibility to the exhibits and an opportunity for the meeting attendees to meet with these exhibitors. This year there was plenty of space for the exhibits and for the attendees to easily roam the various booths.

INMM Annual Meetings are outstanding opportunities to meet colleagues and friends in the nuclear materials management community. The President's Reception on Sunday, July 10, provided such an occasion in an informal manner. And, despite what a few folks said, almost unlimited food and beverages were available.

The Awards Banquet took place on July 12, the food was better than most institutional dinners and the awards were worth mentioning: Ronald Cherry received the Distinguished Service Award. Furthermore, for her long and dedicated service to INMM (and for her influence on keeping her husband, Ed, focused on success), Jerry Johnson was awarded the Special Service Award. (Jerry, as humble as she could be, accepted the award in bare feet!) But however enjoyable the banquet was for many it is always sad to hear of the passing of some of our colleagues. Resolutions of Respect for six of our deceased members were read: Carl G. Ahlberg, James Russell Griggs, Lewis Hansen, Edward Kerr, James W. Lee, and Lewis Calvin (Cal) Solem.

Jerry Johnson receives the Special Service Award for 2005.

For the third year, and in continued response to our speakers' comments, Paul Ebel (BE Inc.) conducted a Speakers and Session Chairs Tutorial following the Speakers Breakfast each day. Participant ratings for this event continued to be in the "good-excellent" range. (Ebel wished that a few of the speakers this year had heard or adhered to his suggestions on how to keep their presentation to within twenty minutes.) The topic this year was "Encouraging Questions"—bringing his pointed instructions to the audience adequately laced with his usual humorous delivery. Wait until next year—I think he is planning a short review of the previous sessions with some exciting new material. (The pony grows older each year!)



Paul Ebel giving private lessons at the conclusion of his tutorial.

"By golly, it really works!" Paul Ebel and surprised presenter Leigh Gunn (right) loading his talk.

After several years of informally using LCD PowerPoint© projection systems for speaker presentations, INMM formally endorsed and managed their use at this Annual Meeting. I felt comfortable that Ebel, in his other role as LCD projection coordinator, could successfully manage the solicitation of equipment, arrange for their setup, oversee the loading of presentations on each computer by session, and monitor the process throughout the meeting. Needless to say the entire process was nearly flawless—the very few instances of concern were immediately remedied by a cadre of projection managers and others assigned to each session. INMM, and Ebel especially, express their gratitude to the Technical Division chairs and their colleagues for taking on the projection task and making it work successfully. They found projection managers, hustled to find projectors, ensured the presentations were loaded on the computers by session on time, and generally provided oversight of the technical sessions. The projection managers who volunteered (a few under duress!) deserve recognition for their contribution. The speakers did a fine job in cooperating to get their presentations loaded and ready for use. We all felt that the LCD projection process at the INMM Annual Meeting went far smoother than we could ever have imagined.

The Report Card for the INMM 46th Annual Meeting this year was similar to the ratings received in previous years with some notable exceptions that were mostly very positive. We value our participants' comments and try to address all the concerns and issues that arise at the Annual Meeting. That's why, when INMM is in a position to control the meeting process, our meetings steadily improve year by year; unfortunately, sometimes what we should or need to do to make the meeting more effective and enjoyable is not always within our ability. We even listen to the more trivial comments—it pleases us at times that folks don't find more serious matters to bring forth. We must be doing some things right. These days the comments have much more substance than five years ago when some of the responses focused on "not having food at the coffee breaks." (However, we did have some delightful coffee breaks this year though the efforts of our sponsors.)

Now for the ratings. We don't get a very large response either through the electronic survey or verbally at the meeting—this year it was 25 percent (versus 31 percent last year) and 28 percent in 2003 but only 5 percent before we started using the electronic survey. This year the **Overall Annual Meeting** process was rated similar to last year's—mostly as good-excellent with excellent commendations for the **Online Abstract** and **Final Paper Submission process, Preliminary** and **Final Programs,** the **Online Program,** the **Pocket Schedule-at-a-Glance** (highest rating!), the **Registration Process, Audiovisuals (LCD Projection), Technical Program Committee** and our hard working and highly effective **INMM HQ Staff.** The **Opening Plenary** session was highly commended; however, although we did get some good comments on the **Closing Plenary** session we also received a generally mixed review. (However, before we make any harsh criticisms, it must be appreciated that soliciting plenary speakers appropriate for the varied INMM audience is a most arduous task for us. INMM asks your assistance in identifying specific speakers and topics you would like to propose. However, merely suggesting names and themes is not helpful; you must be in a position to make meaningful contact with potential speakers on behalf of INMM. Please let us hear from you.) The **Technical Information Exchange, Logistics,** and **Exhibits** areas were also rated highly good-excellent (mostly good). The **Hotel** and **Facilities** were rated the highest of all the meeting elements (66-75 percent rated them excellent.) ***Once again, regardless of any other factors, greater than 95 percent of the responders indicated that the INMM Annual Meeting met their needs and expectations!***

INMM continues to receive good meeting evaluations from those attendees who took the time to respond. Ordinarily, we would summarize these responses here but the evaluations were in excess of 300 individual comments. We plan to address all of these comments during the coming season but take the opportunity at this time to provide some selected responses that appear to be representative:

- Loved the idea of the Speakers' Breakfast.
- Some speaker's presentation materials were not prepared in accordance with the Speakers Manual; some speakers did not follow the rule to make their presentation in 20 minutes.
- Some session chairs did not repeat the question from floor so that the question could be understood.
- Some speakers still are just reading their material, do not speak to audience, and spoke too fast not realizing that English is not the native language of many of the participants from other countries.
- Everything went very well. Keep up the good work each year.
- Since my main interest is waste management, I was surprised and disappointed about the low number of waste disposition attendees/papers. So, I intend to work with Ed Johnson to stimulate more interest from this portion of the waste management community.
- This was among the best organized professional meetings, with the strongest content, I've attended.
- In the pocket schedule-at-a-glance please add the name of the day on each page (corner); it could be even better if it were tabbed, morning and afternoon sessions, for each day.
- Good—the hotel is excellent but the climate is horrific. No more meetings where the temperature is above 100°F!
- Wonderful meeting! Great range of topics and information (technical, political, etc.) Great resort selection!
- This was absolutely the best conference I have ever been to. Thank you for your efforts to get students involved. My only critical comment would be regarding food. College students on a $40 a day per diem could not really afford the expensive meals at the hotel ($6 for a glass of juice). The first day the hotel offered a $17 all-you-can-eat lunch buffet but they stopped it because of a lack of interest.
- The student mentoring program at the Annual Meeting was absolutely fantastic, however organizing it entirely at the student orientation meeting should be re-thought.
- LCD PowerPoint projection: It is an important and welcomed improvement; we have to thank the projection managers who were very helpful and dedicated. However, presenters need to be coached on "slide" preparation. Too many slides were so crowded with words that only the presenter could read them!
- It would be nice to have a greater selection of room sizes for presentations. The very large rooms overwhelmed many less well-attended sessions. Some session rooms were too small for the number of persons wishing to attend while at the same time larger rooms were not well occupied.
- Meeting during July in places that are the hottest in the country does allow for great rates on hotels but it does not allow the attendees many options for things to do when there are no sessions of interest.
- My only real complaint would be directed to the session chairs. The majority I saw lacked many fundamental social graces.

- A lot of papers were withdrawn. Disappointed.

Among the "problems" INMM had this year were paper withdrawals, speaker changes, and final paper submittals. I won't belabor the continuing issue of withdrawal of papers and changes in speakers this year only to say that we still have that problem and it is disturbing not only to the Technical Program Committee who worked so diligently to put together a superb program but especially to our attendees. It's only your cooperation in making such changes early enough, at least one month before the Annual Meeting, that will solve the problem.

Another sore spot is the submittal of final papers—INMM policy is that authors submit these papers four weeks before the Annual Meeting so that HQ staff can prepare for their early publication in the *Proceedings of the Annual Meeting.* INMM recognizes there are a few (but very few!) legitimate reasons for authors not submitting their papers on time. The infamous *Delinquent Final Papers Blacklist*, although disturbing to those offenders, seems to be at least one way to attract attention to this serious matter. INMM looks forward with joy to the day when we can abandon that practice. Again, these negligent authors will now have to be judged for their participation as speakers in future INMM Annual Meetings. INMM continues to recognize all of you who cooperated so well to make the meeting a success and provide a history of the event through the *Proceedings.*

One of the highlights this year was abundant membership and student activities. The annual New Member/Senior Member Reception on Monday evening was hosted by the Membership Committee Chair Scott Vance and the Executive Committee. Once again the reception was very well attended with about 100 people present. Approximately half of these attendees were either members who joined within the previous year or newly elected senior members of the Institute. In addition, several of the attendees were student members, a group that was heavily represented at this year's meeting. In addition to the opportunity for the Executive Officers and other leaders within the Institute to meet the new members and congratulate the new senior members, the reception served as an opportunity for INMM President Cathy Key to welcome these new members into the Institute, with some sage counsel from Student Activities Chair Mark Leek, to the new student members and a few words of wisdom from long-time active INMM member Dennis Mangan.

Leek and his Student Activities Committee sponsored three activities, two of which were new this year. The traditional student orientation on the final night of the meeting featured presentations by each of the Technical Division chairs, who provided substantive overviews of their divisions, the type of education needed for a career in this area, and where the jobs are located. A special feature was a presentation by the Texas A&M Student Chapter officers on how the chapter was formed and their ongoing activities. The two new activities build directly on INMM's initiative to increase student participation at the Annual Meeting and increase student membership.

The Executive Committee provided financial support to bring three international students to the conference, support some domestic student travel, and purchase a block of hotel rooms for student use. These efforts increased student participation threefold over last year's conference. To enhance the experience of students at the conference two new activities were introduced. Students assembled as a group on Sunday evening to meet each other prior to the Annual Meeting and subsequently were matched one-on-one with an INMM mentor. Students and mentors met periodically to discuss how the meeting was going, address any questions, and meet other members. By all accounts students found the mentor program extremely worthwhile.

We look forward to our student population growing in future years as additional student chapters are established and opportunities for student involvement in the meetings are increased. From the students' perspective, several indicated that they were overwhelmed with the accessibility of leadership at the meeting, and one indicated that he had never felt as comfortable at another professional meeting that he had been attending for years as he did at this year's INMM meeting. There is a high level of enthusiasm on the part of these new student members and those who commented on the meeting indicated that it had served to fuel this enthusiasm even more.

David Burk, Texas A&M, a Happy Student Award Winner, Key (l) & Nicholas (r)

INMM continues to promote student participation in the Institute by, among other incentives, encouraging students to present the results of their research at the Annual Meeting. This is the fourth year of such an initiative and seventeen papers were in competition for the *J. D. Williams Student Paper Award.* Many of our colleagues are responsible for making this student initiative a success including Yvonne Ferris, Nancy Jo Nicholas, Mark Leek, and about a dozen others too numerous to mention. This year there were two recipients of the student award this year: David Burk, Texas A&M University and Ross Radel from the University of Wisconsin. Burk presented "Forward Model Calculations for Determining Isotopic Compositions of Materials Used in a Radiological Dispersal Device." Radel offered "Detection of Highly Enriched Uranium Using a Pulsed Inertial Electrostatic Confinement D-D Fusion Device."

Three speakers covered varied areas of interest during the Closing Plenary Session, led by Government Industry

Relations Committee Chair Amy Whitworth. The topics were "U.S./Russia Nuclear Security Cooperation," by Glenn Podonsky, director, Office of Security and Safety Performance Assurance, U.S. Department of Energy (DOE); "DOE's Steps Toward Materials Consolidation," by Meggen Watt, Secretary of Energy Senior Advisor for National Security, DOE; and, "The Terrorist Threat to the United States," by Adam Angst, FBI special agent. There was lively interest in these presentations but Angst's talk hit home personally with his portrayal of the potential terrorist threat affecting all of us.

Closing Plenary (left to right): Adam Angst, Cathy Key, Amy Whitworth, Meggen Watt, and Glenn Podonsky

Meeting attendees have told me personally that this 46th Annual Meeting was very valuable to them and others have validated those sentiments in their formal evaluations. We seem to have reached a plateau in how much better we can make this event but we continue to try. The "we" is all of us but most of all the hundreds of dedicated speakers who prepare and present papers with the latest and most significant information regarding nuclear materials management, the session chairs who manage the sessions, the Technical Program Committee that laboriously puts the program together, and the INMM HQ staff that effectively administers these activities. Thanks to all.

Now, you should note that next year's meeting is at the Nashville Convention Center/Renaissance Hotel, Nashville, Tennessee, July 16–20, 2006. Begin now to plan for it. This meeting offers opportunities to organize or chair a session (or both), present a paper or poster, be an exhibitor or sponsor, or just attend. And if you can, encourage students to participate. Whatever your choice, don't wait until the last minute. Complete your research, get your subject approved by management, write your abstract, and submit it by February 1, 2006, and write your paper and submit it early. Make it easy on yourself. So, come, fly with the eagles (or crawl with the turtles)!

(left to right): Madhuri Carson, Kesha Bunting, Charles Pietri, Lyn Maddox, and Leah McCrackin

Opening Plenary Speech
Promoting Global Best Practices

Charles B. Curtis
President, Nuclear Threat Initiative

46th INMM Annual Meeting
July 11, 2005
Phoenix, Arizona, USA

"If not you, who? And if not now, when?"
Charles B. Curtis, NTI

It's an honor to address the premier international professional society for nuclear materials management. My talk today is a simple appeal to all of you to play a larger role in the world's number one security imperative—keeping nuclear weapons out of terrorist hands.

This is the most significant, clear, and present danger to global security, and there is a dangerous gap between the threat and our response. For more than four years now, the organization I serve as president, the Nuclear Threat Initiative, has worked to help close that gap between the threat and the response—and reduce the chance weapons of mass destruction will ever be used by anyone, anywhere, whether by intent or accident. We pursue this goal by serving as a catalyst for new thinking, by encouraging governments to act and transform public policy, and by developing start-up programs that we hope governments and the private sector will replicate on a larger scale.

There is a special advantage we bring to our work, and it is an advantage we share with your organization and all non-governmental entities: although we act with full transparency to our government, we can act without the regulatory restrictions and policy constraints of government. This ability, I believe, is key to an important new approach we need to bring to preventing nuclear terrorism. It's this approach I will be urging you to examine, advocate, and perhaps take on as your own.

The Heritage of INMM

In reviewing the history of your organization, I was struck by a *New York Times Magazine* article from 1973 discussing a threat that most citizens today consider only a recent development—the possibility that terrorists could acquire nuclear materials and make a bomb.

In those days, they were afraid that terrorists would use the bomb to blackmail governments; these days, we fear they wouldn't bother with blackmail. The writer of the article, a nuclear physicist, quotes approvingly from a report done by "a professional society of nuclear experts who became concerned about the adequacy of the AEC's safeguards." The group, of course, was the Institute of Nuclear Materials Management. The article said: "In a candid manner, untypical of professional societies, a May 15, 1970, report singled out transportation as the weakest link in the chain of security enveloping nuclear materials."

The article then quotes directly from the report, as follows: "As a professional society, the Institute of Nuclear Materials Management can do no less than follow objectively where professional responsibility and logic lead. When logic applied by calm and reasonable men leads to alarm, as in the matter of safeguards for nuclear materials in transportation, then the Institute must be alarmist."

You can tell something about the heart and spirit of an organization from its history, and this article makes it clear that, at a time of concern in the United States about nuclear materials security, your organization was a leader in offering a blunt assessment of the facts and the risks.

The Institute of Nuclear Materials Management played an important role in making our nation more secure against the terrorist nuclear threat in the 1970s. It has an even higher obligation to do the same now.

The Greatest Threat

The chair of the 9/11 Commission, Thomas Kean, recently said, "A nuclear weapon in the hands of a terrorist is the single greatest threat that faces our country today." Commission Vice Chair Lee Hamilton has said, "You have to elevate this problem above all other problems of national security, because it represents the greatest threat to the American people." Why are the chair and the vice chair of the 9/11 Commission so completely convinced that nuclear terrorism is our greatest threat? Let me answer with four quick points—enumerated in their report.

1. Al Qaeda has been seeking nuclear weapons for ten years.
2. The nuclear material they need is housed in hundreds of sites around the globe.
3. If they get that material, we have to assume they can build a nuclear weapon.

4. If they build a nuclear weapon, we have to assume they will use it.

The Right Response

The most effective, least expensive way to prevent nuclear terrorism is to secure nuclear weapons and materials at the source. Acquiring weapons and materials is the hardest step for the terrorists to take, and the easiest step for us to stop. By contrast, every subsequent step in the process—building the bomb, transporting it, and detonating it—is easier for the terrorists to take, and harder for us to stop.

Therefore, the defense against catastrophic terrorism must begin with securing weapons and fissile materials in every country and every facility that has them—to keep them out of terrorist hands. No nuclear material, no nuclear weapon. No nuclear weapon, no nuclear terrorism.

That is a simple formula, but a complicated endeavor. There are nuclear materials in a large number of countries. Terrorists trying to steal nuclear materials won't necessarily go where there is the most material; they will go where the material is most vulnerable. Our security, therefore, is only as strong as the weakest link in the security chain. In the post-9/11 world, each nation has a supreme national interest in making sure every other nation secures its nuclear materials to the highest practicable standards. That interest is not being met, and it will not be met until there is wider understanding of the urgency and greater public pressure for action.

So, we at NTI have been sounding the alarm. That is why we recently released the video docudrama—"Last Best Chance"—that portrays a terrorist plot to detonate nuclear devices in the United States and Europe. We don't relish alarming the public—if that is the consequence of this docudrama—but we believe that seeing the danger is the first step to safety. We need you to add your professional voice and efforts to this task. The professional credibility of this organization would be an enormous asset in making the case for quicker action—for doing everything we can to strengthen our defenses against sabotage, theft, and diversion of nuclear materials. To borrow a phrase from your report of thirty-five years ago, this is simply to: "follow objectively where professional responsibility and logic lead."

New Tools

The world community is aware of the danger of nuclear terrorism. Right now there are several new international efforts aimed at making it harder for terrorists to acquire nuclear weapons. The first is the Convention on Physical Protection of Nuclear Materials. Throughout the history of the Atomic Age, there has been no international requirement for physical protection of nuclear material within a state—until last week, when nations from around the world, meeting in Vienna, adopted an amendment to the Convention on Physical Protection of Nuclear Materials.

As you know, the Convention used to require protection of nuclear materials only in international transport. Now it requires physical protection of the nuclear materials within a state. It also establishes a set of principles that countries should follow in safeguarding the material. It covers sabotage, which the original Convention did not. It also allows the IAEA Office of Nuclear Security to ask countries what they are doing to comply with the specific principles outlined in the Convention. For these reasons, the amendment is an important development, and we welcome it.

In another major effort to keep nuclear materials from falling into terrorist hands, the UN Security Council, in April 2004, unanimously passed Resolution 1540. This measure codifies an explicit responsibility of states to prevent the proliferation of nuclear, biological, and chemical weapons, and their means of delivery, including by taking "appropriate effective measures to account for and secure" nuclear materials. The Resolution has the force of international law and is enforceable by the Security Council. It holds every country accountable, including those who have chosen to remain outside international nonproliferation treaties.

In a third recent effort, the UN General Assembly in April of this year unanimously adopted the International Convention for the Suppression of Acts of Nuclear Terrorism. The Convention will provide a legal basis for international cooperation in the investigation, prosecution, and extradition of those who commit terrorist acts involving radioactive materials or a nuclear device. This new treaty also reinforces the previous two initiatives by calling on state parties to make every effort to adopt appropriate measures to ensure the protection of radioactive material.

The Conventions and the Security Council Resolution collectively represent an acknowledgment that more urgent action on the part of the international community is needed to keep nuclear materials out of terrorist hands.

The Gaps Between Threat and Response

Unfortunately, all three measures fall short. To make the conventions binding, for example, each individual country has to vote to adopt the amendment, which will likely take years. That is time we do not have. Further, the Physical Protection Convention does not apply to military nuclear material, which represents up to 80 percent of the global total.

The Security Council Resolution, on the other hand, must be implemented to be effective, but there is no assurance that member states will follow through and actually do what they have resolved to do. First year progress has not been confidence building. Every nation has its own issues with regard to cost, sovereignty and the protection of state secrets. The UN Security Council will face thorny questions about how to respond if nations do not comply with its terms. Finally, the amended Physical Protection Convention and the Resolution do not have specific standards for nuclear materials security. The Convention has a series of principles, which each country can interpret as it chooses. The Resolution does require an "appropriate effective" nuclear security and accounting system, but there is no agreement on what that means, and until there is, it will mean nothing.

This brings us to the two indispensable elements of nuclear materials security—both of which are missing from the Amendment to the Physical Protection Convention and the Resolution: *The first element: Identify the world's best practices in nuclear materials security and accounting.*

The second element: Create the institutional infrastructure to put these best practices in place in every nuclear materials facility in the world. Our objective here should be to surpass and run ahead of regulatory requirements. I believe there is an extraordinary opportunity here for the nuclear profession to voluntarily formulate best practices for safeguarding nuclear materials, to communicate them widely, and to put them into practice throughout the world. This would not replace the efforts of governments; rather this path of nuclear security would run parallel to the efforts of the Amendment and Resolution, but run faster—because it would be unhindered by many of the obstacles that come with government action. Not only is the nuclear profession in a strong position to do this—the nuclear profession has a very deep self-interest in doing so.

The Nuclear Profession's Role in Closing the Gap

For more than thirty years, I have been at the center of U.S. energy policy formation and concerns about primary fuels balances. It is plain to me that the world needs nuclear power to meet twenty-first century energy requirements. But the question at the heart of the size and nature of that nuclear future is whether the power of the atom, on balance, brings more benefits and advances to humankind or more damage and destruction.

Unfortunately, the question might be answered in a flash. One single destructive use could end much of the potential for the atom's beneficial use. If a terrorist nuclear attack is carried out anywhere in the world, people all over the planet will immediately demand, and governments will impose, extraordinary measures to lock down and secure nuclear materials everywhere—measures that may well be incompatible with normal operations of nuclear power plants and research reactors or the very conduct of nuclear research.

We should do all we can do to avoid that public response. If we're going to have a bright nuclear future, therefore, we're going to have to have a more secure nuclear present. As a matter of self-interest as well as professional responsibility, the nuclear industry has a special need to see that this essential security job is done and done well. It cannot be left to government alone. This will require new thinking and new methods. It will require the expertise of people who know what works best and costs least—who can take into account the needs and designs of different facilities.

A Model for Defining and Disseminating Best Practices

As we know, there is already a model in the nuclear industry itself for how the nuclear profession can develop a consensus set of best practices, and distribute them throughout the industry and around the world. After the Chernobyl incident in 1986, nuclear power plant operators knew their industry was in trouble—in the eyes of the public, and in the eyes of regulators. In this climate, an international nuclear utility executive meeting took place, with thirty-two countries represented. It led to the founding of the World Association of Nuclear Operators (WANO) with the mission, according to the charter, to "maximize the safety and reliability of the operation of nuclear power plants by exchanging information and encouraging communication, comparison and emulation among its members."

Today, there is universal membership in WANO. Every organization that operates a nuclear electricity generating plant is a member. All members pay dues, and provide experts to do the peer reviews.

1. WANO alerts members to events that have occurred at other facilities—reporting on causes, corrective actions, and lessons learned.
2. It conducts peer reviews that last for two weeks—all done in accordance with specific WANO "performance objectives and criteria." The review team then sends a confidential report to the utility.
3. WANO offers no-fee workshops and seminars, organized in response to member demand.
4. And most importantly, it identifies good practices—and distributes them by secure Web site.

I believe an organization similar to WANO is needed to ensure that nuclear materials are secured and made immune from terrorist theft. Like WANO, it should be done voluntarily through the nuclear profession. Unlike WANO, it should not wait to be formed until after a disaster. In my mind, INMM could be that organization.

The Beginnings of an Initiative

A year ago, in summer 2004, NTI sponsored with your organization two one-week workshops—bringing together a select group of nuclear materials professionals from government, industry and research venues around the world to discuss "best practices" for securing and accounting for nuclear weapons materials. International meetings on nuclear materials management usually focus on policy level discussions. This meeting, on the other hand, was an open forum for technical information exchange among ninety nuclear materials practitioners from thirty-six countries. It was the first opportunity that many participants had had to meet with their colleagues from other countries and share ideas. They universally agreed that published guidelines do not take account of today's threats.

Participants gave presentations on best practices for nuclear materials management at their respective nuclear facilities and in the afternoons they met in smaller discussion groups to exchange ideas and work toward a consensus on best practices. Based on these discussions, NTI and the INMM are developing a catalog of best practices from around the world and making them publicly available through their Web sites. The challenge is to expand on this effort. I was gratified to note the inclusion of U.S./Russian cooperation on best practices for nuclear security in the joint statement from the Bratislava Summit. But this is just a start.

The Role of the INMM

The people here at this conference have a central role to play in this expansion. You are responsible for securing materials, for surveillance, for accounting, for tracking materials as they move. If there is a set of best practices for nuclear materials security, it should come out of a discussion started by the people in this room.

This discussion could then evolve into a set of ideas that could inform state regulatory actions—and, I think more importantly, the evolved practices could be embraced by facilities operators worldwide, resulting in a more comprehensive voluntary application of best practices beyond anything binding regulations could achieve. In other words, the nuclear profession can take the lead. This won't happen—in my view—unless the members of the Institute of Nuclear Materials Management show the way. We need your professional credibility to make the case for such an initiative, and we need your judgment and expertise to develop the right institutional infrastructure to carry it forward.

The New Infrastructure

This new infrastructure should meet several characteristics and discharge certain duties:

- In contrast to WANO, in which all members are operators of power reactors, the membership of this new security organization should be more diverse, to include fuel manufacturers, research reactors, and national labs—indeed it should include any and all entities that have materials requiring physical protection.
- It should have full-time expert staff and a stable resource base.
- It should formulate and communicate broadly best practices for nuclear materials management.
- It should establish quantitative performance benchmarks for security and measure performance against them.
- Lastly, it should carry out peer reviews of facility security operations and make recommendations for improvements, investigate and document lessons learned from security incidents, and provide training for members' employees.

Of course, this cannot all be done at once. A phased approach will be required. Building such an infrastructure would take a steadfast commitment of time and energy. But it is hard to imagine anything more in the interest of your profession, and more worth supporting for your organization. Whether you would wish to build such a capacity and take on that mission is something for you to decide. It won't be easy; it will require resources that you do not now have, and it will require the hardest of all things—institutional change. But, given the breadth of your membership and the huge professional regard for this organization, I believe this is a job INMM can do best, with the speed required to counter the terrorist threat.

A newly formed WANO-type organization cannot be formed and act with the alacrity of INMM. And IAEA, as we all know, has serious scope limitations and perpetual political problems which impair its effectiveness and the pace of its work. So as you ponder this matter, ask yourselves—If not you, who? And if not now, when?

Conclusion

I would like to close these remarks by addressing those conference participants who know the fine details of the best approaches to securing nuclear materials. When you took your jobs, and learned what you needed to know to do them well, you may not have envisioned the rise of global terrorism, and the emergence of terrorist groups that seek nuclear weapons.

You may not have chosen your profession for the role it would give you in preventing the world's greatest threat. But here you are. Your knowledge and your position confer on you an ability to do what no one else can do as quickly or as well—help the world define and disseminate best practices so we can secure nuclear materials and keep them out of terrorist hands. Logic and professional responsibility tell us this job needs doing and that the mission is urgent. By taking on this responsibility, you can both help safeguard the world and preserve a nuclear future.

Thank you.

INMM Roundtable

Monday, July 11, 2005
Phoenix, Arizona, USA
Nuclear Threat Initiative

Opening Plenary Speaker
Charles Curtis
President, Nuclear Threat Initiative

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JNMM Technical Editor, Chair of Roundtable

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Ken Sorenson
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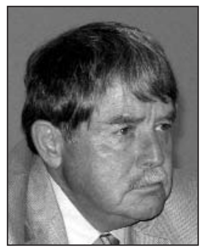


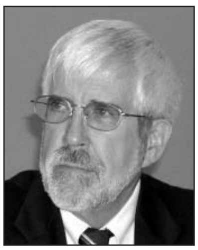
Dennis Mangan: Your presentation (see page 9 of this issue) this morning was extremely interesting and thought provoking and I'm sure many in the audience have various thoughts in their minds about the challenge you posed to the Institute, but I have to ask you: You must have some thoughts in your mind in regard to going from taking an organization like the INMM, which is a truly volunteer organization that lives on a very strapped budget, and to get it into a position to support your vision. Can you give us any guidance on how we go from where we are now to being able to be part of that vision?

Charles Curtis: I might, in retrospect, have spent more time in my remarks on the nature of how this mission might evolve. I think it's obviously going to have to be phased if it were to be taken on. The first step is to promulgate best practices and broadly propagate them. I think that's within the capacity of the existing organization and not a very costly endeavor. Building in peer review, training, and the infrastructure to support no-fee conferencing and those other elements of a fully supported institutional infrastructure would take more time and be more costly—especially the peer review function. So I think one of the first steps is to look at what I had to say and see if I've got the elements of an institutional infrastructure right and also how you would go about it. Because I think that would tease out the necessary phasing of the step-wise process that would have to be followed. The real challenge here is whether the Institute and its membership can commit to the importance of doing this and provide its expert judgment and intellectual support for it. I understand fully that there are challenges to get the necessary resources to support this work and if the Institute can conclude that it needs doing then I think the government might be able to be persuaded to provide the financial support. And again, that financial support would probably be on a stepped basis. It is conceivable that as you grow this thing internationally, and it must be grown internationally, that the G8 Global Partnership on Catastrophic Terrorism can swing some financial support into it as well.

Your question mentioned one last thing that I wanted to comment on, and that's the essential voluntary character of the INMM and its membership. I think that needs to continue. I don't see this evolving to any form of mandatory membership. It should attempt to be as inclusive as it can be in bringing together those who have responsibilities for facilities and materials that require physical protection. But like the adoption of best practices, that has to be a voluntary exercise in which you would use the persuasion of the profession and the peer pressure of inclusion that would come from leadership in this field. I mean a soft peer pressure. This is the broadest based and most respected professional body, which is why I hope you can take on this mission.

Mangan: I'm sure that around this table, you've got people's minds going a 100 miles per hour. And I'm sitting here saying to myself as you're talking, we have seven non-U.S. chapters, and we need to get them on new missions to foster this kind of work.

Curtis: I think they're going to have to opt in. Rather than try to spawn this on a full membership basis. I think it's going to have to be selected in. I also think you're going to have to deal with the weapons issues separately than the civilian issues. But I think teaching opportunities from both sectors are there—and should be taken advantage of.



Jim Lemley: I remember two years ago when you asked us to organize the best practices workshops, you wanted us to play down the involvement of NTI presumably because it was perceived as an American construct. I wonder if you consider that INMM has avoided that, or are we too American dominated? Even though we currently have many international chapters, as Denny mentioned, would we have to become more international somehow?

Curtis: I think it's an excellent question. I found that in the lab-to-lab program that was the key breakthrough in advancing materials protection, control, and accounting in the Russian Federation—that scientists and professionals have a built-in trust and respect for each other that greatly facilitates international cooperation on these matters. I'd prefer to see it funded by the G8. If it were a U.S. government-organized mission alone, it might be handicapped as many U.S. initiatives are handicapped in winning acceptance in the international community. So I would count on your already demonstrated ability to perform in the international arena as a professional organization. Indeed, that's one of the most attractive parts. If you were to not be able to take on this mission, then I think the next question is, can we evolve a new freestanding organization? That would certainly need your intellectual support and help if that were done. But it clearly could not be done without the many advantages that INMM would have, were it to take on the mission. A fifty-plus year history of doing this work and the regard that this has provided the organization, the individuals involved in it—that's an extraordinary asset.

Jim Tape: Continuing on the line of how we might do this, I would start with one of the things that I believe you said this morning when you talked about a full-time professional staff and an office. It strikes me as clearly something that would have to happen if there was to be a group promulgating standards and best practices, and I suppose I could imagine the INMM hiring people to do that. It's not something we've done. We hire a professional management firm to handle our affairs, The Sherwood Group. Everyone else in INMM works either nights and weekends or participates because their labs support it. A full-time office would be a major step. I'd be interested to hear you say more about how you think we can do that. If you look at the American Physical Society Washington Office, it's a fairly large operation, and there are professional scientists who are employed there. They interact with the U.S. Congress; they do all kinds of things like that. INMM today is miles away from.

Curtis: Yes, I'm sincere in saying I really think the professionals in this organization have to work through these things and figure out what they think is the most realistic possibility for providing the professional support, the expertise, the full-time staff that would be required. Again, if you do it on a staged basis, you might be able to work through some of these problems. For example we all know that the national laboratories support a large number of IPAs and they are distributed within the U.S. government in various places. If our government thinks it's a good idea, I can see this staffed with a contingent of IPAs from the laboratories. There are a number of private sector, so-called industry, members and participants at this conference. I think industry participation is essential. Getting them to secund experts into this initiative is also something that I would certainly try for, if you make the commitment to go forward. Certainly test the feasibility of it. I tried to say this morning that I certainly believe that industry has a very substantial stake in making sure this job is done and done right. Because of the essential brittle character of the nuclear option and how vulnerable it is, not only to the next accident, which WANO was trying to address, but to the next radiological event. We all pray that we won't get a terrorist attack with a nuclear weapon but what we do know is that the governmental response is very likely to be uninformed and severe. It can have market ending consequences to the civilian side of this business and that goes for fuels manufacturers, right down through the whole civilian structure. So they've got a big interest in this. Whether they can recognize that in order to contribute resources, I don't know.

Charles Pietri: But my question is, do they recognize that? We recognize that but do they recognize that?

Curtis: You know, Charlie, I think one of the real quandaries here is that at some basic level I have to acknowledge, I don't get it. We sit around in this community of informed people and we know this danger and we know it's not being adequately attended to and yet we treat it as important but not urgent. We need to treat it as urgent. It's not getting the priority it demands. And I don't know why.

Pietri: For decades we tried to attract industry into INMM and we have had minimal success there.

Curtis: You have a change in leadership at NEI, you've got Skip Bowman (Retired Navy Admiral Frank L. Bowman) now who is the head of NEI and he may have latitude that his predecessors did not have. The electric utility industry for years tried to very much keep separate the civilian nuclear power business from the business of nonproliferation and securing weapons and materials. Part of that was, I think, a reluctance to recognize that so-called reactor grade plutonium made a perfectly suitable nuclear weapon. Part of it was they already had a lot of political problems getting new plants licensed and managing the environmental and safety concerns. It was uncomfortable to recognize that there is yet another concern, a proliferation concern, what Eisenhower referred to as the "contrary nature of the atom," that they had a big stake in addressing as well. So they haven't played and they need to. And maybe Skip has an opportunity now that wasn't there before.

Leslie Fishbone: One of the questions we talked about earlier (prior to the official Roundtable session) was sustaining improvements that were made in different places when a particular source of money ends; it becomes the host's responsibility. We find that it's difficult in some cases to get the host to assume that responsibility. Any thoughts on that?

Curtis: Yes. I think this is, in fact, the long-run number one challenge: sustainability. Democratic societies, which we're happy to be a part of, are inherently reactive and so it's very difficult to get them to do the protective things that need to be done, absent a motivating event. The second thing is that, to the extent that we are dependent on political action, we have a time horizon that is very short-term focused, driven by the election cycle, not the half-life of the materials, as we all know. You've got 24,000 years for the half-life of plutonium and 713 million or something like that is the half-life of highly enriched uranium. Election cycles are two years. So this is an extraordinarily difficult problem to the extent that you need sustained political support and resource commitments. It is one reason that this professional society or its members have an opportunity to take actions that governments find difficult to take. Because you can look at the long term, and you can provide a continuity. I mean, look at this gathering, you have several past presidents. There's continuity in this organization that is not observed in government. We don't sit around with four or five former deputy secretaries of energy, I can assure you. We didn't do it when I was in, which was a mistake, and we still don't do it. But you can do it.

Cathy Key: Mr. Curtis, I know we've been talking about the importance of the labs taking responsibility for this. But it's not just the labs, it's also the facilities throughout the complex that do the operations, and I guess that is my point here. INMM as a responsible organization would need to be able to come up with that balance of facility personnel and laboratory personnel. For "best practices" in safeguards and security we need to be able to come together with appropriate technologies and practices that can be implemented and highly sustained. I would like to hear your thoughts on this—as far as being able to keep that balance and make sure that we implement something highly sustainable.

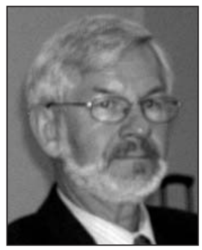
Curtis: In the first instance, we have to realize that we're all in this together. I'm a great believer that you need to integrate more fully the facilities operators, the laboratory expertise and personnel, the research conductors, if you will. There are lessons that can be learned from each and there are judgments that would benefit from a robust integration of this work. It's a matter of regulatory history that there was so much separation here. The division of the NRC (U.S. Nuclear Regulatory Commission) and the Defense Nuclear Facilities Safety Board, the very special security concerns that attended the nuclear weapons business is at the root of that division; but they're the same atoms and they're the same problems. There does need to be a joint effort especially if you want to involve practices that run ahead of regulatory requirements, which is what I think we need to do both in terms of speed and content.

Mangan: In your speech this morning you alluded to the realization that in order to secure nuclear materials worldwide, all countries have to accept the responsibility to do that and it's not clear to me that we're at that particular stage in the game. I'm just wondering if you have any guidance about how might this security culture be universally accepted to achieve this responsible management of nuclear materials?

Curtis: It is certainly a daunting problem because it is the nonparticipant nations, the ones who do not perceive the same threat or danger that are likely to be the weakest links in the system. I've found that number one, in our interdependent and inter-connected world, what 9/11 taught us at a basic level was everyone participated in the 9/11 event because the economic effects rippled through the world. A nuclear event would cause more than a ripple. And that will effect the weakest nations most, the weakest economies most. So because it has the potential of retarding global investment and fracturing the capital markets, it would have tremendous implications for the rest of the world. So they need first to be persuaded that they have a stake in this game, that this is not a U.S. problem, it's not a Western nations problem. It's a problem for everybody. That's diplomacy and that's also, as I said earlier, that's a matter that professionals can really contribute to because they can speak authoritatively without the burden of politics. And they can speak to peers who are likely to have an initial trust and respect of their word.

The second thing is essentially there needs to be an international cooperation here that we have not formed. I think the G8 Global Partnership is a good first step, but it is itself perceived to be Russia and the seven largest Western economies. It's a Western show. It needs to be broadened out. We have hopes that during Russia's presidency, which will be for the first time in the G8, that Russia can be persuaded to exercise some global leadership to broaden out that global partnership and join a broader effort.

I mentioned three things in the speech where the international community has come together recognizing that much more needs to be done, the two conventions—the Physical Protection Convention Amendment and the Convention that the General Assembly adopted on nuclear terrorism, and of course, Security Council Resolution 1540. Giving those acts real life, speeding the entry-into-force of the Amendment to the Convention on Physical Protection, speeding the entry-into-force of the Convention Against Nuclear Terrorism, which would require twenty-two states to bring it into force, is important. (Resolution) 1540 was an important achievement but if it is not followed through, it will be an empty and dangerous achievement because it will imply a security that we won't have achieved. That's the challenge, to give real meaning to those very broad commitments of the international community. When you think of getting anything through the General Assembly, for one thing it is a great undertaking, but getting an invocation of Chapter VII of the United Nations Charter, which is the basis upon which enforcement can be undertaken in 1540, that's important. But again, go back to the common theme; they don't have a chance of developing effective means of security and accounting of nuclear materials unless help is provided by this organization. Many of the countries in the world simply lack the technical means or the understanding of the work. We were talking about some of the countries earlier in this conversation. They don't have any recognizable form of physical protection other than guards and guns and often not guns.



Bernd Richter: I'd like to touch on several items, and I wonder if you may wish to comment on them. First of all, I think the nuclear industry is highly internationalized. For instance, in Europe we have the URENCO, which is a tripartite company, UK, Netherlands, Germany, with a government agreement in the background. Furthermore, AREVA in France has become the dominating company that has absorbed, for instance, the nuclear activities from Siemens in Germany. Apart from the nuclear industry, we have to put some thought into spent fuel management. For instance, more and more spent fuel is arising from nuclear power plants and, in Germany, for the time being, we have some means to suppress transport by using on-site spent fuel storage facilities. But when you look at Europe as a whole, you will probably end up having central away-from-reactor spent fuel storage facilities. I don't see that it will be practical to have a number of geological repositories for final disposal of spent fuel. So, ideally and from an economical point of view, and taking into account that not many countries have adequate geological formations to construct a geological repository for spent fuel, you may have two or three repositories in Greater Europe and, finally, that will imply a lot of transportation of spent fuel, and so your threat may be increased. Do you want to comment on this?

Curtis: Yes. First of all I think the internationalization of the civilian nuclear industry particularly in Europe is useful to these purposes. I think the cooperation that the so-called E-3, Germany, France, and the UK, has been providing in trying to address the Iranian problem is a very, very important initiative and I'm glad the United States has finally decided to support it and hopefully participate in it. I think that also the nuclear industry through the nuclear suppliers group and other structures is going to have to be more of a part of the solution to managing fuel cycle facilities on a going-forward basis. This is a real and a generally recognized vulnerability in the nonproliferation regime. So we've got to figure out better solutions there and URENCO and others need to be part of that solution.

As far as working out a problem on spent fuel disposition, that is probably the thing that holds back the nuclear option more than anything else. We know how to store spent fuel in dry cask storage, away from reactors for long periods of time quite safely. No one has figured out yet a permanent repository, whether that's a permanent repository after the reprocessed discharge, after plutonium is removed from it, or whether it is a repository of one-time-through uranium fuel with embedded plutonium in it. So that's a big problem that this industry needs better solutions to. I tend to think that advanced research on deep bore hole storage options is something that the international community should broadly cooperate on and see if we can work out a better solution.

A lot of spent fuel in transit, in moving from reactor site storage to off-reactor site storage, I think is a quite containable problem. I've seen the environmental impact statement work and analysis that the U.S. has done on transporting the fuel to Yucca Mountain. We know an awful lot about how to transport spent fuel safely and securely. So I think that transportation is not a weak link in the system. I think we know how to do that pretty well and I think the technologies and integrity of the casks we've developed are pretty impressive and well substantiated. That's my impression of it.

Richter: I have an immediate reply, if I may. You question the availability of technical solutions for final disposal of spent fuel; I don't want to see that in the *Journal* without my contradiction. I'm in the technical area and I've been involved in final disposal issues for twenty-five years and I think we do have very good technical solutions to that.

Curtis: I didn't mean to question the technical solutions. What I said was we haven't done it yet.

Richter: That's for political reasons, maybe because there is no acceptance in society right now, so politicians have to come up with a political solution.

Curtis: I understand that if you get the plutonium out you have a much simpler problem. It's still a nasty problem, but it's a simpler problem.

John Matter: Thinking about your challenge to the Institute, one of the concerns we have from the INMM perspective is: Are we a large enough organization to have critical mass? You made a point about the importance of being inclusive in this endeavor. Putting these two thoughts together leads me to think about who might be appropriate partners for INMM in this endeavor. I want to mention a couple of ideas and ask for your reaction.

You made references to some of the recent international agreements, including the amendment of the Convention on the Physical Protection of Nuclear Material and the UN Security Council Resolution 1540, but you did not say anything specifically about a role for the International Atomic Energy Agency (IAEA). Would it be a good partner for the INMM in this endeavor?

We also recognize that the INMM doesn't have as close ties with the commercial nuclear power industry as we do with the U.S. Department of Energy and its contractors. Are there other professional organizations, such as the American Nuclear Society (ANS) or other nuclear societies, which have closer ties to the commercial nuclear side that would be good partners for the INMM?

Curtis: There's a lot there. So let me try to chew through it.

First of all, let me talk about the IAEA. I'm a strong supporter of the IAEA and the importance of its work. We at NTI have invested pretty substantially in that support. I think it is a necessary and useful partner. But they have limits. And most importantly by charter they have no role with respect to nuclear weapons and weapons materials, which is 80 percent of the materials. So it's going to require more than the IAEA, but they certainly need to be part of the solution. The other thing is, God love 'em, they've got 187 state parties and their work is often complicated, sometimes confounded, by the need to arrive at consensus solutions, so that sometimes limits the pace of their work in important ways. Which is why I think you all can move ahead, with their cooperation and form a useful relationship there. And you could help them too, because frankly, the IPPAS (International Physical Protection Advisory Service) Program is in a bit of a muddle right now. As you well know when, by invitation, they go to consult with states, the technical strength of those delegations comes out of the laboratories often, so they need your help in strengthening in the IPPAS Program.

In terms of the breadth of your organization and is it sufficiently broad? No. But it's authoritative and that's a great asset. I think you should not be overly impressed with the limits of your membership and be more impressed with the authority of your membership, the professional respect and authority of your membership, and that will beget a cooperation that will be necessary to get this job done.

And the last thing, and I think I'm repeating myself, I think the U.S. civilian nuclear power side of this equation has to play more. That means you have to go to the leadership that is right now organized in the Nuclear Energy Institute and get their involved play. You're not going to free up the expertise and help from the civilian nuclear power side unless you can get the leadership of the nuclear power side, which are the CEOs and their boards, to help play. I think that's turning around in one important respect because frankly a lot of them had given up on nuclear power. They just sort of saw it as their mission to manage through the remaining economic life of existing facilities and get out of the business. But now that's changed so I think with that changed perspective, there may be a renewed interest in things nuclear. And with that renewed interest, they may see a broader mission. I hope so.

Fishbone: This may go beyond the challenge, but the notion of best practices assumes that various organizations with responsibilities would like to have best practices. There was at least one recent case, and it could happen again, where there was a country that tried to subvert the whole notion of nonproliferation. Whether it was sanctioned at the highest level, we don't know and perhaps never will. But one can imagine a country turns around completely and attempts to proliferate to the bad guys. Does that go beyond this challenge?

Curtis: No, I think the reality is that no system of internal control can withstand insider corruption. We've seen that in accounting, dramatically, in the financial pages, and that's true of security systems as well. It goes back to the security culture and sustainability questions. That's going to be the hardest problem over time. So it's going to require more than just to lock this stuff down. It's going to be necessary to continuously manage it and manage it to improvement. Best practices are best at any given time. It's an iterative process and it must evolve.

Mangan: In your speech this morning as you put forth this vision of getting the material secured, you identified two missing key elements, if my notes are correct. Number one was to identify best practices. I think certainly the Institute can help in that respect.

Number two was to create an infrastructure to put those best practices in place. Could you expand a little on what you have in mind?

Curtis: The problem is the phrase "put best practices in place." That implies an application that may be coercive, which it can't be—it has to be voluntary. What I mean by that is an infrastructure that can propagate those best practices, communicate them broadly, and provide the technical underpinnings to the practice's support so that those who may be willing to volunteer can in fact apply the best practices articulated. In putting best practices in effect, it's going to have to be a process of persuasion, communication, and over time providing the technical support for the application and sustainability of those best practices. The way WANO does that is through these no-fee continuous workshops and by peer review, and sharing lessons learned from incidents that they investigated and responded to. It's a continual teaching process.

Fishbone: Best practices could always be subverted by resource constraints, and one could imagine that if you say there were fifty bad guys in a major capital wreaking havoc or about to wreak havoc and the best physical protection practice has to be able to counter fifty well-armed bad guys, it becomes a difficult resource issue. I just wondered what your thoughts were on that.

Curtis: Look, the reason the profession needs to get involved is you all have the best judgment as to what are the most cost-effective means for doing this job. The resource issues will always be issues.

You've got INFCIRC225. It's gone through four revisions, but it doesn't provide guidance on addressing a threat from a concerted force attack. At this conference you will undoubtedly discuss needed strengthening through a fifth revision of that circular. You ought not hesitate to provide the guidance on the basis that some facilities operators will conclude they can't afford it. There's going to be a natural tug and pull of resource concerns, sovereign sensitivities, and security concerns in this process, in the take-up and in the application, of best practices. What happens in a regulatory context, as we've all seen, is the regulations tend to be driven to a lower common denominator than they otherwise might be because of these types of concerns. They're legitimate concerns; they have to be evaluated across the board. But voluntary practices that might be defined as best, because they are voluntary, can reach farther to a higher level of security than the regulatory apparatus will ever produce, particularly in an international setting. The real value of this work is that you can do more than government will ever figure out how to do and you can do it smarter. That's a pretty attractive combination.

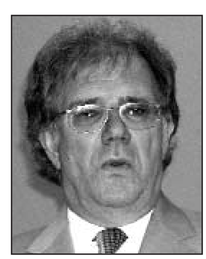
Tape: I'd like to pick up a different point that I think we haven't touched on, and that's the role of technology, something that's near and dear to the hearts of many in the INMM. Obviously part of best practices is employing the best technology and in my opinion, an important aspect of that is having a sound R&D base. When I got into this business some years ago, it was a few years after the Munich Olympics, which was a big driver for physical protection. And it was right after the Indian Test in 1974, which was a big driver for the nonproliferation/international safeguards business. In those years, let's say in the next decade after the mid-1970s, in this country at least, the R&D budgets for safeguards and security were quite substantial. I recently participated in a study with the American Physical Society and we couldn't identify more than $5 million being spent now in this country for base technology development related to nuclear materials safeguards and security. There are a lot of technology transfer funds available, for example, the MPC&A program and the U.S. support program to the IAEA. But the base R&D has diminished here. I wonder if you could react to that or if you have recommendations or observations that will be useful to us.

Curtis: My reaction is that I'm surprised that that is so—particularly after the reevaluation of the design basis threat of the DOE complex, which identified a very high-ticket requirement for upgrades. One of the ways you contain those costs is through better technical means, so I'm surprised they're not putting more money into R&D.

Tape: It hasn't happened yet.

Curtis: This is something I'm just not current on, but I know DOE contains in its budget a very significant additional investment in the physical security of the complex—I mean on the order of the $150 million-$160 million per year. So why they couldn't get this R&D job done, I can't explain. But there are lots at DOE I can't explain.

(laughter)



Gotthard Stein: Like Bernd Richter, I am from Germany representing the international safeguards complex. I would like to blow in the same horn as Jim. I think it is a very important fact that we have a complete change in the safeguards structure after the introduction of the Additional Protocol to support the IAEA—especially since there are now new and appropriate tools available to strengthen the IAEA's detection capabilities. But to further improve this situation, new research capabilities have to be installed. Due to the broad areas that are here of concern (information analysis, satellite imagery, forensics, micro- and nanotechnology, etc.) interdisciplinary and multinational research activities outside the IAEA are necessary. I think we are here at the beginning of a process and we have to start to inform the safeguards community and governments on this urgent problem.

But what I would like to say, because I'm coming from Europe, is to support your interesting speech this morning that INMM as a global institute should be involved in best practice issues. Since we have in Europe the ESARDA, that is the European Safeguards Research and Development Association, it is my belief that also this institution can be involved. ESARDA is now starting to enlarge its activities from safeguards to security in general, so activities in this field will match their interest.

Curtis: It's going to take all hands. I think that's a very interesting suggestion and I hope it is followed up on.

Matter: You have been talking about an initiative for the INMM: Let me turn that around. What do you see in the future for NTI? What initiatives are you planning that you can divulge? Secondly, while NTI was originally funded with generous funds from Mr. Ted Turner, they are finite. What are you doing to secure additional funding for NTI to continue its mission?

Curtis: What we have been doing is laid out in our annual report, which is available at our Web site and that's www .nti.org. We've spent a lot of time and effort on that Web site to make it content rich, and I hope that it's found to be so.

We are in the position of refunding the initiative. Warren Buffett has recently made a substantial gift of $7 million a year for five years, which will basically cover all of our core expenses and program management expenses. It's designed so that we can seek funds from others on a promise of 100 percent efficiency, so every dollar collected goes directly and fully to program activity. We're setting up two funds, a nuclear security fund and a global health and security fund. We also have a substantial bio program, notwithstanding our name, and we hope to use those funds as receptacles for additional funding. Because getting funding program by program is difficult. It takes a lot of effort and money to develop projects to a maturity that there is enough there that funders can appreciate the ambition and the possibilities. Just to give you an example, on the bio side, we've got a project of cooperation on infectious disease surveillance and response among the Palestinian Authority, Israel, Jordan, and Egypt. A medical device company has made a generous contribution of $1.7 million in equipment in this. But we've got $1.6 million into this program, so we're raising money to complete the program. It's expensive work. And on the nuclear side, everything is expensive. So that's what we're doing. We are trying to raise money for the Initiative through these means. We're having some success.

Laura Holgate: We are using the INMM Annual Meeting to break news this year. We have an accelerated HEU blend down project that we've had in the works for two years. It's kind of similar to this bio project in the sense that we're on the path to spend $3 million in the initial analysis of how you can go about accelerating blend down of Russian highly enriched uranium with the hope that it will catalyze the greater government investment, or perhaps private investment, that it will take to actually execute such ideas. Our cost data is at a rough-order-of-magnitude level, but at the moment it's the best data available. We've been briefing it to the federal government for the last month to great interest and enthusiasm, and I'll be using this forum to bring it before the broader community tomorrow.

Curtis: It's a very interesting project because it's also being parallel briefed to the Russian government and it's a study done by them. We engaged the Russians in this study to develop the options, so it's homegrown. It's something that they weren't willing to do on a government-to-government basis, but they were willing to do it with us. Laura has done just a fabulous job of fostering the cooperation here that has been effective beyond the expectations of all parties when we entered into this.

Mangan: I believe it's time to wrap up. Very very interesting discussion. Thank you Mr. Curtis and Ms. Holgate, and all of you.

I'd just like to close by saying that your speech this morning at the opening plenary was very provocative. I know that a lot of things went through a lot of people's minds with regards to…

Curtis: Why you invited me?

(laughter)

Mangan: I would just like to point out that I'm sure the INMM will seriously consider some of the things that you said, but I think all past presidents sitting around this table, as well as the president, will attest to the fact that the INMM is not a fast-moving organization…

Key: I do want to say that you've given us a great compliment from your presentation and from your talk today. And we do appreciate that. We are a very proud organization and we've got a lot to share. We look forward to holding the next workshop in the near future. You will be hearing from us soon.

Curtis: Well, I know you will take a careful look at it and give it your best judgment, which is all I can ask. We all know this is an urgent issue, so if there's any opportunity to suspend past practices, in favor of best practices, I hope you'll avail yourself of that.

A Summary of the Closing Plenary Session of the 46th INMM Annual Meeting

Amy Whitworth
Chair, Government-Industry Liaison Committee

In planning this year's closing plenary program, the Government-Industry Liaison Committee discussed speakers and potential topics that would inspire the community and underscore the importance of our every day efforts in nuclear materials management.

This year's closing plenary program met that mark. We were fortunate to have three very distinguished individuals presenting this year: Glenn Podonsky, U.S. Department of Energy (DOE) Office of Security and Safety Performance Assurance; Meggen Watt, senior policy advisor to the Secretary of Energy on national security matters; and Adam Angst, special agent of the Federal Bureau of Investigation. Podonsky set the tone by challenging the community to critically examine our work to determine if the way we conduct every day business is the best way. Podonsky spoke about new efforts in U.S./Russian nuclear security cooperation following the Bush/Putin Summit in Bratislava in February 2005 and the efforts of a task force on materials control and accountability he commissioned within his office. Watt also discussed the need for innovative thinking to address the changing threat environment with the DOE's Materials Consolidation Initiative. Finally, Angst inspired the community to remain vigilant in their work by providing realistic information on groups that would seek to do harm to our country and other countries. In this issue of the *Journal,* we are publishing summaries of Podonsky's and Watt's presentations.

Attendance at this Closing Session remained at a record high with more than 300 conference attendees present. It is the goal of the Government-Industry Liaison Committee to maintain this high quality for future Closing Plenary sessions.

Glenn Podonsky

Podonsky began his discussion with the overarching theme of avoiding doing things the same way just because we have always done it that way. The theme of "getting past doing things the way they were always done" was carried throughout his presentation as he provided insight into two topics of strong interest to the INMM: the U.S./Russian Interagency Group for Nuclear Security Cooperation and the task force he commissioned for materials control and accountability within the DOE.

As background, Podonsky summarized the Bush/Putin Bratislava Summit that resulted in a joint statement agreeing to establish bilateral efforts in five areas aimed at improving nuclear security. A senior-level interagency working group within the U.S. government was established to pursue these efforts. The five areas are:

Adam Angst, INMM President Cathy Key, Amy Whitworth, Meggen Watt, and Glenn Podonski

- Emergency response to nuclear or radiological incidents
- Best practices for security at nuclear facilities
- Establishing/improving a security culture at nuclear facilities worldwide
- Developing low-enriched uranium fuel for research reactors currently using highly enriched uranium in third party countries
- A broad effort to improve nuclear security, primarily at sites in the Russian Federation that includes MC&A elements

Podonsky said that his office and the National Nuclear Security Administration are directly involved in two of these efforts: identifying best practices for security at nuclear facilities, and sharing these through joint consultations with other nations having advanced nuclear programs and focusing increased attention on building a security culture at facilities in both countries and potentially worldwide through joint consultations.

Identifying and sharing best practices is intended to promote and disseminate specific policies, techniques, and procedures that can improve the effectiveness of specific critical security functions. Podonsky remarked that promoting and advancing security cultures at nuclear facilities is a seemingly more nebulous effort, but one that affects all elements of a facility's security program, including the MC&A component.

While these initiatives are distinct, they are closely related and are being addressed simultaneously in an integrated manner.

Podonsky noted that significant progress has been made to date including:

- Conducting a successful working meeting in Moscow in late April 2005, to exchange opinions, define the work in the areas of cooperation, and plan and schedule follow-on efforts
- Further technical exchanges held in Washington in mid-June 2005, and at that time Russian Federation representatives attended an annual meeting of security managers of U.S. nuclear facilities

Progress continues on this important initiative in the form of bilateral workshops for each area, scheduled for Moscow in mid-September 2005, to share ideas and establish appropriate content and context for possible third nation consultations.

Podonsky also discussed the task force of experienced and well-respected materials control and accounting (MC&A) experts he commissioned last January to review MC&A programs and activities within the headquarters' Office of Security. The task force focus included MC&A policy, MC&A technology development, MC&A field assistance, current and planned headquarters MC&A databases, and activities at the New Brunswick Laboratory.

Last month, the task force presented several recommendations including:

- Establishing an office of nuclear material control and accountability, with its own budget, reporting directly to Podonsky, and responsible for MC&A policy, technology development and deployment, field assistance, headquarters MC&A databases, and management of New Brunswick Laboratory
- Preparing a strategic plan by the end of the year to strengthen MC&A efforts
- Establishing an executive level direct link to the Nuclear Regulatory Commission to facilitate development of a national approach to regulating nuclear materials
- Realigning MC&A technology development and associated funding processes
- More effectively integrating the various headquarters nuclear material and radionuclide data management systems

Podonsky was pleased with the efforts of the task force and is now in the process of taking appropriate actions to ensure that the headquarters MC&A programs are better focused and able to provide the direction and support needed by the field.

Meggen Watt

Watt discussed the department's corporate approach to consolidation of nuclear material.

Watt outlined the background of the department in the area of materials consolidation beginning with the department's Nuclear Materials Stewardship Initiative in 2000 that produced a report for the U.S. Congress on integrated nuclear materials management. Many of the activities in that report have been completed including:

- Numerous shipments of excess plutonium to the Savannah River Site
- Removal of all the nuclear material at the Rocky Flats Plant
- Plutonium stabilization at the Hanford Site in Richland, Washington
- The recent shut down of the FB-line at the Savannah River site—a plutonium recovery facility that had been operational for more than fifty years
- Removal of all the highly enriched uranium from the Portsmouth Gaseous Diffusion Plant
- Continuation of the Central Scrap Management Organization ("CSMO") that identifies scrap uranium materials and sponsors off-site processing at commercial facilities

Still, with all these successes, Watt noted that the issue of materials consolidation needs to be continually evaluated in the context of current program and security operations. In April 2004, a department-wide evaluation of nuclear materials consolidation opportunities was initiated. A special task team studied the issue of materials consolidation, with a focus on reducing the number of nuclear facilities that need high-level protection and reduce potential terrorist targets. Increases in the Department of Energy Design Basis Threat, revised last year, necessitate creative approaches to maintain strong security for the department's special nuclear material assets in a cost effective manner. Upon the recommendation of that 2004 Task Team, the Nuclear Material Disposition and Consolidation Coordination Committee (NMDCCC) was established in early 2005 to perform cross-cutting nuclear materials consolidation planning, with an emphasis on increasing security for our nuclear material assets while reducing overall security costs. Watt chairs this committee.

The NMDCCC will address, coordinate, and take into account across the entire DOE complex each program's requirements for nuclear materials management, safeguards, and security, and secure transportation and related issues as they pertain to nuclear materials consolidation and seek to leverage resources where practical. Specifically, the NMDCCC will:

- Develop, approve, revise, and ensure implementation of a strategic plan for the consolidation of special nuclear material and an associated implementation schedule
- Act as necessary to resolve conflicts created by priority use of departmental resources (secure transportation, packaging, and containers, etc.) in concert with other established cross-cutting planning organizations, such as the Secure Transportation Asset Advisory Board, to assure that adverse impacts on program missions are minimized
- Track and review progress against the approved strategic plan and implementation schedule and report on progress to the Secretary of Energy

The NMDCCC membership includes senior representatives of the headquarters program offices with nuclear materials management, and safeguards and security responsibilities including representatives from the offices of Defense Programs, Secure

Transportation, Defense Nuclear Nonproliferation, Naval Reactors, Defense Nuclear Security, Environmental Management, Nuclear Energy, Science, and Technology, Security and Safety Performance Assurance, and Science. What all of these offices have in common is that they have some aspect of responsibility for nuclear materials within the DOE. Watt noted that for decades nuclear materials were managed by a single entity within the department. In the early 1990s there was a shift to managing the weapons stockpile separately from surplus materials and environmental cleanup. Watt's intentions are to ensure that consolidation and disposition decisions are made on a complex-wide set of data and information, and to involve the Secretary of Energy, deputy secretary, and other leaders to make some tough decisions and to overcome potential barriers.

Watt noted one of the ongoing efforts of the NMDCCC was to examine various options among existing buildings, and to consider how to retrofit them and protect them in accordance with the department's design basis threat. The committee had identified a potential opportunity to use two buildings at Idaho National Laboratory, and was pursuing a feasibility study. Once this and other opportunities for consolidation are identified, the DOE would examine all such options before making a decision. If the department chooses to carry out a consolidation mission in Idaho, it would also work with the state of Idaho to ensure any materials that may be shipped there would not violate any state restrictions.

Watt said that a major part of the NMDCCC's next steps will be to ensure sufficient focus exists for materials consolidation by forming a small, dedicated project team that can develop a plan of action with milestones and decision points and is capable of integrating site efforts, tracking facility upgrades for security and safety, and alerting senior management of potential roadblocks.

In conclusion, Watt emphasized that consolidation is an issue that is at the forefront of the DOE's efforts. The DOE's priority is to effect consolidation so the 2004 design basis threat can be implemented across the entire DOE complex. Past accomplishments have been significant and the future accomplishments will be no less significant. It is recognized that there are challenges ahead. As the threat environment evolves, countries must respond. The DOE remains proactive in pursuing opportunities to reduce the overall security footprint so there are fewer locations to protect.

Forward Model Calculations for Determining Isotopic Compositions of Materials Used in a Radiological Dispersal Device

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Abstract

In the event that a radiological dispersal device (RDD) is detonated in the United States or near U.S. interests overseas, it will be crucial that the actors involved can be identified quickly. If spent nuclear fuel is used as the material for the RDD, law enforcement officials will need information on the origin of the spent fuel. One signature that may lead to the identification of the spent fuel origin is the isotopic composition of the RDD debris. In order to use this signature, it is necessary to have a well-developed understanding of the uncertainties in predicting the isotopic composition of spent nuclear fuel from fundamental reactor physics calculations.

The objective of this research was to benchmark a forward model methodology for predicting isotopic composition of spent nuclear fuel used in an RDD while at the same time optimizing the fidelity of the model to reduce computational time. The code used in this study was Monteburns-2.0. Monteburns is a Monte Carlo-based neutronic code utilizing both MCNP and ORIGEN. The size of the burnup step used in Monteburns was tested and found to converge at a value of 3,160 MWd/MT per step. To ensure a conservative answer, 2,500 MWd/MT per step was used for the benchmarking process. The model fidelity ranged from the following: 2-dimensional pin-cell, multiple radial-region pin-cell, modified pin-cell, 2D assembly, and 3D assembly.

The results showed that while the multi-region pin-cell gave the highest level of accuracy, the difference in accuracy between it and the 2D pin-cell (0.07 percent for ^{235}U) did not warrant the additional computational time required (seven times that of 2D pin-cell). For this reason, the 2D pin-cell at normal operating temperature and pressure was used to benchmark the isotopics with data from three other reactors. The isotopic concentrations from all three of the reactors showed good agreement with each other.

The SENTRY database at Los Alamos National Laboratory contains reactor data from around the world. Using the forward model methodology developed in this research, each of these reactors could be simulated and isotopics of spent fuel can be determined. If an RDD event occurs, material can be collected and compared to the data from the forward model calculations to determine the reactor of origin of the spent fuel.

Introduction

The events of September 11, 2001, clearly show the willingness of terrorists to use unconventional means for inflicting great casualties. Nuclear terrorism is also one of those possible means. While it is unlikely that terrorist groups would have the capability to fabricate a nuclear weapon, these groups would likely have the capability to produce a radiological dispersal device (RDD), the so-called "dirty bomb." The threat of a terrorist using an RDD inside the United States or against U.S. interests overseas is greater than ever. This is due both to the increased sophistication of terrorist organizations and to the large amount of nuclear and radiological material at use or in storage throughout the world. It is possible that terrorist organizations already have radiological materials in their possession. Nuclear smuggling events since the early 1990s have suggested that large amounts of nuclear and radiological material have been pilfered from former Soviet Union nations.[1]

The objective of this research was to benchmark a forward model methodology for predicting the isotopic composition of spent nuclear fuel used in an RDD while at the same time optimizing the fidelity of the model to reduce computational time. There are two major differences between this research and previous research in this area.[2, 3] The first difference is that the methodology developed here must be purposefully generic since the material recovered from the RDD will not contain important reactor modelling information such as axial location, boron concentration, location in the core, and a detailed irradiation history. The second difference is that the optimization and benchmarking performed in this study will focus on isotopic signatures of specific interest to attributing RDD material.

Once complete, this forward model can then be used in conjunction with the SENTRY database at Los Alamos National Laboratory (LANL) to determine the specific reactor facility of the origin, date when the fuel was removed from the reactor, and the fuel manufacturer. The SENTRY database at LANL contains reactor data from around the world. Using the forward model methodology developed in this research, detailed time-dependent data for the isotopic composition of fuel irradiated in any reactor listed in the SENTRY database can be determined. If an RDD event occurs, material can be collected and compared to the data from the forward model calculations to identify the specific origin of the spent fuel. Operationally, this determination must be completed within approximately five days of the event. This would allow for a timely response by law enforcement officials.

Background

The use of Monte Carlo codes has been widely accepted in applications such as flux calculations, but due to their large computational requirements have not been as accepted for calculating isotopic concentrations. Most isotopic calculations have relied more on deterministic codes such as CASMO,[4] HELIOS,[5] SCALE,[6] or ORIGEN.[7]

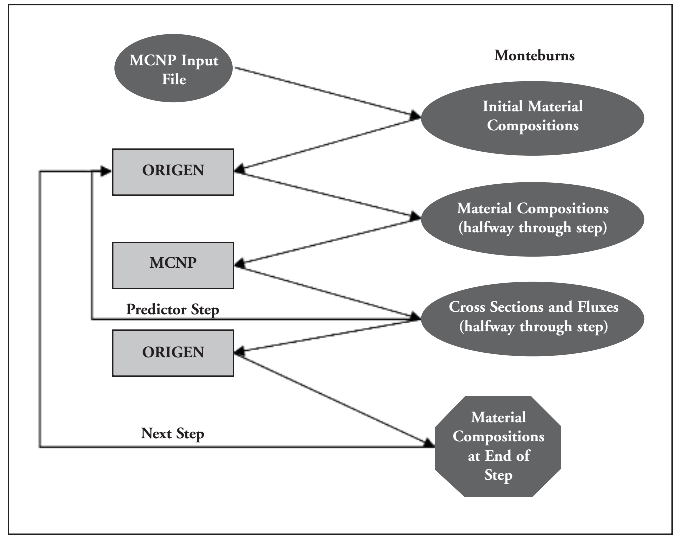
MCNP (Monte Carlo N-Particle Transport) is a widespread Monte Carlo transport code used for stochastic simulation and the coupled transport of neutrons, photons, and electrons. MCNP can be used for a variety of applications including, but not limited to, dosimetry, radiation shielding, radiography, accelerator target design, and fission and fusion reactor design. The popularity of this code is largely due to its versatility, comprehensive geometry features, and its overall physics capabilities, including continuous energy treatment.[8]

Monteburns (developed by LANL)[9] is a code that has been recently benchmarked[2, 3] for use in isotopic composition calculations. Monteburns is a Monte Carlo based neutronic code utilizing both MCNP and ORIGEN. MCNP serves as the transport solver and ORIGEN serves as the burnup module. Monteburns transfers one-group cross-sections and flux values from MCNP to ORIGEN. The following equations demonstrate how the one-group fluxes and cross-sections are generated with these codes. MCNP calculates one-group fluxes ($\bar{\phi}_i$) for any volume *i* by using the track length estimator of particle fluxes. One-group cross-sections are calculated using track length estimators for reaction rates that essentially uses:

$$\bar{\sigma}_x^i = \frac{\int_0^\infty \int_{4\pi} N_i \sigma_x^i(E)\psi(\vec{\Omega},E)\,d\Omega\,dE}{N_i\bar{\phi}} \qquad (1)$$

Once the burnup and decay calculations have been performed by ORIGEN, Monteburns then transfers the isotopic compositions of the materials back to MCNP. Through the use of MCNP, Monteburns allows for the calculations of complex geometries and material compositions. This implies that Monteburns can simulate a vast array of different reactor types and is thus the code of choice for this project (where the type of material could be from nearly any type of reactor including thermal reactors, fast reactors, naval reactors, and research reactors). Figure 1 shows the interaction of Monteburns with MCNP and ORIGEN.

Figure 1. Interaction of Monteburns with MCNP and ORIGEN



Forward Model Development

The attributes of the spent nuclear fuel that must be determined in order to identify the reactor of origin are: burnup, reactor type, fuel age, and enrichment. A list of isotopes of interest was produced for each attribute of interest. The isotopes measured in the literature review were compared to the list of isotopes of interest. The isotopes benchmarked in the forward model were those found to be in both lists. Analysis of isotopic composition of spent nuclear fuel is very difficult and expensive and is not always easy to find in unclassified documentation. For this reason, not all of the isotopes of interest were able to be modelled. There was, however, at least one isotope for each attribute of interest. Table 1 shows the complete list of isotopes of interest and their respective attribute.

Takahama Unit #3 Test Case

The Takahama Unit #3[10] reactor is operated by Kansai Electric Power Company (KEPCO). Takahama Unit #3 is a three-loop pressurized water reactor (PWR) with an electric output of 870 MW. The reactor core contains 157 assemblies arranged in a cylindrical geometry. Each assembly is 4.1 m in height and contains a 17x17 square fuel matrix of which there are 264 fuel rods and twenty-five water holes. Of the 264 fuel rods, fourteen of them contain 6.0 wt percent gadolinium, which is used as a burnable poison. Table 2 shows the nominal reactor parameters for the Takahama Unit #3 reactor that were used in the simulation.

The specific fuel rods that were analyzed from the Takahama Unit #3 reactor were SF95 and SF97.[10] SF95 came from the NT3G23 assembly, which underwent two irradiation cycles, and SF97 from the NT3G24 assembly, which underwent three irradiation cycles. Five samples were taken at various heights from specific fuel rods and measured by isotope dilution mass spectrometry. A gamma-ray spectrum measurement was also performed using a high-resolution germanium detector. The iso-

Table 1. Attributes and isotopes of interest

Attribute of interest	Isotopes of interest	Isotope analyzed
Burnup monitors	^{140}Ce, ^{100}Mo, ^{148}Nd, ^{101}Ru, ^{99}Tc	^{148}Nd
Reactor type monitors	^{240}Pu, ^{109}Ag, ^{153}Eu, ^{156}Gd	^{240}Pu
Fuel age	^{109}Cd, ^{137}Cs, ^{154}Eu, ^{155}Eu, ^{147}Pm, ^{241}Pu, ^{106}Ru, ^{90}Sr	^{241}Pu, ^{154}Eu, ^{137}Cs
Enrichment	^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu	^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu

Table 2. Nominal reactor parameters for Takahama Unit #3

Vendor	Mitsubishi
Type	17x17 (square)
Pin-to-pin pitch	1.26 cm
Fuel pellet diameter	0.805 cm
Clad outer diameter	0.95 cm
Fuel density	10.42 g/cm^3
Fuel enrichment	4.11 wt percent ^{235}U
Active fuel length	366 cm
Clad material	Zircaloy-4
Clad density	6.53 g/cm^3
Coolant material	Light water
Coolant density	0.714 g/cm^3
Specific power	37.39 W/g

tope concentrations were then decay corrected to account for the cool-down time since being discharged from the reactor. Isotopes belonging to decay chains were corrected using Bateman's formula, while others were corrected using only their half-lives.

MCNP Statistical Accuracy

Since MCNP is a Monte Carlo simulation code, the number of particles to be simulated was first determined. The accuracy of two parameters were considered: the critical eigenvalue (from Kcode calculation) and the scalar flux in the fuel (from an F4 track length estimator for the flux). A criticality simulation in MCNP consists of a specific number of particles per cycle, a total number of cycles, and a number of cycles to skip before recording results. The optimal level of each of these parameters was determined by iteration until the estimated uncertainty in the criticality and flux were both less than 0.1 percent with the smallest required computational time. An additional consideration in this effort is that these simulations were performed using a parallelized version of MCNP. This significantly decreases the required computational time but also adds some additional considerations due to the manner in which a parallelized criticality simulation is performed. The computer system processes the code as follows:

1. Code is received by the master node.
2. The master node breaks the code into twenty pieces and sends each piece to a separate node.
3. Each node sends the results back to the master node at the end of one cycle.
4. This process is repeated for each MCNP cycle until the calculation is complete.

Because of this configuration, the greatest lag in the system occurs when the nodes are communicating with the master. In order to facilitate the need for decreased computational time, it was more beneficial to increase the number of particles per cycles and decrease the total number of cycles to obtain the desired level of statistical accuracy. In the end, it was found that the optimal combination of these parameters was 1,000 particles per cycle and 325 total cycles for this particular model. This combination was used for all variations of the 2D pin cell, but was re-determined for the multi-region and assembly models.

Monteburns Convergence

The Monteburns code utilizes three different input files: MCNP deck, Monteburns input deck, and irradiation history feed file. At this point, the MCNP input deck (containing geometry and material composition) has already been created. The Monteburns input deck contains information on the individual isotopes to be tallied, the power (MW) of the model, and the number of burnup steps in the feed file. Most of this information is taken directly from the reactor data given in the literature.[10]

As previously mentioned, ORIGEN requires a predetermined reactor-specific library in order to acquire one-group cross sections, fission yields, and flux spectra. This library is one of the inputs in the Monteburns input file. Although Monteburns will modify this library using the MCNP output, it is still required for initial conditions. For this methodology, the PWRU library was chosen.

The isotopes to be tallied in Monteburns consisted of the previously mentioned isotopes of interest and a standard set of actinides. A list of these actinides can be found in Table 3. Tallying these additional actinides improves the overall accuracy of the code by allowing Monteburns to update the one-group cross-section sets for various reactions. It should be noted that while tallying all of the isotopes for which there are libraries would significantly increase the accuracy of the code, the tremendous increase in computational time would far outweigh the benefits. For this reason, extra isotope tallies must be chosen very carefully.

The feed file contains the irradiation history of the fuel. The feed file allows the user to specify as few or many burnup steps as the situation requires. While more burnup steps (resulting in lower burnup per step) are desirable for purposes of accuracy, each step requires additional computational time.

Table 3. Monteburns tally isotopes

Isotopes				
^{233}U	^{239}U	^{240}Pu	^{99}Mo	^{147}Pm
^{234}U	^{237}Np	^{241}Pu	^{99}Tc	^{147}Sm
^{235}U	^{238}Np	^{242}Pu	^{101}Ru	^{153}Eu
^{236}U	^{239}Np	^{241}Am	^{109}Ag	^{154}Eu
^{237}U	^{238}Pu	^{242}Am	^{137}Cs	^{156}Gd
^{238}U	^{239}Pu	^{243}Am	^{148}Nd	^{157}Gd

A convergence test was performed to determine the optimal allowed burnup per step. The convergence test consisted of twelve different Monteburns input decks and feed files. Each of these feed files contained a total burnup of 47,500 MWd/MTU but varied in the total number of steps used from three to twenty-five. This corresponds to a range from 15,833 to 1,900 MWD/MTU per step. Using ^{235}U and ^{87}Rb, the grams of material at the end of the irradiation cycle were plotted. While ^{235}U was chosen for obvious reasons as a fissile isotope, ^{87}Rb was chosen because it is a typical fission product and is located at the peak of the fission product yield curve. Convergence points were found with both isotopes to be around fifteen steps. This corresponds to a burnup step of 3,160 MWd/MTU. To ensure that the outputs remained conservative, the burnup step to be used for the remainder of this research was chosen to be 2,500 MWd/MTU. Figure 2 shows the convergence of ^{235}U and ^{87}Rb. 2,500 MWd/MTU per step would correspond to nineteen burnup steps on this graph.

It should be noted that none of the cases considered in this research contained Gd burnable absorber isotopes in the pins measured. It is expected that the inclusion of burnable absorbers would increase the required number of burnup steps to allow for convergence due to the large absorption cross-sections of gadolinium. This effect however was not studied here and is left as future work.

2D Pin Cell

The first model analyzed was a 2D pin cell. This model consisted of a single fuel rod (fuel and cladding) surrounded by moderator. The fuel region consisted of a single radial region of fuel surrounded by cladding. The gap between fuel and cladding was ignored. The width of the pin cell was equal to the pin-to-pin spacing for the assembly. The pin cell was surrounded by reflecting boundaries on all sides. All of the materials in this model were at room temperature (300 K). The density of the fuel was 10.42 g/cc. The water density was 1 g/cc. The clad density was 6.531 g/cc. The isotopic concentration (g/THM) of ^{235}U for the 2D pin cell was analyzed using the root mean square (RMS) method as shown in the following equation:

$$RMS = \frac{\sqrt{\sum_{i=1}^{l}(x_i - m)^2}}{L} \quad (2)$$

where x_i is the calculated value, m is the measured value, and L is the total number of measured values. The percent 1σ standard deviation of ^{235}U was found to be 18.81 percent for this model. Since the concentration of ^{235}U is in direct relation to the burnup of the fuel, this large error showed some serious deficiencies in this level of model fidelity.

Advanced 2D Pin Cell

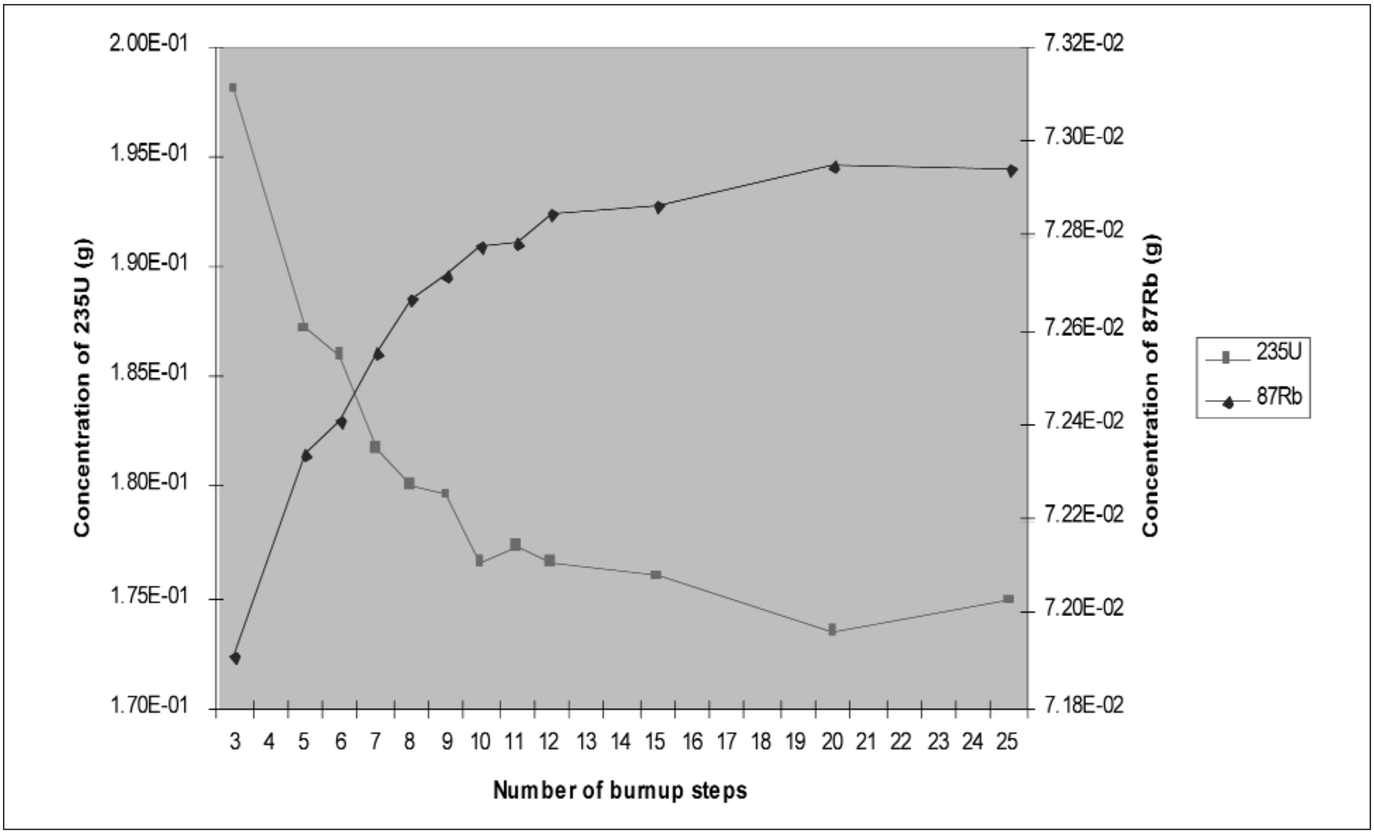
The advanced 2D pin cell model contained the same geometrical properties as the previously mentioned 2D pin cell. The difference was in the operating properties of the materials used. In the previous model, all of the materials were at room temperature (300 K). It is well known that neutron cross-sections vary with changes in temperature. Some of these effects include doppler broadening of the cross-section resonances, change in density of the moderator, and thermal neutron scattering effects. The thermal neutron scattering effects are included through the use of an $S(\alpha,\beta)$ treatment in MCNP. This generates neutron cross-sections (particularly for nuclides such as hydrogen) for neutron energies less than 4 eV.

The first correction factor implemented was the density of the moderator. As axial locations are not known in these models, the average moderator temperature in the core was used to determine the density. Using steam tables,[11] the average density of the moderator in the core was determined. The 2D pin cell was then re-run utilizing the moderator density correction factor.

The next correction factor applied was the $S(\alpha,\beta)$ tally. This tally consisted of an mt card in the MCNP input file. The mt card chosen was the lwtr.62t. This cross-section was created from the ENDF/B-VI Rev 3 and the SAB2002 library and is for use specifically with hydrogen in light water at a temperature of 600K. This correction factor, along with the fuel temperature and moderator density correction factors, were used to re-run the 2D pin cell.

The next correction factor was the fuel temperature. A review of the available cross sections in the MCNP library found a cross section that better fit the environment of the model. The cross sections chosen were 92235.15c, 92238.15c, and 94239.15c. These three cross sections were created from the endf62mt library with a temperature of 800K. The 2D pin cell model was then re-run with this correction factor in place.

Figure 2. Monteburns convergence of ^{235}U and ^{87}Rb with burnup step



The last correction factor to be used was the addition of U^{234} and U^{236} to the initial fuel isotopics. While this information may not be known for the forensics problem, there are a set of equations that can be used to predict accurately the concentrations of these isotopes based on the enrichment of the fuel. These equations are as follows:

$$^{234}U\ wt\% = 0.0089 \times {}^{235}U\ wt\% \quad (3)$$

$$^{236}U\ wt\% = 0.0046 \times {}^{235}U\ wt\% \quad (4)$$

where ^{X}U is an isotopic designation and *wt percent* is the weight percent of that isotope with respect to the rest of the fuel.

While ^{236}U does not exist in nature, it should be noted that the inclusion of ^{236}U isotopes in fresh fuel is only for U.S. born fresh fuel. This occurs because U.S. enrichment plants are contaminated with ^{236}U due to a previous processing of naval reactor spent fuel through the plants.

The results showed a significant increase in accuracy with each additional correction factor being used. It should also be noted that the addition of these correction factors did not significantly change the computational time required to run the code. For this reason, all four correction factors were used in all the models that followed. Table 4 shows the RMS percent error of ^{235}U of the various correction factors tested in the advanced 2D pin cell.

Multi-Radial-Region Pin Cell

The multi-radial-region pin cell was a 2D pin cell that had the fuel region broken into several different radial regions. This adjustment allows for a more accurate simulation of the burnup effects due to pin self-shielding. To account for this, the fuel region was broken into several radial regions using the following exponential equation:[1]

Table 4. RMS percent error of ^{235}U in advanced 2D pin cell

Correction factor	1σ Standard deviation (%)
No correction	18.81
Moderator density	7.86
S(αβ) card	3.65
Fuel temperature	2.31
^{234}U & ^{236}U	1.56

$$r(i) = R_{fo}\left[\frac{1-\exp(-\Sigma_a i)}{1-\exp(-\Sigma_a N_r)}\right] \quad (5)$$

where $r(i)$ is the outer radius of fuel region i, R_{fo} is the fuel outer radius, N_r is the total number of radial fuel regions, and Σ_a is the one-group macroscopic absorption cross-section.

It was found that the system converged at seven radial regions. However, it was found that the addition of radial regions added significant computational time to the model. The computational time required for the seven-region model was approximately seven times greater than that of the single-region model. When compared to that of the advanced 2D pin cell, the seven-region model had an increase in accuracy of only 0.07 percent for ^{235}U. As the accuracy for most of the isotopes being examined was around the 2-5 percent range, this increase was inconsequential. For this reason, it was decided that the forward model would contain only one radial fuel region.

Modified Pin Cell

The modified pin cell was a 2D pin cell that accounted for the increased moderator in the assembly due to water holes and the inter-assembly region. The formula which determined the amount of moderator in the model was as follows:[1]

$$P_{FM} = \frac{P_{asb}}{\sqrt{N_{pins}}} \quad (6)$$

where P_{FM} is the adjusted pin-to-pin pitch, P_{asb} is the assembly pitch, and is N_{pins} the number of fuel pins per assembly.

The results of this model did not compare with previous research[2] in that the accuracy of the modified pin cell was worse than that of the advanced 2D pin cell. In particular, the amount of ^{235}U was well below the level it should have been. This indicated that the additional moderator had caused too much fission of ^{235}U to occur. This outcome, peculiar at first, was further investigated to verify the validity of the results. It was thus determined that the culprit was a lack of boron in the system.

2D Assembly

This model consisted of a full assembly of fuel rods, water holes, and Gd-bearing fuel rods. Each of the fuel rods consisted of only one radial region and included the correction factors of the advanced 2D pin cell. The inter-assembly area was not accounted for. The outer surfaces of the assembly again consisted of reflecting boundaries. This model contained reflecting boundaries on the axial top and bottom of the fuel region assembly. MCNP tests were run to determine the required number of cycles and particles per cycle. Because the size of the assembly model was almost 300 times the size of the pin-cell models, a larger number of particles (60,000 particles per cycle with 200 cycles) was required to retain the desired accuracy of MCNP.

3D Assembly

This model retained the same geometrical characteristics as the 2D assembly except that the reflecting axial boundaries were removed and replaced with an appropriate stainless steel cap and moderator region. This effectively changed the axial neutron flux profile in the fuel rod. With the neutron flux in the upper and lower quadrants being reduced, the number of fissions occurring in those regions will also be reduced. This will in turn change the axial isotopic concentrations of the fuel rod. MCNP tests were again run to determine the required number of particles and cycles.

Additional Factors of Consideration

After analyzing the data, it was determined that other factors might need to be explored to ensure optimal accuracy of the models. The first of these factors was the value of Q-fission in the Monteburns input file. It is known that the fissioning of ^{235}U releases on average 196 MeV of energy per fission. However, throughout the irradiation process there is a buildup of other fissionable isotopes such as ^{239}Pu. As the concentration of these additional fissionable isotopes increases, the mean value of Q-fission will also change. While Monteburns does account for this change in the Q-fission value, it is important to give it the correct starting point. The value used thus far for this term was 200 MeV per fission. This value was chosen because it is a more generic value for models such as this. Nonetheless, it was deemed necessary to re-run the best model (advanced 2D pin cell) with a value of 196 MeV per fission for Q-fission. As expected, the accuracy of the model utilizing 196 MeV per fission was lower than that of the 200 MeV per fission. Thus, 200 MeV per fission was retained as the value for Q-fission.

Of the isotopes being analyzed, only one of them showed a significant amount of error in its accuracy. This isotope was ^{154}Eu. Upon inspection of the cross sections and fission yields in the ORIGEN libraries, it was determined that there might be additional isotope tallies necessary to add to the Monteburns input file. This determination was largely based on the fact that the most prominent path to ^{154}Eu was through the neutron absorption and decay of other isotopes through ^{153}Sm and ^{153}Eu. It was possible that Monteburns was not accurately calculating the neutron absorption cross-sections of these two isotopes. As there were no cross-section files available for ^{153}Sm, the model was re-run with only ^{153}Eu as an additional isotope tally.

The use of the ^{153}Eu isotope tally contributed to a decrease in the error of the accuracy by 50 percent. Even with this reduction in error, the accuracy was still not sufficient. It was thus decided to try adding the ^{153}Sm to the tally. As there were no cross-section files for this isotope, one was created from the JEF 3.0 library using NJOY. Unfortunately, the use of the ^{153}Sm isotope tally did not show any significant change in the isotopic composition of

Table 5. RMS percent error of isotopes of interest utilizing additional correction factors

	Adv. 2D pin cell	^{153}Eu tally	196 MeV Q-fission	^{153}Sm tally
^{235}U	1.56	1.56	2.95	1.56
^{238}U	0.04	0.04	0.03	0.04
^{238}Pu	8.25	8.25	8.32	8.25
^{239}Pu	4.41	4.41	4.45	4.41
^{240}Pu	2.58	2.58	3.11	2.58
^{241}Pu	6.81	6.81	5.83	6.81
^{237}Np	6.14	6.14	6.52	6.14
^{137}Cs	1.65	1.65	0.75	1.65
^{148}Nd	0.64	0.64	1.5	0.64
^{154}Eu	26.82	16.42	17.53	16.44

the model. For this reason, it was decided that ^{153}Sm would not be included in the isotope tallies. Table 5 shows the RMS percent error of the isotopes of interest utilizing the additional correction factors on the advanced 2D pin cell.

Best Estimate Model

The results of the forward model methodology showed conclusively that the advanced 2D pin cell provided the greatest level of accuracy while maintaining a minimum degree of computational time. The correction factors that were found to be needed were as follows: fuel temperature cross-section, moderator density, S(α,β) tally, and initial concentrations of ^{234}U and ^{236}U in the fuel. It is also recommended that 200 MeV per fission be used as the value for Q-fission in the Monteburns input file. If the ^{154}Eu isotope is to be tallied, it will also be necessary to tally the ^{153}Eu isotope along with it. Figure 3 shows a graphical representation of the advanced 2D pin cell for the Takahama Unit #3 reactor.

Forward Model Benchmarking

Calvert Cliffs Unit #1

Calvert Cliffs is a Combustion Engineering-designed two-loop PWR operating at 883 MW electric. There are 390 assemblies containing a 14x14 square lattice of fuel rods and waterholes. Each assembely contains 172 fuel rods. The enrichment of the fuel varies from 2.05 wt percent to 2.99 wt percent depending on the location in the core.[12] The dissolved residue is then analyzed by isotopic dilution mass spectrometry. Destructive analyses were then performed using mass spectrometric analysis to determine the isotopic abundances in the fuel.[13] The results of these tests were reported at the time of the test and not decay corrected.

Table 6. RMS percent error of isotopes of interest in various models

	Adv. 2D pin cell	Multi-region pin cell	Modified pin cell	2D assembly	3D assembly
^{235}U	1.56	1.49	5.03	2.22	2.26
^{238}U	0.04	0.05	0.13	0.08	0.07
^{238}Pu	8.25	10.76	19.59	12.79	12.63
^{239}Pu	4.41	4.63	11.63	6.32	6.26
^{240}Pu	2.58	2.34	1.96	1.81	1.85
^{241}Pu	6.81	6.70	13.47	7.71	7.69
^{237}Np	6.14	7.57	12.22	7.74	7.98
^{137}Cs	1.65	1.63	1.64	1.58	1.56
^{148}Nd	0.64	0.66	0.59	0.69	0.69
^{154}Eu	16.42	16.45	13.29	15.73	15.66

Trino Vercelles Unit #2

Trino Vercelles is a Westinghouse designed PWR operating at 825 MW electric. The core has fuel enrichment from 2.719 wt percent to 3.897 wt percent depending of the location in the core. The core also contains 120 fuel assemblies in a 15x15 square lattice of 208 fuel rods. The remaining space in the assembly is taken by cruciform control blades.[14, 15] Eighteen samples from various fuel rods and axial positions were analyzed. The analyses were performed at two separate facilities, Karlsruhe Laboratory and Ispra Laboratory, and their results compared. Each of the labs performed radiochemical analyses on the samples that included both alpha and gamma spectrometry. The results of these tests were then decay corrected to the date of discharge from the core.

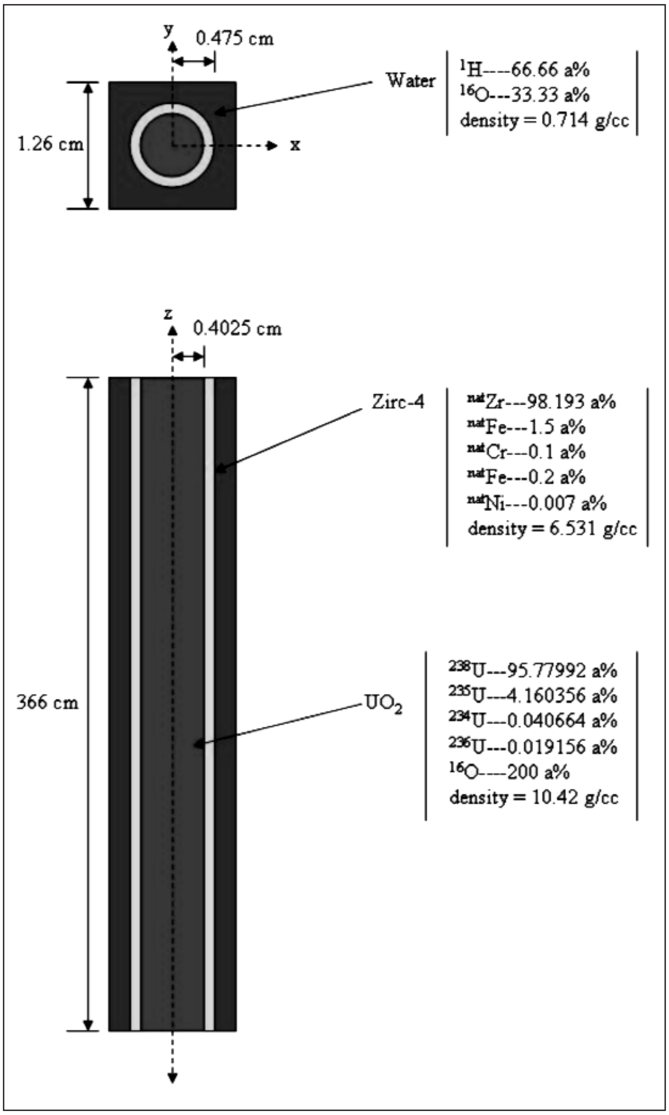
Results

The benchmarking of the forward model methodology demonstrated good agreement with the isotopic concentrations evaluated. The percent error in isotopic concentration for each reactor as well as the RMS of these values is shown in Table 7. With the exception of ^{237}Np and ^{154}Eu, the total error associated with each isotope was less than 5 percent. Two isotopes, ^{238}U and ^{148}Nd, had total errors of less than 1 percent, which is exceptional. This is very important as ^{148}Nd is the primary isotope for determining the burnup of the fuel. If the burnup of the fuel is wrong, that error will propagate throughout the entire system.

Conclusions

A forward model methodology for determining the specific reactor facility of origin for spent nuclear fuel used in an RDD was developed using the LANL code Monteburns. Models of the Takahama Unit #3 reactor were developed using optimization

Figure 3. Graphical representation of advanced 2D pin cell with all correction factors



techniques to determine the fidelity necessary to achieve adequate statistical accuracies for the isotopes of interest. Along with model fidelity, a variety of correction factors were also examined to determine their effectiveness in improving the accuracy of isotopic concentrations. Using this forward model methodology, the forensics project will be able to generate one-group cross sections and verify isotopic compositions with a level of accuracy that is necessary to yield unique reactor facilities in the event of an RDD event.

Once the forward model methodology had been developed, it was verified by a benchmarking technique. The Calvert Cliffs Unit #1 and Trino Vercelles Unit #2 reactors were modeled using the forward model methodology. The isotopic concentrations from all three reactor models were then compared to determine the level of agreement between them.

Table 7. RMS percent error for benchmarked isotopics

	Takahama	Calvert Cliffs	Trino	Total
^{235}U	1.56	3.55	0.7	1.31
^{238}U	0.04	0.02	1.48	0.49
^{237}Np	6.14			6.14
^{238}Pu	8.25	2.68		4.34
^{239}Pu	4.41	1.67	3.15	1.89
^{240}Pu	2.58	3.92	0.85	1.59
^{241}Pu	6.81	1.21	3.8	2.64
^{137}Cs	1.65			1.65
^{148}Nd	0.64	1.7	0.34	0.63
^{154}Eu	16.42		6.99	8.92

The results from the forward model methodology showed that the advanced pin cell with seven radial regions and several correction factors gave the greatest degree of accuracy. However, the computational time required for this model was seven times greater than that of the single-region advanced pin cell and the difference in accuracy was only 0.7 percent for ^{235}U. For this reason, the single radial region advanced pin cell with the above mentioned correction factors was established as the forward model methodology. The correction factors employed were as follows: appropriate fuel temperature cross-section file, moderator density, S(α,β) tally, ^{234}U and ^{236}U initial fuel concentration, and ^{153}Eu tally if the ^{154}Eu isotope is being examined.

With the exception of ^{154}Eu and ^{237}Np, the total error associated with each isotope was less than 5 percent. Two isotopes, ^{238}U and ^{148}Nd, had total errors of less than 1 percent, which is exceptional. ^{154}Eu, which can be used as an age monitor, was unfortunately shown to not be as accurate as needed for this research. The total percent error for each isotope, as shown in Table 7, will be used in the reactor verification portion of the forensics problem as the standard deviations associated with each isotope.

Future research into this type of model analysis should focus itself on determining better isotopic correction methods to be employed in the input files. A prime example of this is ^{154}Eu. While the cross-sections for this isotope were found to be very accurate, there is some debate as to the accuracy of the fission yield values of ^{154}Eu as well as other isotopes that through neutron absorption and decay would form ^{154}Eu. It was found that the majority of ^{154}Eu does not actually come as a direct fission product but through the neutron absorption and decay of other isotopes. This also raises the question as to the legitimacy of the neutron absorption cross sections of these isotopes. Solving this problem can be a very daunting task as the number of variables involved can be quite large.

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2005 J. D. Williams Student Paper

Detection of Highly Enriched Uranium Using a Pulsed Inertial Electrostatic Confinement D-D Fusion Device

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Abstract

This paper overviews the work that has been done to date toward the development of a inexpensive, reliable, and portable means to detect highly enriched uranium (HEU) and other fissile materials. The specific goals of this research include the characterization of the current inertial electrostatic confinement (IEC) ion source to determine optimum conditions for pulsed IEC operation, the development of a pulsed IEC neutron source that can provide 10^{10} D-D neutron/s pulses, with a 10^{8} average D-D neutron/s level, and the construction of a detector system to detect delayed neutrons generated by a uranium target being irradiated by a pulsed IEC neutron source. It is proposed that the completion of these goals will allow the construction of a proof-of-principle HEU detection system at the University of Wisconsin-Madison.

Introduction

The smuggling of illicit nuclear material has been an issue of serious concern for U.S. officials since the early 1990s, and has gained increased attention in the wake of September 11, 2001. In the past decade, there have been more than 150 confirmed incidents of smuggling of nuclear material in the International Atomic Energy Agency's (IAEA) Illicit Trafficking Database.[1] Of these, nearly half involved enriched uranium or plutonium. In the wrong hands, these materials could represent a serious threat to national security in the United States, and preventing this from occurring has become a high priority for the newly formed U.S. Department of Homeland Security.

The development of an inexpensive, reliable means to detect fissile and other nuclear materials will allow the United States and other countries to inspect cargo as it enters their borders. This paper overviews some of the work that has been done to date toward that development, and proposes a research plan for the design and construction of a pulsed inertial electrostatic confinement (IEC) fusion device to be used for the detection of highly enriched uranium (HEU) and other fissile materials.

HEU Detection Methods

There are two fundamental nondestructive methods of detecting HEU or other forms of special nuclear material (SNM)—active and passive interrogation. Passive assay relies on the emission of either photons or neutrons from the HEU, either by decay or by spontaneous fission. It is, however, relatively easy to shield these particles using a small volume of material. In addition, all of these decay modes have long half-lives, resulting in low count rates. Active interrogation utilizes either a neutron or gamma ray source to irradiate the nuclear material. These will then initiate fissions within the material, releasing prompt neutrons and gammas. In addition to the prompt radiation, fission product nuclei will continue to emit delayed neutrons and gammas for several minutes after the initiating event. Detection schemes can be developed to target either the prompt or delayed spectra. Active interrogation offers a number of advantages over its passive counterpart. Neutrons and high-energy gammas are both very penetrating radiation sources. The fission neutrons and resulting gammas are also highly penetrating and difficult to shield. In addition, the source strength—and therefore signal strength—can be tuned to appropriate levels for various applications. Active interrogation is also more universally applicable, as it is appropriate for both plutonium and U-235.

UW-IEC Background

There are a number of ways to produce neutrons. Fission reactors produce large numbers of neutrons, but are kept far from public areas, due to safety and security concerns, and are large, expensive facilities. Radioactive sources, utilizing either spontaneous fission or (α, n) reactions can also produce a high neutron flux, but cannot be turned off when not in use, and pose a risk themselves for nuclear terrorism. A third way to produce neutrons is through nuclear fusion. This is a potential source that can be turned on and off as needed, requires no radioactive fuel, and can be constructed in small, inexpensive configurations. There are a number of different fusion reactions, but only two will be examined in this paper. The first is the deuterium-tritium (D-T) reaction. As seen in Figure 1 the D-T reaction yields a 14.1 MeV neutron. The second fusion event of interest is the deuterium-deuterium (D-D) reaction. As shown in Figure 1 the D-D reaction has two possible reaction paths, each of which is equally likely to occur. As it results in no fusion products of interest for this application, the second will be largely ignored. Half of the D-D reactions, therefore, yield a 2.45 MeV neutron.

Each method of creating fusion utilizes a combination of high temperature, density, and confinement time to encourage fusion reactions to occur. The Inertial Electrostatic Confinement (IEC) fusion device sacrifices density to achieve high energies and

Figure 1. Fusion reactions. The first is the D-T reaction, the second is the D-D reaction.

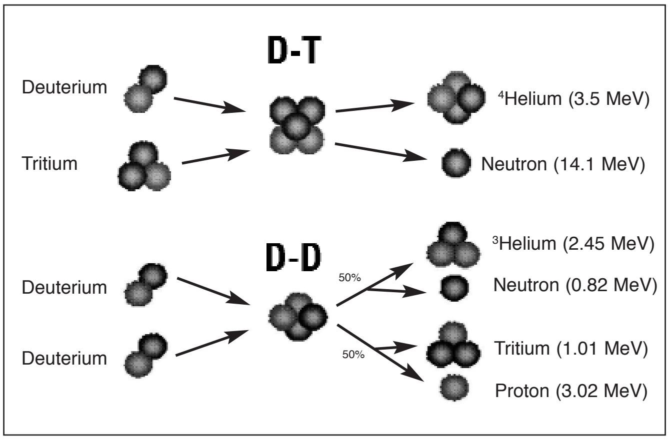
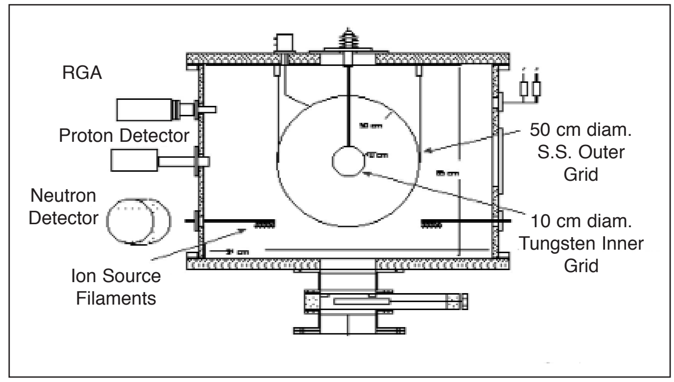


Figure 2. IEC experiment schematic. The outer vessel maintains vacuum, while the inner grids provide the potential necessary for fusion reactions to occur.



long confinement time. As shown in Figure 2, the University of Wisconsin IEC device consists of a cylindrical vacuum chamber 65 cm tall and 90 cm in diameter using a 1,000 L/s turbo pump. Base pressures in the mid-10^{-7} torr are measured with an ion gauge.[2] Within this chamber are two highly transparent grids. The outer stainless steel grid is 50 cm in diameter and is kept at ground potential. The inner W-25 percent Re grid is 10 cm in diameter and is connected to a 200 kV power supply through an insulating boron nitride stalk and a high voltage feed through.

During operation, deuterium gas is fed into the chamber at 10-20 sccm (standard cubic cm per second) to produce a background pressure around 2 mtorr. This gas is then ionized using electron bombardment from hot tungsten filaments. Negative voltage is applied to the inner grid cathode, and the positively charged ions are attracted to the center of the grid. The ions will accelerate down this potential well to the cathode potential, pass through the center of the device, and decelerate back to ground potential as they reach the outer anode. As ions with enough energy hit other ions or neutral particles, they will fuse. Current operation in steady-state mode at 166 kV and 68 mA has resulted in D-D neutron production rates as high as 1.8×10^8 n/s.[3]

MCNP Model of Pulsed System

In order to determine the feasibility of active HEU detection utilizing a pulsed IEC fusion device, the proposed concept was first modeled using MCNP5; a Monte Carlo based particle-tracking code.[4] First, a series of test modules was developed to test the validity of the code for this specific task. Then, a detailed model of the IEC and detection hardware was constructed to determine the minimum amount of HEU needed for valid detection statistics.

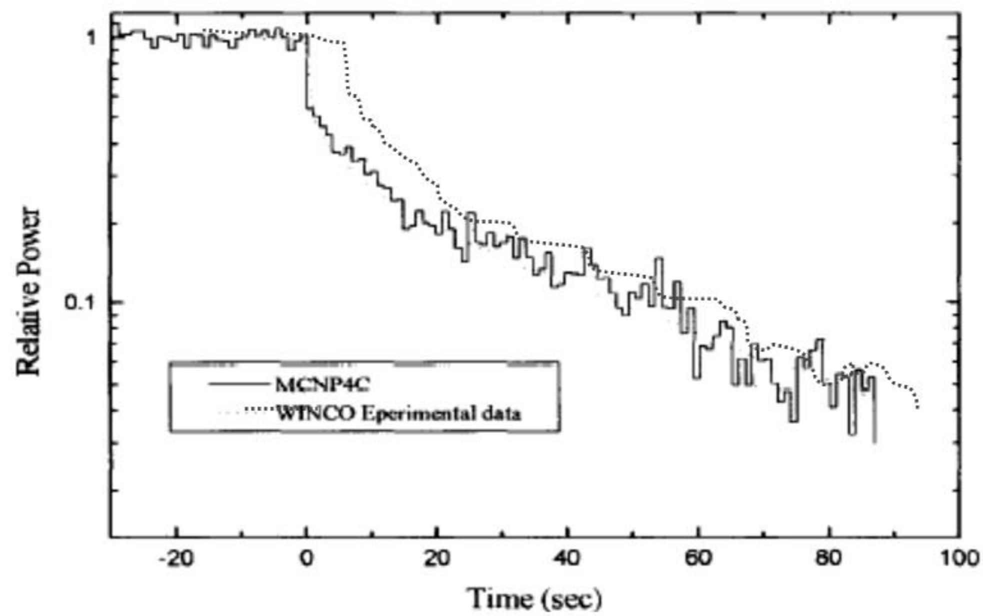
Delayed Neutrons in MCNP

Proper accounting for delayed neutrons was not incorporated into the MCNP program until version MCNP4C.[5] Previous versions had represented all secondary production of neutrons created in the fission process as prompt neutrons. This deficiency has been corrected by adding delayed neutron data to the MCNP data libraries and modifying the MCNP code to sample delayed neutron time of emission and energy. Werner[5] verified the delayed neutron effects in the code both analytically and experimentally. Figure 3 shows a plot of delayed neutrons as a function of time for both experimental data and an MCNP4C model of the same apparatus.

Before designing a realistic model of the IEC and HEU detection system, an effort was made to verify that MCNP was capable of correctly modeling the time-dependant behavior of delayed neutrons produced from the fission of ^{235}U and ^{239}Pu in a pulsed system. A model of a bare subcritical metal sphere of fissile material was used to perform this verification. A pulsed source of thermal neutrons was introduced at the center of the sphere, and a volume tally was taken within the sphere to observe the time-dependent neutron flux during and after the pulse. MCNP5 is capable of running in modes with and without delayed neutrons, so the model was first run with the delayed neutrons shut off. As seen in Figure 4, there are almost no neutrons present within the sphere 10 ms after the 30 ms pulse is complete, and those present are due only to scattering. Error bars are included on the graph, but are generally smaller than the data points. Also note that the counts represent a flux averaged over the volume of the sphere, per source neutron. Therefore to calculate actual fluxes, the values must be multiplied by the total number of source neutrons in the system.

This experiment was then repeated with the delayed neutron feature turned on for both ^{235}U and ^{239}Pu spheres of 4 cm radius. Figure 4 shows the two spectra plotted on top of each other. Error bars are present, but are smaller than the data points. In both cases, the source neutrons were stopped at 30 ms, but tallies were extended out to 100 ms to observe the delayed neutrons. The higher cross section for thermal neutrons is reflected in the slightly higher counts in the plutonium sample.

Figure 3. MCNP results with benchmarking data



The next step in the validation process was to develop a model in which the source exhibited pulsing behavior. As an initial step, the source was set as a 1 ms pulse followed by 99 ms of no source neutrons being created. The MCNP program was then set up to provide five of these pulse sequences. Figure 5 shows the resulting volume flux tally for a 4 cm radius uranium sphere enriched to 100 percent ^{235}U. Error bars are present, but generally smaller than the data points. Although the delayed neutrons are decaying between pulses, the cumulative effect of each pulse is consistently increasing the total delayed neutron population. However, the delayed neutron population will begin to reach a steady-state value over time, as seen in Figure 6. This will be true in the experimental case as well, and will have to be taken into account when neutron measurements are made.

MCNP Model of the IEC

Once it was determined that MCNP5 was capable of properly modeling delayed neutrons with a pulsed neutron source in place, work was begun on a simple model of the IEC device. Figures 7 and 8 show side and top views, respectively, of the device with the HEU and detection module in place. This geometry was chosen to maximize the number of fission neutrons that survive to enter the ^{3}He detectors. It was also chosen due to the relative ease of construction. The detection unit is modeled after a modified long counter with the central detector replaced with a HEU sample. The real detector system will be surrounded by cadmium to capture thermal neutrons ambient in the room, so this model neglects the effects of the concrete walls in the room to drastically decrease computation time.

After running this model, results were obtained that had reasonable levels of error present in the delayed neutron counts. Error in the prompt neutrons is less than 1 percent. However, the error in the delayed neutrons is as high as 50 percent in the initial counts and is still ~25 percent at 500 ms. Even with this error, the delayed neutron flux is increasing with time as it approaches a steady-state value. This data was then used to determine the total number of reactions occurring in the detectors, and therefore the number of counts available for detection. A tally multiplier was added to the volume tallies corresponding to the detector tubes that performed the operation:

$$V\int \varphi(E) N \sigma(E) dE \qquad (1)$$

where $\varphi(E)$ is the energy-dependent fluence (particles/cm^2), N is the number density of the ^{3}He, $\sigma(E)$ is the energy-dependent absorption cross section and V is the volume of the detector assembly.[1] The resultant number of reactions plotted as a function of time is shown in Figure 9.

Assuming about 80 percent of these counts could be scored by the detector during the 90 ms between the pulses, this would correspond to ~2 counts/second for this 550 grams of 20 percent enriched uranium, corresponding to roughly 110 grams of ^{235}U Based upon this data, the amount of ^{235}U that would correspond to a detector response of 1 count/second with a neutron rate of $5x10^8$ was estimated to be approximately 11 grams, which falls within the UW-Madison license limit. Searching for delayed neutrons after turning off the IEC may provide even greater sensitivity.

Figure 4. MCNP5 spectra of delayed neutrons. Counts are normalized per source neutron and are taken in 10 ms bins.

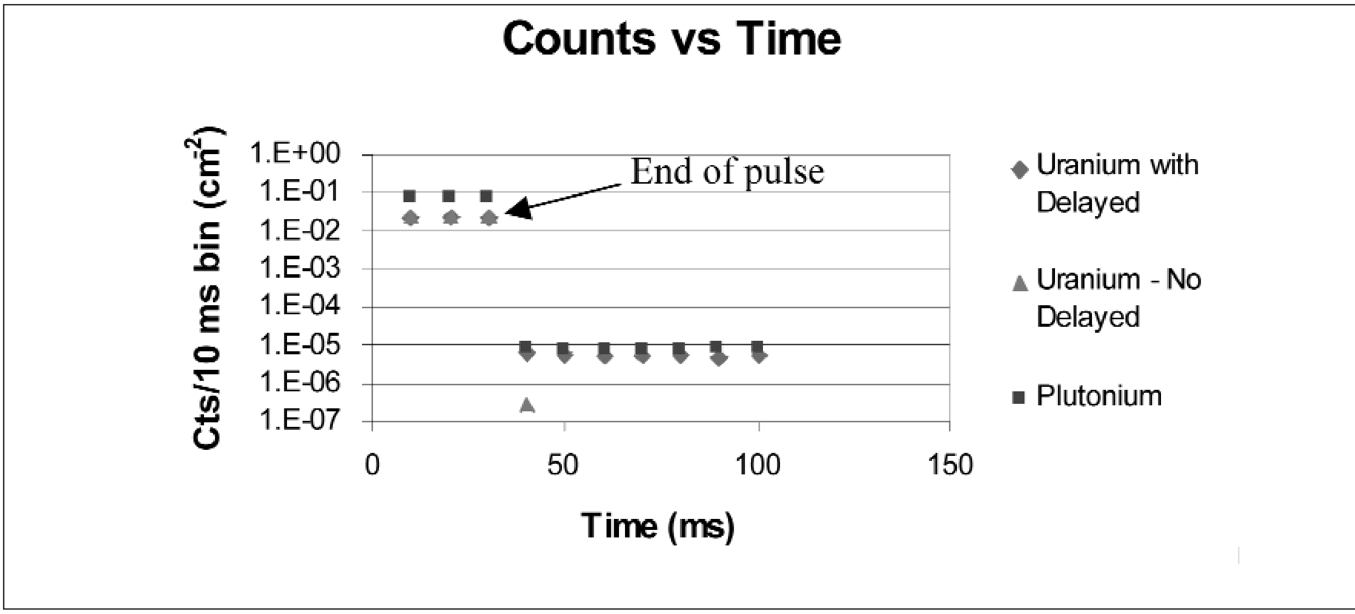
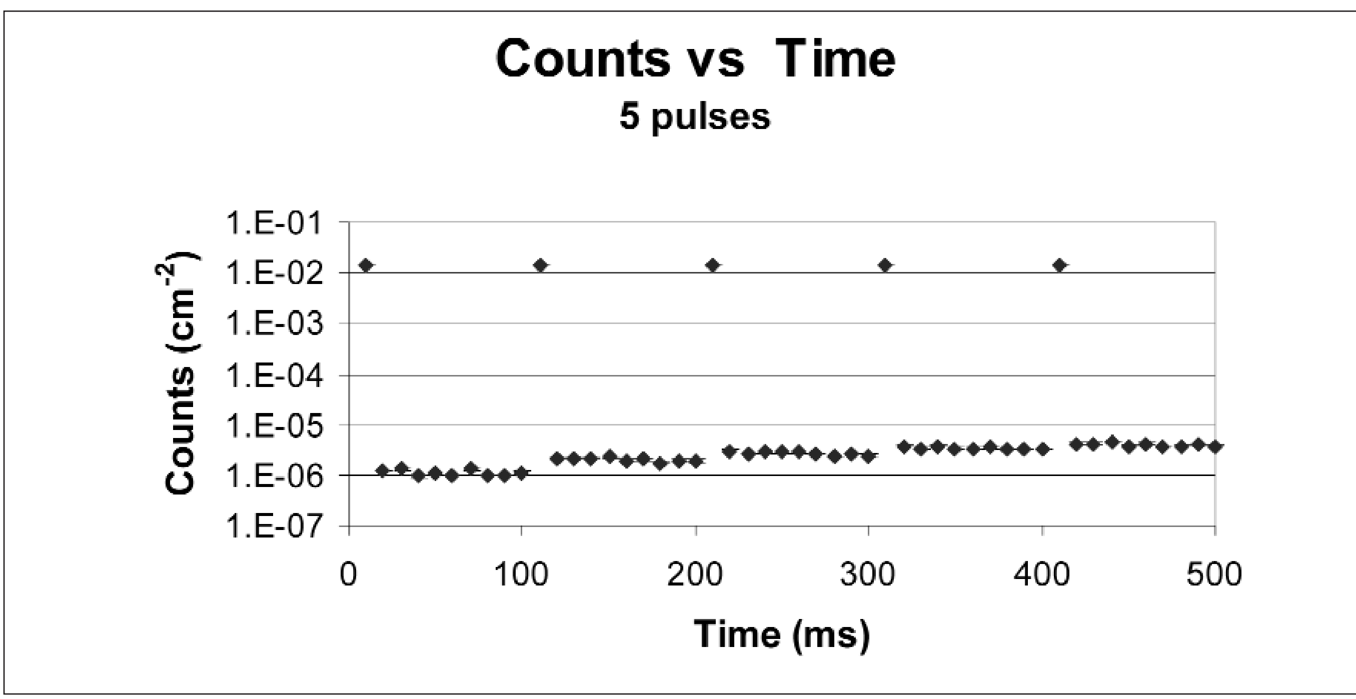


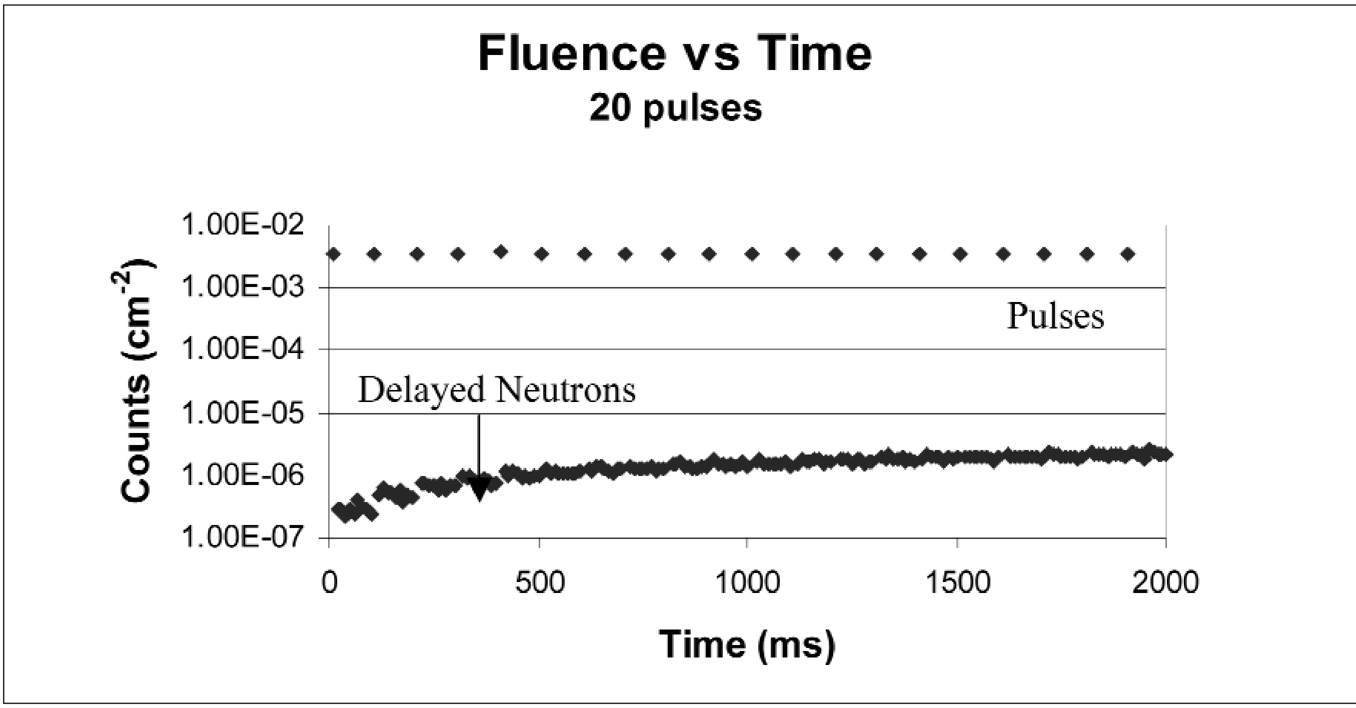
Figure 5. Calculated fluence for a series of five pulses in test case. Counts are normalized per source neutron and are taken in 10 ms bins.



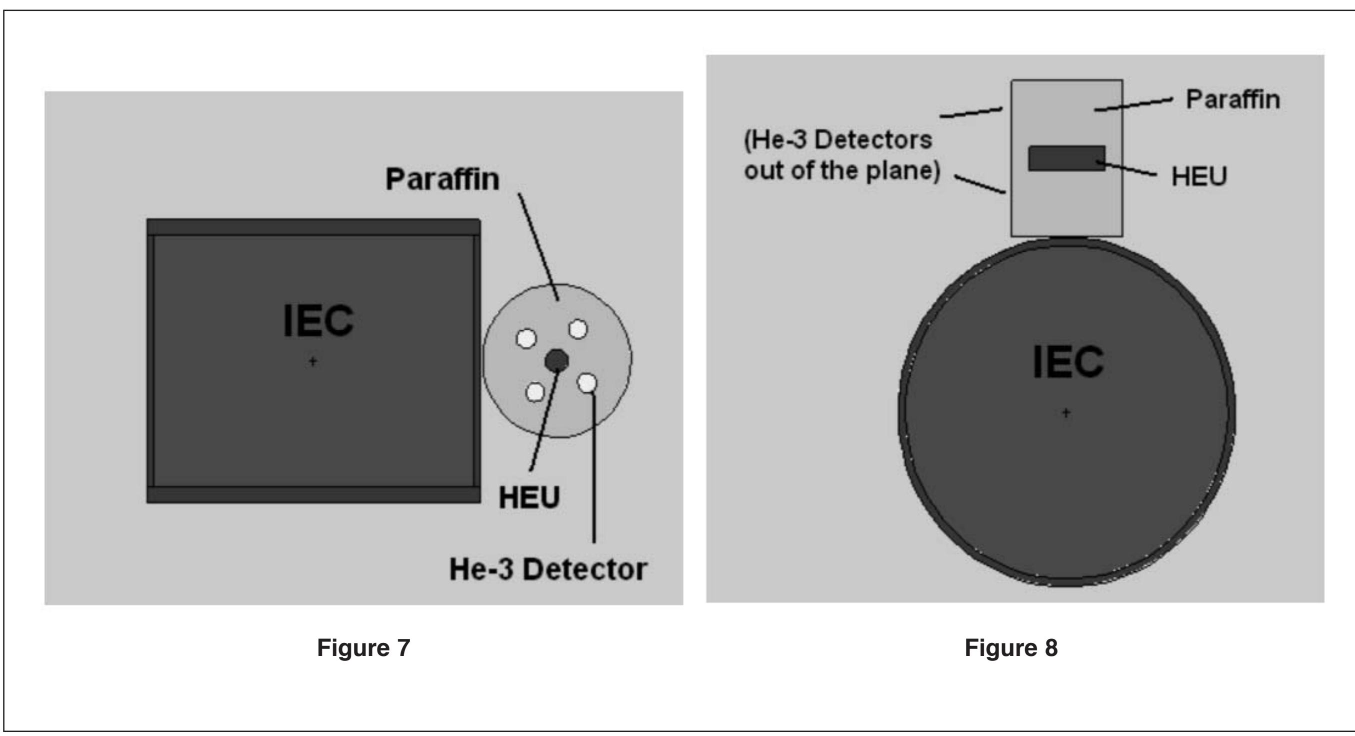
Summary

This paper overviews some of the work that has been done to date toward the development of an inexpensive, reliable, and portable means to detect HEU and other nuclear materials. The specific goals of this research include the characterization of the current IEC ion source to determine optimum conditions for pulsed IEC operation, the development of a pulsed IEC neutron source that can provide 10^{10} D-D neutron/s pulses, with a 10^{8} time averaged D-D neutron/s level, and the construction of a detector system to detect delayed neutrons generated by a uranium target being irradiated by a pulsed IEC neutron source. The two primary areas of proposed future work—pulsed high-current operation of the UW-IEC and the use of this pulsed source to detect HEU in the laboratory—represent achievable research goals in the specified

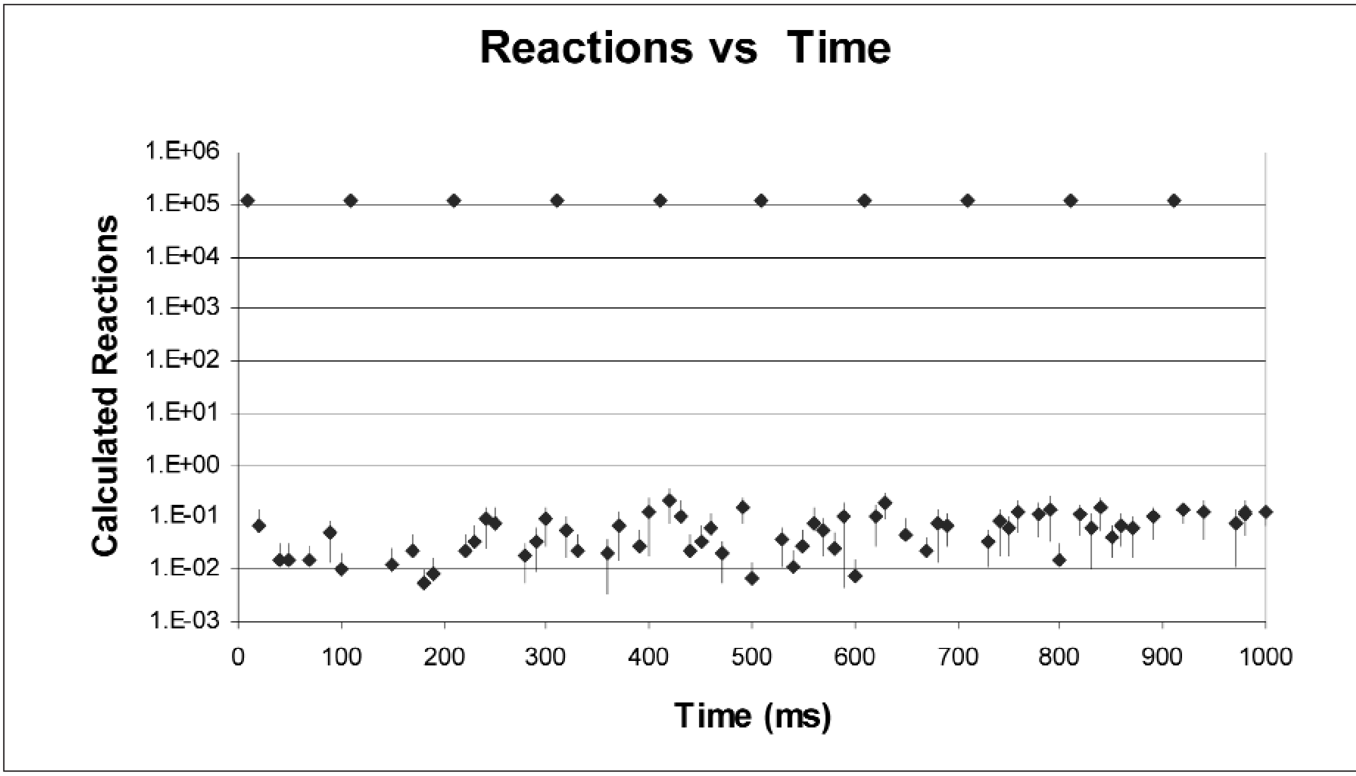
Figure 6. Calculated fluence for a series of twenty pulses in test case. Counts are normalized per source neutron and are taken in 10 ms bins.



Figures 7 & 8. Side view and top view of the HEU detection model in MCNP.



Figures 9. Calculated reaction rate within the ^{3}He detectors. Counts are taken in 10 ms bins.



timeframe. The first of these areas will primarily consist of circuit modeling and the modification of existing facilities currently in operation at UW-Madison, and a specific plan has been laid out to construct the initial prototype of a pulsed IEC device. The second represents an entirely new area of research for the UW-IEC team. As discussed in this paper, modeling work in MCNP-5 has already begun to characterize detection regimes and anticipate minimum levels of HEU required for detection, and design and construction of a delayed neutron detector will follow as the pulsed source becomes operational. Initial modeling indicates that samples as small as 11 grams will be detectable utilizing the proposed pulsed IEC coupled with a simple detection system. It is proposed that the combination of these components will allow the construction of a proof-of-principle HEU detection system at UW-Madison.

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Toward the Simulation of Photofission for Nuclear Material Identification

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Abstract

The detection of shielded highly enriched uranium is a challenging problem that is being addressed by numerous researchers. The measurement systems that are being investigated require fast, accurate, and simple read-out responses to be used at ports of entry. A number of currently proposed techniques make use of photon sources to induce fission in the nuclear material and to detect the subsequent gamma rays and neutrons from fission. The design of such devices and the analysis of the measurement results rely on Monte Carlo codes to simulate the interaction of neutrons and photons with the nuclear material, the shielding, and the radiation detectors. However, currently available Monte Carlo codes lack the ability to accurately simulate the emission of secondary particles from photonuclear events. This ability is vital for investigating novel efficient techniques capable of identifying nuclear materials and of estimating their amount.

The goal of this study is to provide a tool that addresses and solves these deficiencies. This paper presents a methodology that relies on the acquisition of correlated signals from prompt neutrons and photons emitted by photonuclear interactions. The proposed measurement system makes use of organic scintillators for measuring the signals from the fast neutrons and photons.

In this paper, we describe the currently implemented photofission simulation in MCNPX and propose an extension to improve the simulation of secondary particles. Our approach is based on the use of two existing and well-benchmarked codes, MCNPX and MCNP-PoliMi.

Introduction

In the context of global economy, the present historical and social events call for raising security standards without affecting worldwide trade and business. This necessity requires the development of new measurement techniques to detect concealed nuclear material. It is, of course, desirable that these techniques provide fast and accurate responses. Our study draws on the recent efforts and achievements of safeguards and nuclear nonproliferation applications[1, 2] while proposing a novel promising technique.

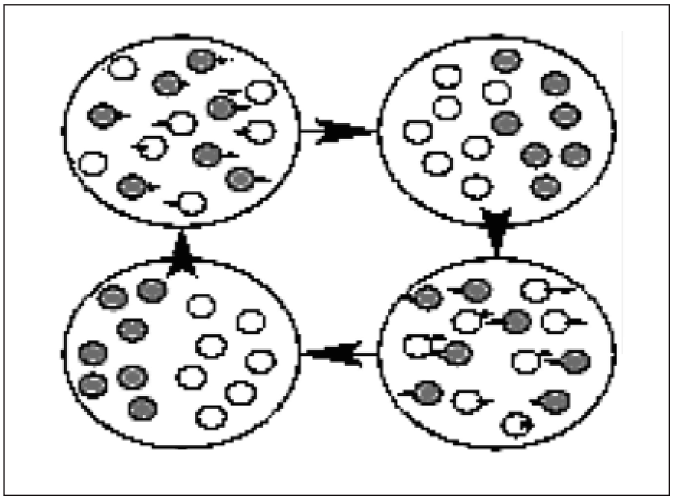
In the past, measurements that relied on the interrogation of fissile targets by neutron sources were designed to detect the presence of fissile and/or fissionable material in sealed containers. The use of neutrons as interrogation sources is limited by the attenuating properties of the shielding material. Recent attempts have been made in which the interrogating neutrons are replaced by gamma rays having energy of 10-20 MeV. Gamma rays of this energy are highly penetrating and can reach the nuclear material through heavy shielding.

Glimpse of the Underlying Physics Phenomena

Photon absorption is a necessary, although not sufficient, condition for the fission event to occur. The dominant feature in the photonuclear absorption cross-section is the photonuclear giant dipole resonance. This peak represents a value of the cross-section that is typically 50 to 100 times greater than that for neighboring energies. This resonance appears in all nuclei. In the medium and heavy elements, it is found between 13 and 18 MeV, whereas in lighter nuclei it lies near 20 MeV. The giant resonance is mainly due to the absorption of the electric dipole component of the incident photon wave. It is a nucleon's collective reaction to photons at these relatively low energies, whose wavelength is much greater than the nuclear dimensions. The oscillatory electric field of the incident photon causes the protons to vibrate while the neutrons move in the opposite direction to keep the center-of-mass fixed. Protons and neutrons oscillate out of phase and appear to have an effective charge $(+\frac{1}{2}e)$ and $(-\frac{1}{2}e)$, respectively. A schematic representation of this phenomenon is shown in Figure 1.

The peak of the giant electric dipole resonance extends over a width of 5-10 MeV. Relatively wide peaks correspond to short lifetimes. In fact, the giant electric dipole oscillation goes through only a few complete cycles before it dissipates, corresponding to a lifetime of roughly 10^{-21} s.[3, 4]

Figure 1. Schematic representation of the giant dipole resonance in nuclei[3,4]



Using Photons for the Interrogation of Actinides

Photofission is being considered instead of neutron-induced fission because photons of energy 10-20 MeV are highly penetrating. Photofission is the only photonuclear interaction to emit multiple neutrons and gamma rays, typically 2-3 neutrons and 7-8 gamma rays, on average. This characteristic suggests the use of correlation (or multiplicity) counting as a means to detect the presence of actinides. Delayed neutron and gamma ray emissions can also be an indicator of the presence of nuclear material.[5]

Delayed emission can also be caused by prompt neutrons from photofission that thermalize in the system and induce further fissions.

This study is focused on detecting fissile and fissionable material: U-235, U-238, Pu-240, Pu-239, and Pu-241. Figure 2(a-e) show the photonuclear cross-sections for the actinides of interest. The non-elastic cross-section encompasses all the partial cross-sections: (γ,n), (γ,2n), and (γ,f). At first glance, we can immediately notice that the non-elastic (γ-absorption) cross-section peaks in the giant dipole resonance range for each of the selected elements. Figure 2f shows the photonuclear cross-sections for Pb-207: 2a represents the total photo-absorption cross-section (γ,abs), 2b represents the neutron-production inclusive cross-section (γ,xn), 2c represents the exclusive cross-section for the production of one neutron only (γ,n), and 2d represents the exclusive cross-section for the production of two neutrons (γ,2n).

Photofission does not occur in Pb-207 for energies in the giant dipole resonance range, as is shown in Figure 2f by the absence of the photofission cross-section.

Monte Carlo Tools for Simulation

The design and analysis of measurements based on photofission require the use of Monte Carlo tools to simulate the interaction of gamma rays with the materials in the system, the production of secondary neutrons and gamma rays, and the interaction of these with the detectors. The simulation of higher moments of the distribution of neutrons and photons in the system requires that the individual interactions be described accurately.[8] The simulation of the individual interactions relies on the knowledge of the multiplicity, energy, and time of emission of secondary neutrons and gamma rays for a given material. Given the known correlations and distributions of delay times for a given material, the Monte Carlo program should be able to correctly simulate the multiplicities and spectra of output neutrons and gamma rays.

We have evaluated the most-established radiation transport Monte Carlo codes available in terms of photofission implementation. EGS4 and EGSnrc Monte Carlo codes are not designed to simulate hadronic processes: They do not transport neutrons. GEANT4 implements photofission but not at the level of accuracy required by our application. It does not include both prompt and delayed neutrons. FLUKA simulates photofission and transports neutrons and gamma rays at all energies but does not distinguish between prompt and delayed neutrons.

MCNPX is a well-established radiation transport Monte Carlo code, flexible and efficient at modeling materials, complex sources, and target geometry.[9,10] A feature added recently to MCNPX allows for using library data as well as switching to physics models[11,12] when this mode is selected or to make up for missing library data. This allows for the realization of the three photonuclear stages (pre-equilibrium, fission, evaporation) for a wide variety of energy ranges and materials.

We have analyzed the way actinides' photonuclear reactions are implemented in MCNPX11 and detected some inadequacies for using this code in simulating correlated detection of photons and neutrons.

- Secondary gamma rays are not modeled at all in the current actinide library.
- Secondary neutron emissions are performed on average, according to their average yields and not by single reaction.

It follows that the emitted particles carry no memory of the reaction type they originated from. As a consequence, energy is not conserved in the single interaction. According to the cross-sections in figures 2a through 2e, the following are competing processes in the photonuclear interrogation of the actinides: (γ,n), (γ,2n), and (γ,f). Photofission is the predominant interaction in the case of fissile isotopes.

MCNPX does not relate the secondary neutrons to the reaction that produced them. Therefore, any photonuclear secondary neutron, is independently sampled from any reaction that can produce it.

To verify this program flow, we introduced a small modification to MCNPX, which consists of a printout of the secondary particles emitted in photonuclear events. The simulated geometry consisted of a point source emitting monoenergetic gamma rays at 15 MeV and a U-238 sphere having radius 5 cm. The mass of the sphere was approximately 10 kg. The point source was placed

Figure 2a. Photonuclear cross-section for U-238. Data taken from the Bofod01u library[6]

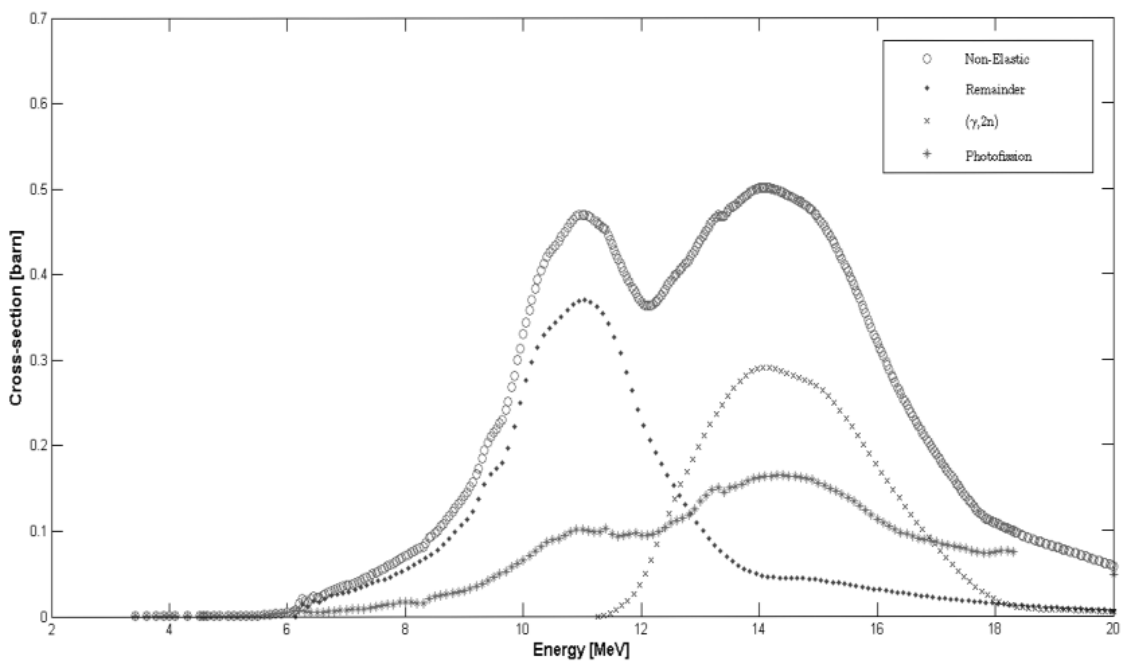


Figure 2b. Photonuclear cross-section for U-235. Data taken from the Bofod01u library[6]

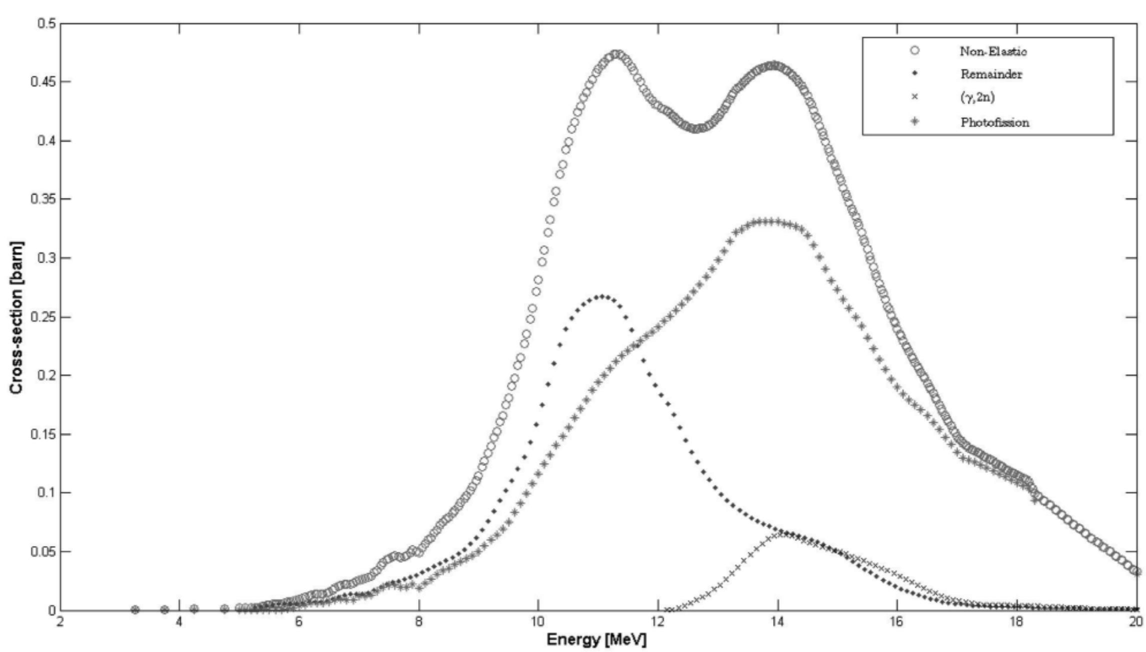


Figure 2c. Photonuclear cross-section for Pu-239. Data taken from the Bofod01u library[6]

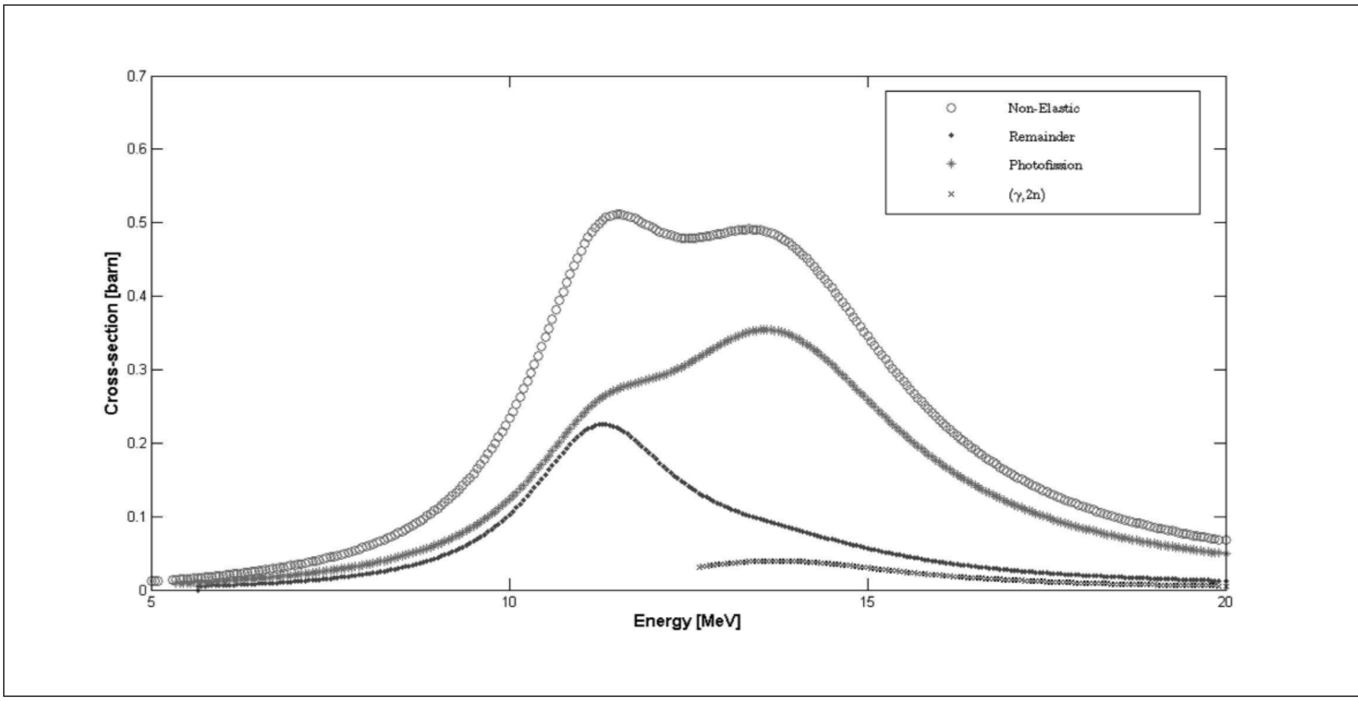


Figure 2d. Photonuclear cross-section for Pu-241. Data taken from the Bofod01u library[6]

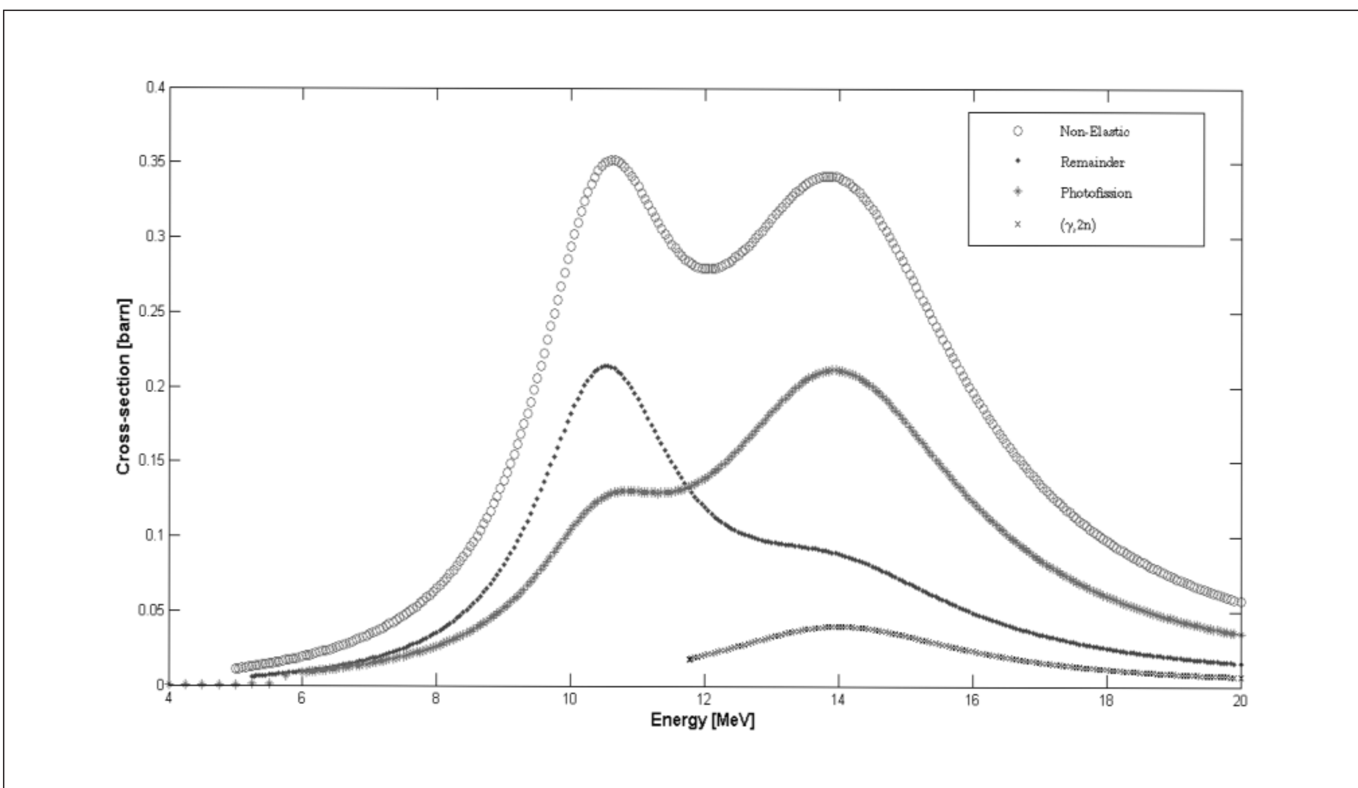


Figure 2e. Photonuclear cross-section for Pu-238. Data taken from the Bofod01u library[6]

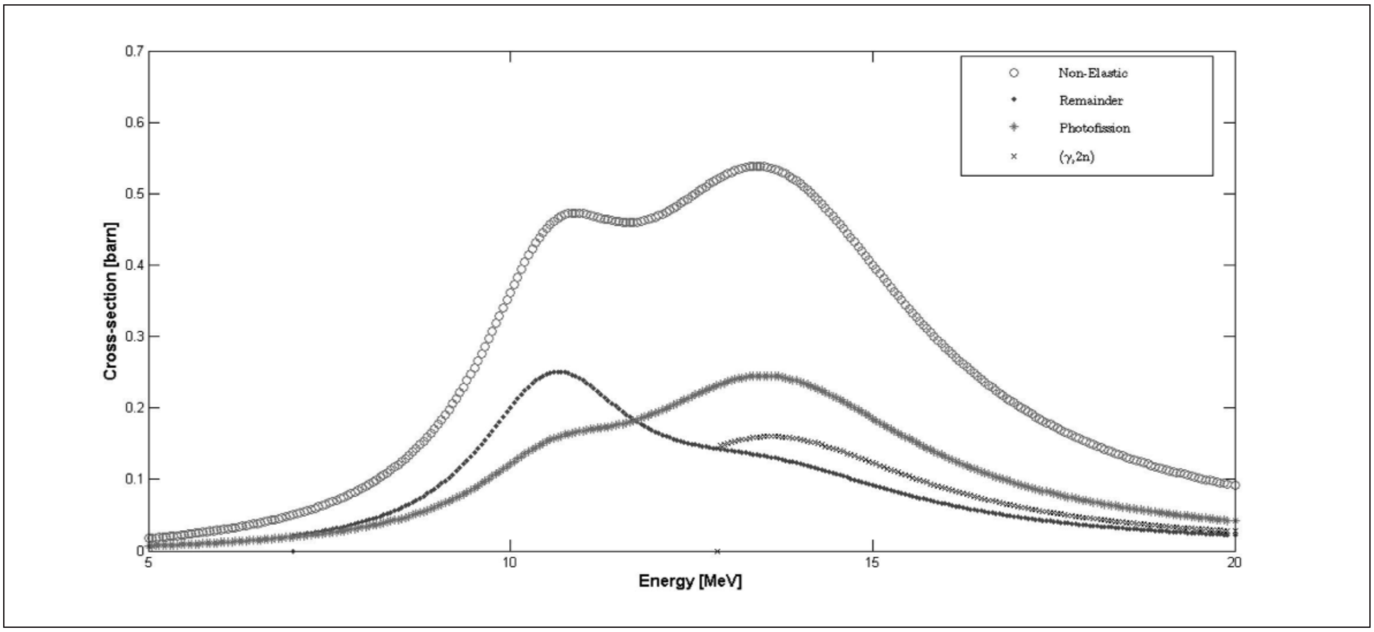


Figure 2f. Photonuclear cross-section for Pb-207. Data taken from the IAEA-TECDOC-1178[7]

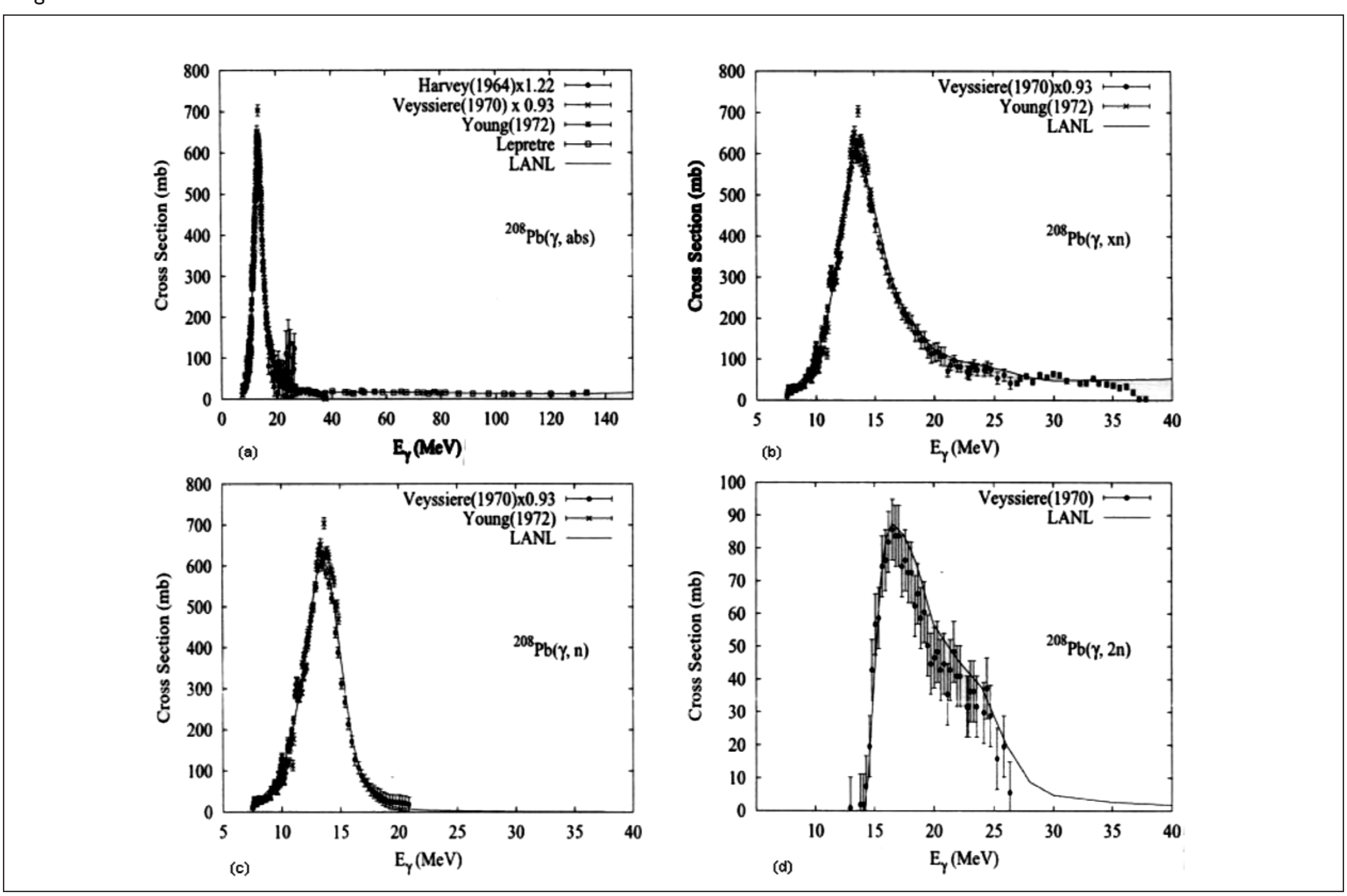


Table 1. Excerpt from MCNPX printout

nps	ipt	ntyn	mtp	zaid	ncl	tme	xxx	yyy	zzz	wgt
164	1	1	16	92238	1	0.02	-4.06	-0.72	0.6	1
164	1	1	16	92238	1	0.02	-4.06	-0.72	0.6	1
251	1	1	18	92238	1	0.032	-1.27	-2.15	3.16	1
251	1	1	16	92238	1	0.032	-1.27	-2.15	3.16	1

Table 2. Meaning of MCNPX variables

nps	number of source particle
ipt	type of particle
ntyn	type of reaction
mtp	reaction code
zaid	target nucleus identifier
ncl	problem number of the cell
tme	time of the particle emission
xxx	x-coordinate of the particle position
yyy	y-coordinate of the particle position
zzz	z-coordinate of the particle position
wgt	particle weight

Table 3. Excerpt from MCNPX output file

photon	tracks	weight (per source particle)	energy loss (per source particle)	photon	tracks	weight (per source particle)	energy creation (per source particle)
source	200000000	1.0000E+00	1.5000E+01	escape	58030464	2.9122E-01	2.1510E-01
photonuclear	0	0.	0.	photonuclear abs	4165795	2.0829E-02	3.0905E-01

10 cm from the center of the sphere. The simulation processed 200,000,000 source histories which resulted in roughly 0.007 photofission events per source history.

Table 1 shows an excerpt from the MCNPX printout. The columns in Table 1 represent MCNPX variables. Their meaning is given in Table 2. History number 251 shows that two secondary neutrons from two photonuclear interactions are produced as a result of a photonuclear event. In particular, a fission neutron (mtp = 18) is emitted together with a (γ,2n) neutron (mtp = 16). This is clearly a nonphysical representation of the photonuclear process.

Table 3 shows an excerpt of the photon creation summary table from the MCNPX output file. As can be seen, 0 photons were created as a result of photonuclear events on U-238. In fact, the Bofod libraries, which are the only ones to have information on the elements thorium, uranium, and plutonium, do not contain any data on secondary photon production by photonuclear events. This is clearly a limitation when the application that is being modeled relies on the detection of both neutrons and photons.

Modification of Monte Carlo Codes

We have customized MCNPX 2.4.0[9] and MCNP-PoliMi[8] to simulate the required physics. The calculation methodology is split into three steps as follows:

1. The modified MCNPX code is used to transport the interrogating photons throughout the problem geometry. It determines the type and position of photonuclear interactions that occur within the system being modeled. This information is saved to an output file.
2. MCNP-PoliMi reads the file created in the previous step, and transports the secondary photons and neutrons, regarding them as new sources. In our application, the interactions occurring in each of two detectors are stored, together with the arrival time at the detector, in an external file.
3. A post-processor reads the file generated in the previous step, and calculates and plots the time-correlation of the signals from the two detectors.

The customized MCNPX version simulates only the beam-on data acquisition. The photo-fission yield is dealt with as follows. The average number of neutrons is read out of the Bofod01u library. No distinction is made between the prompt and the delayed neutrons average. This value is used to calculate the neutron multiplicity by Terrel's formula.[12]

No information is provided about the photon yield in the Bofod01u library. The average number of photons is calculated by a Valentine's formula[13] whose validity we extend to the case at hand. The photon multiplicity is sampled from a negative binomial distribution as indicated in Reference 13, the same way as the photon multiplicity is obtained for neutron-induced fission.

No delayed neutrons are generated at this time. This is work-in-progress for the next release.

Delayed photons are optionally generated at the user's discretion. If this option is chosen, a delay is sampled from a distribution adjusted to the delayed gamma rays emitted by ^{252}Cf spontaneous fission. The photon energy is sampled independently from the emission delay. The same rules apply to the delayed photons from neutron-induced fission. Gamma rays can be emitted together with neutrons during the evaporation stage of the reaction and even during the pre-equilibrium stage, before evaporation, and before fission.[14] Currently, the description of prompt gamma spectra (as well as neutron spectra) for any of the investigated actinides, makes use of the distribution valid for neutron-induced ^{235}U fission. This choice is justified by the similarity of photon emission spectra at energy values greater than 0.7 MeV. Photons in this energy range contribute the greatest amount to the total detected signal, as they are less likely to be captured.

Replacement of the photofission gamma yield with the neutron-induced fission yield is justified by the fact that once the scission of the target nucleus has taken place, the deexcitation channels of the daughter fragments lose memory about the fission type. Modeling the unknown photofission yield through the known neutron-induced fission yield has been done in the past by M. B. Chadwik and W. B. Wilson at Los Alamos National Laboratory who deal with photonuclear reactions and transmutation of long-lived nuclear waste in high photon fluxes. The same hypothesis turned out to be reasonably sustainable in a study comparing the yield from photofission and thermal neutron-induced fission of plutonium isotopes.[15] The same study also shows that the spectra of plutonium and uranium isotopes are similar. For this reason, in our implementation the missing data for ^{238}U is obtained by interpolating the prompt photon multiplicities and spectra for ^{235}U and ^{239}Pu measured by Verbinsky, Weber, and Sund.[16]

For the photonuclear interactions (γ,n) and (γ,2n), an energy balance is applied to determine the total energy available for the deexcitation gamma rays that accompany the neutron emission. The photonuclear neutron and gamma ray yield is dealt with as follows:

- If photon emission data are available for the material where the reaction has taken place then this information is used. If only the Q-value is available, then some photons are generated with isotropic direction in such a way as to fulfill the energy balance. The number of photons that are emitted is input as an adjustable parameter by the user.
- Neutron multiplicities and spectra for actinides are read out of the Bofod01u library.

Prototype Testing

In order to test the efficiency and accuracy of the proposed interrogation system, it has been applied to the real problem of detecting nuclear material concealed in packages. The scenario consists of a luggage belt conveyor lying on a concrete stand. In the concrete a cavity with a 10 cm radius has been designed to accommodate a photon source placed 50 cm below the belt plane.

The photon beam is collimated to a conical shape in such a way as to irradiate one piece of luggage at a time. The beam cone size is ~76.2 cm in the x-y plane. On each side of the belt, in correspondence to the beam cone, are two scintillation detectors, each having dimensions 100 by 100 by 8 cm, which collect the signal from the package. The two detectors, which are sensitive to both neutrons and photons, are 228 cm apart. The goal is to detect the presence of nuclear material, if any, inside the luggage.

In order to account for a large number of possible scenarios, forty-six different cases stemming from different combinations of sizes of the problem geometry components and different materials in the target are being examined and simulated. In this paper the results for a subset of our survey is presented.

The package sizes considered so far are: small (43 x 40 x 18 cm) and large (76 x 76 x 76 cm). The package is made up of Celotex and can contain a 5 or 10 kg highly enriched uranium sphere. To test the discriminating capability of our system against high-Z material versus nuclear material, the respective volumes of the 5 kg and 10 kg uranium spheres were kept constant and the uranium was replaced with iron or with lead. Finally, the largest lead sphere that could be fit in the small package (33.6 kg lead) has been chosen. Analogously, the large package with a 100 kg lead sphere was also simulated.

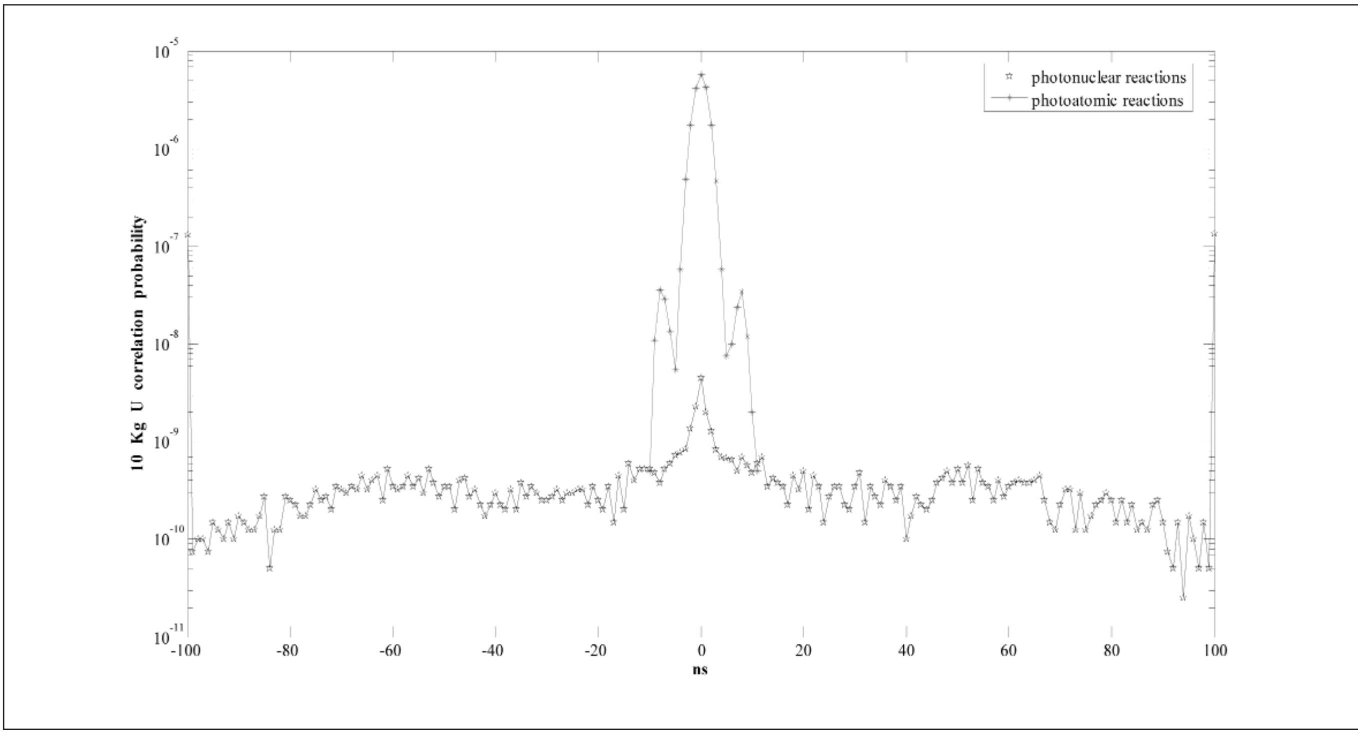
The results for the belt conveyor project presented in this paper were obtained by averaging twenty-one simulations run with the modified MCNPX code, each transporting 2 x 10^9 particles for each system configuration investigated.

Analysis of Results

Figures 3 and 4 show the separate contributions to the detector-detector correlation function of the photonuclear and photoatomic reactions from our simulations. The figures show the result for the large package with a 10 kg uranium sphere inside and without any sphere inside. It can be seen that the amplitude of the photoatomic signal, which is significant only in the range –10 to +10 ns, is roughly the same for all material samples, whereas the intensity of the correlation signal at higher delays, which is due to neutron production, scales with the mass with which the source photons interact. The photoatomic signal for various materials exhibits a sharp cusp around time t = 0 due to time-coupled γ-γ detection, and also shows two symmetrical side peaks due to Compton scattering between the two detectors. The two symmetric wings in the photonuclear portion of the signature are due to the contribution of neutrons.

Drawing on our analysis, the full-width-at-50,000_th-Max

Figure 3. Contribution of the photo-nuclear and photo-atomic reactions for the 10 kg uranium sphere inside the large Celotex package



of the γ-γ correlation function has been calculated for the two package sizes. The results, shown in figures 5 and 6, confirm that this feature stands out as a possible key for material detection.

Conclusion

Active measurement techniques that use gamma rays in the giant dipole resonance energy range have the potential of discriminating concealed actinides from other elements. The proposed technique could be used to analyze cargo containers. The design and analysis of such measurement systems require the use of Monte Carlo codes to simulate the photon interactions with the container. In this paper, we describe the modifications applied to the MCNP-X and MCNP-PoliMi code to simulate photonuclear interactions on an event-by-event basis. While approximations were made when data were missing, the proposed approach allows the user to simulate the statistics of the neutron and photon field generated by photonuclear events with greater accuracy than by using existing codes.

The paper also presented the application of the modified codes to a luggage-belt conveyor scenario. Our preliminary results show that identification of fissile material is possible by analyzing the photonuclear prompt radiation. Our proposed investigation system has been validated through the analysis of a real scenario. It has been shown that the prompt photon-photon correlation function contains information that can be used to identify the presence of actinides in shielded packages.

A proposed further enhancement to the MCNP-PoliMi code to include the emission of delayed radiation from photonuclear events will complete the treatment and allow the code to be used to simulate measurements with the beam off. It is possible that the measurements with the beam off will turn out to be more sensitive to the presence of fissile material, or that they work better in certain scenarios.

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Figure 4. Contribution of the photo-nuclear and photo-atomic reactions when no sphere is inside the Celotex large package

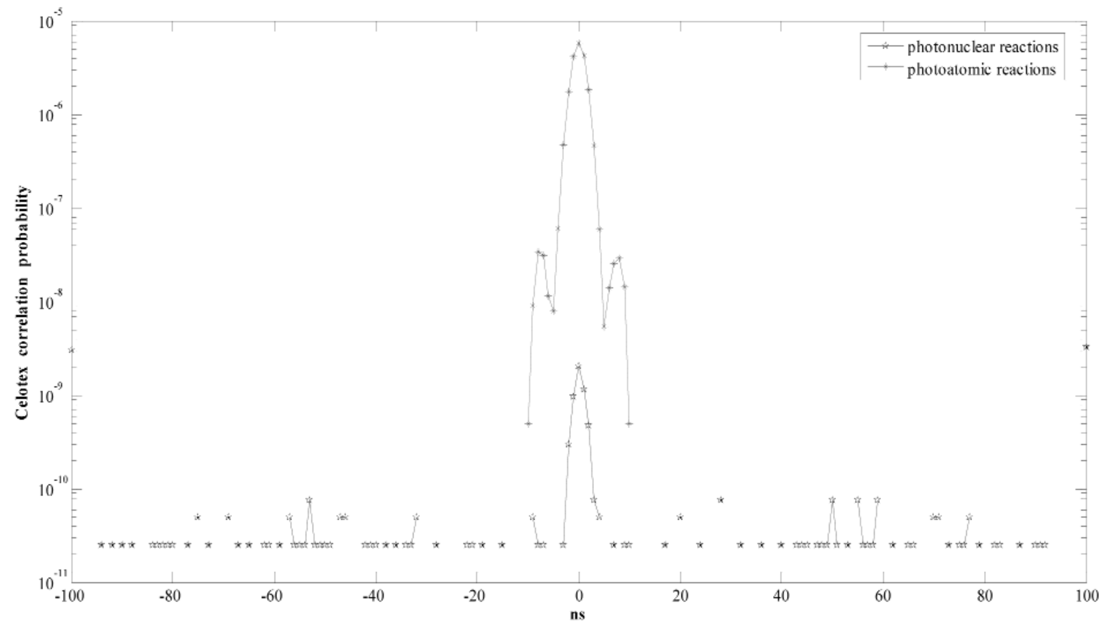

Figure 5. Full width at 1/50,000 maximum of the γ-γ cross-correlation function for the materials investigated and the small package

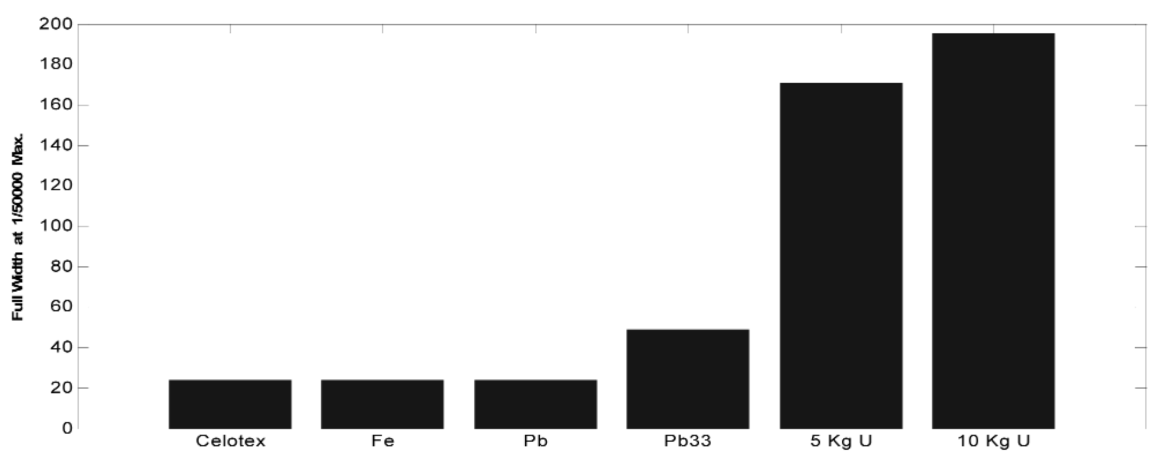

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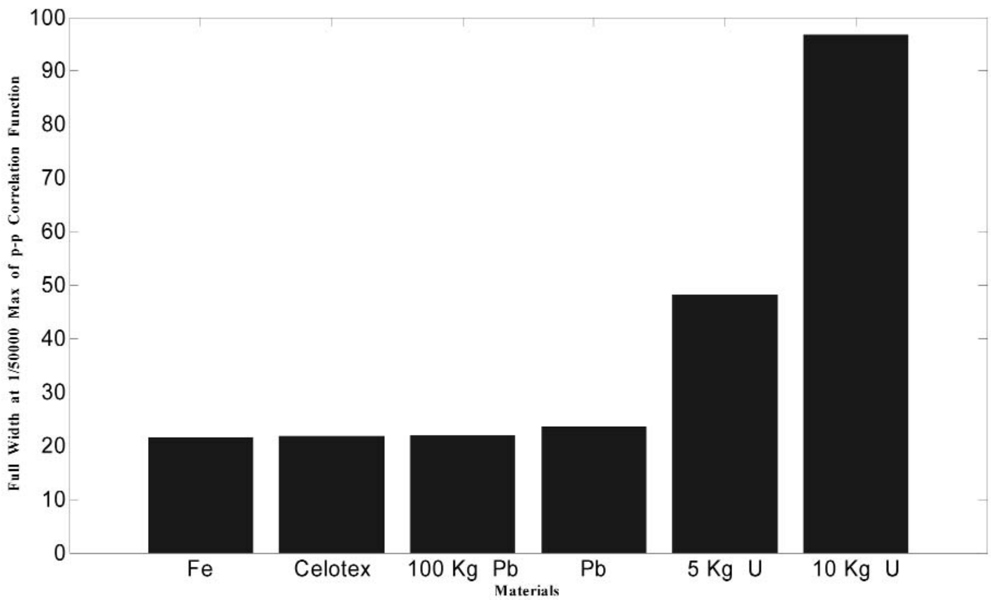
Figure 6. Full width at 1/50,000 maximum of the γ-γ cross-correlation function for the materials investigated and the large package



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A Concise Algorithm for Determining Sample Sizes for Inspections

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Abstract

A model to determine multi-level sample size distributions necessary to achieve certain detection goals is presented here. The model deals with both random and systematic errors and allows a flexible rejection limit. In particular, when binomial approximation is used, the solutions for the sample sizes to achieve a stipulated detection probability goal are expressed in a closed, analytical form. The results obtained are compared with those obtained with the existing method used in international safeguards.

Introduction

Inspection procedures involving the sampling of items in a population to determine their quality often require increasingly sensitive measurements, with correspondingly smaller sample sizes; these are referred to as *multi-level* sampling schemes. To verify that there has been no diversion of special nuclear material (SNM) for international safeguards inspections, these procedures have been examined (see references 1, 2, and 3) and increasingly complex algorithms have been developed to implement them (see references 4 and 5). More recently, Reference 6 gives an overview of various formulations of data verifications—including variable sampling, attribute sampling and variable sampling in attribute mode. Reference 7 provides a game-theoretical treatment to the problem. However, it recognizes that in general cases when measurement errors are considered, the solution becomes intractable analytically.

Our aim is to provide an integrated approach, and, in so doing, to describe a systematic, consistent method that proceeds logically from level to level with increasing accuracy using variable sampling in attribute mode.[1] The purpose is to provide an algorithm to allow the inspector to determine sample sizes to meet the inspection goal and, at the same time, with minimum sizes for higher-level measurement in order to save inspection resources. We emphasize that the methods discussed are generally consistent with those presented in the above references, and yield comparable results when the error models are the same. However, this paper addresses both systematic and random errors in measuring instruments, expanding the existing capability in Reference 1, where only the random error was modeled.

In an inspection, it is important to detect with a certain probability if a certain amount of material has been diverted from the total population. Such a diversion could be accomplished by diverting from a small number of items (when a large fraction of each of the diverted items is missing) or diverting from a large number of items (when a small fraction of each of the diverted items is missing). Several instruments with different capabilities to detect different levels of defect in each item may be available for the inspection and it is assumed that the number of items selected for the more capable instruments should be minimized in order for the inspection to be more cost-effective. The problem is then to decide an optimum number of items that should be sampled with each instrument in order to achieve the inspection goal.

Here, we outline a step-by-step procedure for such a multi-level sampling scheme in order to achieve the inspection goal and we develop the relationships between the accuracy of measurement and the sample size required at the various levels. The logic of the underlying procedures is carefully elucidated; the calculations involved and their implications are clearly described, and the process is put in a form that allows systematic generalization.

To facilitate presentation of the methodology, the paper will be limited to the case of over-statement, when the actual mass of an item is less than declared, and discussion will be limited to three levels of sampling and measurement. We describe the basic mathematical model underlying the methodology; present the derivation of a sample size algorithm for random errors and systematic errors, with a few examples provided for each. Finally, our conclusions are summarized.

Basic Equations

Notations

The notation is as follows:

- x: amount of nuclear material in an item, in kg
- N: total number of items in the population
- G: detection goal or significant quantity, in kg, of nuclear material
- M: $[G/x] = M$, is the least number of defective items when the total defect is one detection goal quantity.
- $[y]$: the least integer not smaller than y
- γ: defect fraction, i.e., the fractional amount of material diverted in an item

m: number of defective items when the total defect is G, m= [G/γx]. For this study, m=mk=M+$_k$ where k=0,1,2,…,N-M, with the corresponding γ_k=G/(x(M+k)).
[Note: m=m_k for $\gamma_k \leq \gamma < \gamma_{k-1}$ for k=1,2,3,…,N-M, and m=M for $\gamma_0 \leq \gamma \leq 1$]

σ_i: relative standard deviation of the measurement to detect the i-th level defect, i=1 or G (for gross defect measurement), 2 or P (partial), and 3 or B (bias) when three levels of defects are considered. In general, it is the standard deviation of the difference between the operator's and the inspector measurement, but, to simplify the following discussions, the *operator's* measurement error is considered negligible.

n_i: number of items sampled for the i-th level measurement

r: rejection limit

β_G: 1-β_G is the overall detection goal

β_{si}: 1-β_{si} is the probability of including a defective item in the n_i samples randomly selected.

β_i: 1-β_i is the probability of detecting a defect in a level i measurement when the sample size for that level is n_i.

$F_i(j)$: $F_i(j)$ is the probability that none of the defective items are detected by the inspector's measurement when there are j defective items in the sample when i-th level measurement method is used.

Basic Model

Suppose that n items are sampled for measurement. The probability of not including any defect in the sample, i.e., the non-sampling probability is

$$\beta_s = \prod_{j=1}^{m}\left(1 - \frac{n}{N-j+1}\right), \tag{1}$$

where the subscripts i for n_i and m_i have been dropped temporarily. We note that, by symmetry, n and m can be exchanged. In addition,

$$\beta_s \leq \left(1 - \frac{n}{N}\right)^m \tag{2}$$

thus, setting

$$\frac{n}{N} = 1 - \beta_G^{\frac{1}{m}}, \tag{3}$$

where 1 - β_G is a "detection goal" (probability $\beta s \leq$ of detection of a defect), then βs β_G.

In other words, when n items are sampled according to Equation 3, the probability of including at least one defective item in the sample is not smaller than the stipulated detection goal, 1 - β_G. The total sample size for n_T, is obtained by assuming the diverter diverts the minimum number of items necessary (m=M)

$$\frac{n_T}{N} = 1 - \beta_G^{\frac{1}{M}} \tag{4}$$

The sample size n_T would be the largest sample size necessary for any diversion if the instrument used for inspections is able to detect the defect when a defective item is sampled.

To determine the overall detection capability, the capability of the inspector's measurement also must be considered. A defect is "detected" when the measured amount of an item is smaller than the declared value by a "rejection limit." The rejection limit is usually set at some multiple, r, of the standard deviation σ of the measurement used in order to control the false alarm rates. (Typically, when r=3, the false alarm rate is 0.135 percent.) In other words, when an item with a declared content of x is measured by an inspector with an instrument whose standard deviation is σ, then, if the measured amount is less than (1-rσ)x, the item is classified as a defect, subject to further examination.

If $F_i(j)$ is the probability that none of the defective items are detected by the inspector's measurement when there are j defective items in the sample, then the overall non-detection probability β satisfies

$$\beta = \sum_{j=0}^{n} \frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}} F(j) = \sum_{j=0}^{n} H(N,m,n,j)F(j) \tag{5}$$

This is the basic relation that underlies further considerations, and shows how both the combinatorial and measurement characteristics play a role in the detection process. Equation 5 (and all similar equations throughout the remainder of this paper) should be considered for m=m_i=M+i with the corresponding γ=γ_i=G/x(M+i) for i=0,1,2,…, N-M. H(N,m,n,j) denotes the hypergeometric distribution for the probability of including j defective items in the n samples selected when the population is N and the total number of defective items is m.

When a fraction γ of the material of an item has been diverted, the probability that the item is classified as a defect when it is measured with an instrument with standard deviation σ is

$$\Phi\left(\frac{\gamma - r\sigma}{(1-\gamma)\sigma}\right) \tag{6}$$

where Φ(z) denotes the value of the cumulative normal distribution[1] at z,

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-\frac{u^2}{2}} du. \tag{7}$$

Therefore, the probability that a sampled defective item will not be so classified is

$$F(1) = 1 - \Phi\left(\frac{\gamma - r\sigma}{(1-\gamma)\sigma}\right) = 1 - \Phi\ , \tag{8}$$

where Φ is the probability that a defect will be identified when it is sampled for measurement. Combining both sampling and measurement probabilities, the overall non-detection probability for a defect of m items is now

$$\beta = \sum_{j=0}^{n} \frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}} F(j) = \beta_s + \sum_{j=1}^{n} \frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}} F(j)$$
$$\le \beta_s + F(1)\sum_{j=1}^{n} \frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}} = \beta_s + (1-\beta_s)F(1) \tag{9}$$

since it is clear that F(1) ≥ F(j) for j ≥ 1. If there are several (more than one) defective items in the sample, the measurement non-detection probability will clearly be less than or equal to

$$F(1) = 1 - \Phi\ ,$$

the non-detection probability when there is only one defective item in the sample.

The overall detection probability then satisfies

$$1-\beta \ge (1-\beta_s)(1-F(1)) = (1-\beta_s)\Phi\left(\frac{\gamma - r\sigma}{(1-\gamma)\sigma}\right). \tag{10}$$

If the expression Equation 4 is used for the sample size n, the detection probability satisfies

$$1-\beta \ge (1-\beta_G)\Phi\left(\frac{\gamma - r\sigma}{(1-\gamma)\sigma}\right). \tag{11}$$

Thus, when the instrument used can detect a defect, so that

$$\Phi\left(\frac{\gamma - r\sigma}{(1-\gamma)\sigma}\right) \tag{12}$$

is very close to 1, the stipulated detection probability goal ($1 - \beta_G$) can be achieved. On the other hand, the diverter may choose to decrease the size of defect in each item in order to evade possible detection. However, in that case, he must increase the number of items diverted to divert the same goal quantity, G. Thus, the probability of including a defect in the sample would increase since Equation 4 was used as the basis of the sample size, but this increase may not be enough to compensate for the decrease in the instrument's detection probability

$$\Phi\left(\frac{\gamma - r\sigma}{(1-\gamma)\sigma}\right).$$

Under these circumstances, as long as this quantity is not smaller than the detection goal ($1 - \beta_G$), the sample sizes can be increased so that

$$(1-\beta_s)\Phi\left(\frac{\gamma - r\sigma}{(1-\gamma)\sigma}\right) \ge 1 - \beta_G\ , \tag{13}$$

or

$$\beta_s \le 1 - \frac{1-\beta_G}{\Phi\left(\frac{\gamma - r\sigma}{(1-\gamma)\sigma}\right)} \tag{14}$$

to achieve the same detection probability goal. Although such a strategy is not currently used in Reference 1, increasing the sample size should be considered if more accurate methods of measurement do not exist or are very difficult to apply during inspections. However, such increases in sample size may not be effective in all situations.

Instead of increasing the sample sizes, more accurate measurement methods could be used to solve the problem. One would then subject parts (n_p) of the total number of samples for better measurement ("partial defect" measurement) and the resulting overall non-detection probability would become

$$\beta = \sum_{j=0}^{n_G} H(N,m,n_G,j)F_1(j)\sum_{k=0}^{n_p} H(N-n_G,m-j,n_p,k)F_2(k). \tag{15}$$

When three levels of instruments are available, the overall non-detection probability becomes

$$\beta = \sum_{j=0}^{n_G} H(N,m,n_G,j)F_1(j)\sum_{k=0}^{n_p} H(N-n_G,m-j,n_p,k)F_2(k)$$
$$\sum_{l=0}^{n_B} H(N-n_G-n_p,m-j-k,n_B,l)F_3(l) \tag{16}$$

Note that n_B is the bias-defect (best instrument) sample size and n_G and n_p, are the partial- and gross-defect sizes, respectively, $n_T=n_G+n_P+n_B$. Equations 5, 15, and 16 provide the fundamental relations between the detection probability, sample sizes and instrument detection capabilities and will serve as the basis for the remainder of this paper. The aim is to find an optimum set of sample sizes that satisfies the detection probability goal for a stipulated diversion.

Random Errors

It is important to distinguish between situations with random errors versus those with systematic errors. For random errors, $F(j)=F(1)^j$; while for systematic errors, $F(j)=F(1)$.

From Equation 5 the non-detection probability β for one-level of inspection is

$$\beta=\sum_{j=0}^{n}\frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}}(1-\Phi)^j \quad .$$

By the properties of the combination symbols, this is also equal to

$$\beta=\sum_{j=0}^{n}\frac{\binom{n}{j}\binom{N-n}{m-j}}{\binom{N}{m}}(1-\Phi)^j \quad . \tag{17}$$

Since

$$\binom{n}{k}=0 \; for \; k>n$$

the sum becomes

$$\beta=\sum_{j=0}^{\min(n,m)}\frac{\binom{n}{j}\binom{N-n}{m-j}}{\binom{N}{m}}(1-\Phi)^j, \tag{18}$$

or

$$\beta=\sum_{j=0}^{\min(n,m)}\frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}}(1-\Phi)^j. \tag{19}$$

The hypergeometric distribution is rather cumbersome to deal with. Applying the usual binomial approximation (which is conservative [i.e., overestimating the non-detection probability] and is a good approximation when m, n « N) so that

$$\frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}}\approx\binom{m}{j}\left(\frac{n}{N}\right)^j\left(\frac{N-n}{N}\right)^{m-j}, \tag{20}$$

we find that, from Equation 18

$$\beta\le\left(1-\frac{n\Phi}{N}\right)^m. \tag{21}$$

Similarly, a rather straightforward manipulation, via repeated application of the mathematics above, yield, for inspections with three-level of sampling and measurement

$$\beta\le\left(1-\frac{\sum_{i=1}^{3}n_i\Phi_i}{N}\right)^m. \tag{22}$$

Here, Φ_i is the detection probability for the level i instrument as in Equation 6 with σ_i for the standard deviation of the level i instrument. This is an important, new result that gives the overall detection probability in closed, analytical form. Although the same binomial approximation was used in earlier models (see references 1 through 4), the results given there were rather complicated and difficult to manipulate.

For a given total sample size (n_T), the required minimum instrument detection probability (Φ) could be easily obtained from Equation 22 by setting the number of defective items to the total number of populations, m=N, and assuming only the best instrument is applied to all the samples

$$\Phi_{\min,r}=\frac{N}{n_T}\left(1-\beta_G^{\frac{1}{N}}\right). \tag{23}$$

The required maximum standard deviation (σ) of the instrument could then be obtained via Equation 8 with $\gamma=G/Nx$.

Assuming that the instruments selected for inspection satisfy the minimum requirement as given in Equation 23, and the total sample size n_T given by Equation 4, the minimum bias defect sample size is obtained analytically by solving for n_B when $n_G=0$:

$$n_B=n_T\left(\frac{\frac{1-\beta_G^{\frac{1}{m}}}{1-\beta_G^{\frac{1}{M}}}-\Phi_P}{\Phi_B-\Phi_P}\right). \tag{24}$$

Additional sets of sampling sizes satisfying the detection probability goal are then obtained by increasing n_B while decreasing n_P and increasing n_G at the same time but maintaining the same total sample size, $n_G+n_P+n_B=n_T$. The minimum partial defect sample size for a given bias defect sample size is obtained from the expression below:

$$n_P = n_T\left(\frac{\dfrac{1-\beta_G^{\frac{1}{m}}}{1-\beta_G^{\frac{1}{M}}}-(1-b)\Phi_G - b\,\Phi_B}{\Phi_P-\Phi_G}\right) \qquad (25)$$

where $b=n_B/n_T$.

In this way, multiple sets of sample sizes are obtained. The optimum set may be selected from them based on considerations including cost, time, and efforts involved for each instrument used in inspections.

If a better approximation for the hypergeometric distribution is desired (e.g., when m or n $\approx$N), the solution obtained as described can be refined via Equation 16 where an appropriate approximation of the hypergeometric distribution, as shown in the Appendix, is used in this study.

A computer code has been developed to calculate the detection probability based on the algorithm described. Extensive comparisons were made with the solutions provided for the cases given in Reference 3.

The detection probability curves for a few cases are presented in figures 1a to 3b. The parameters used to specify each set of curves differ only in the values assigned to the size of the gross (n_G), partial (n_p) and bias (n_B) sample sizes. The first figure in each of the three sets (1a, 2a, and 3a) shows the detection probability achieved using the sample sizes computed by the new algorithm. (In the figures, AvgWt is the weight of each item, GQ is the goal quantity and BetaG is β_G.) The second figure (1b, 2b, 3b, etc.) shows the distribution achieved when the sample sizes are assigned according to Reference 3. (In most cases, when the defect fraction approaches 1, the detection probability approaches the detection probability goal as it is limited by the total sample sizes based on Equation 4.)

A comparison of figures 1a and 1b shows that, although both sets of sample sizes attain the goal, Reference 3 substantially overshoots the target, i.e., the detection probability is above the goal. While either solution acceptably achieves the sampling goal, the new solution maintains a conservative sampling while reducing the overall expense associated with the process by biasing sample collection toward the less costly methods.

Figures 2a and 2b exhibit the same behavior seen in the previous example, namely the size of the bias sample has been restricted at the expense of the less costly methods while maintaining a conservative solution.

Figures 3a and 3b indicate a bias sample size Equation 3 from Reference 3 that is less than that determined by the new algorithm Equation 4. The larger value appears to suggest that the new method fails to sufficiently restrict the value of the bias sample size. On further inspection of figures 3a and 3b, however, it is apparent that Reference 3 fails to satisfy the goal but the new solution does for defect fractions near 0.05 so that the sample sizes determined via the algorithm presented has a smaller number of bias samples and is conservative.

Systematic Errors

For systematic errors, F(j)=F(1), and thus, from equations 5 and 9

$$\beta = \sum_{j=0}^{n}\frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}}F(j) = \beta_s + F(1)\sum_{j=1}^{n}\frac{\binom{m}{j}\binom{N-m}{n-j}}{\binom{N}{n}} = \qquad (26)$$

$$= \beta_s + (1-\beta_s)F(1) = 1-\Phi(1-\beta_s)$$

With binomial approximation for βs,

$$\beta \le 1-\Phi+\Phi\left(1-\frac{n}{N}\right)^m . \qquad (27)$$

Similarly, after rather laborious but straightforward algebraic manipulations, the overall non-detection probability for an inspection with three levels of sampling and measurement becomes

$$\beta \le \beta_{s,m} + \sum_{i=1}^{3}(1-\Phi_i)\left(\left[1-\frac{\sum_{j\neq i} n_j}{N}\right]^m - \beta_{s,m}\right)$$
$$+\sum_{i=1}^{3}\left(\prod_{j\neq i}(1-\Phi_j)\right)\left(\left(1-\frac{n_i}{N}\right)^m - \sum_{j\neq i}\left(1-\frac{n_i+n_j}{N}\right)^m + \beta_{s,m}\right)$$
$$+\left(\prod_{i=1}^{3}(1-\Phi_i)\right)\left[1-\sum_{i=1}^{3}\left(1-\frac{n_i}{N}\right)^m + \sum_{j\neq i}^{3}\sum_{j>i}^{3}\left(1-\frac{n_i+n_j}{N}\right)^m - \beta_{s,m}\right] \qquad (28)$$

where

$$\beta_{s,m} = \left(1-\frac{n_T}{N}\right)^m .$$

Figure 1a. Detection probability for the diversion of one goal quantity

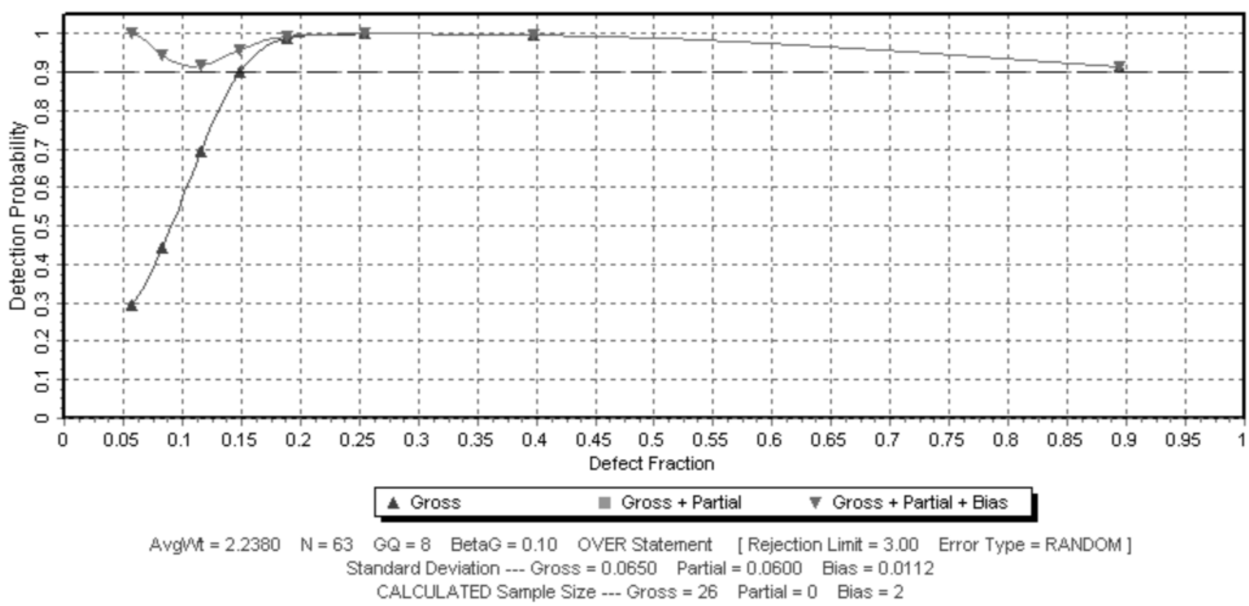
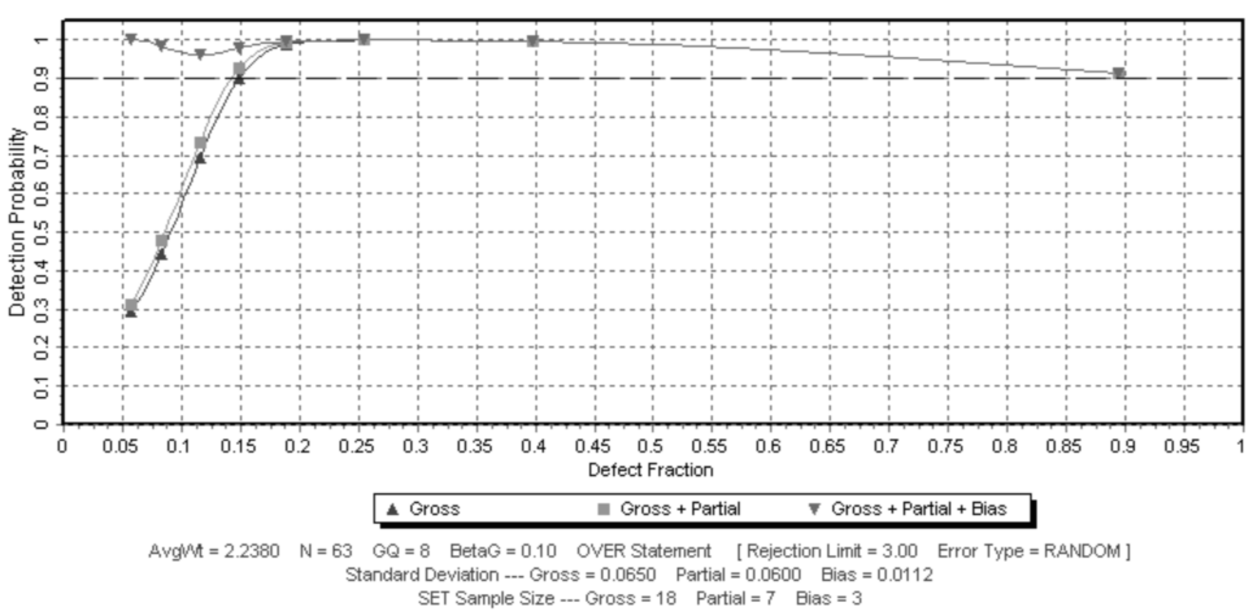


Figure 1b. Detection probability for the diversion of one goal quantity



Similar to the cases when the error is random, the required minimum instrument detection probability (Φ) could be obtained via equations 27 or 28 by setting the number of defective items to the total number of the population, m=N and assuming only the best instrument is applied to all the samples

$$\Phi_{\min,s} \ge \frac{1-\beta_G}{1-\left(1-\frac{n}{N}\right)^N} \qquad (29)$$

The required maximum standard deviation (σ) of the instrument could then be obtained via Equation 8 with γ=G/Nx.

Assuming that the instruments selected for inspection satisfy the minimum detection probability requirement as given in Equation 29, one can then proceed to obtain other sets of possible solutions via Equation 28. Unlike the cases when the error is random, the solutions cannot be given in closed form. However, they can be obtained readily, e.g., via the use of a spreadsheet.

If a better approximation for the hypergeometric distribution is desired (e.g., when m or n ≈ N), the solution obtained as described can be refined via Equation 16 where an appropriate approximation of the hypergeometric distribution may be used as in the case when the error is random.

The existing method for determining the sample sizes as described in Reference 3 is exclusively based on the assumption that the error is random and the rejection limit is 3. When the error is systematic, the existing method is not applicable. The algorithm developed was tested for a few sets and the answers compared with Reference 3.

The detection probability curves for a few cases are presented via figures 4a through 6b. The first figure in each of the sets (4a, 5a, and 6a) shows the detection probability achieved using the sample sizes computed by the new algorithm using the systematic error method. The second (4b, 5b, and 6b) show the detection probability achieved using sample sizes obtained in Reference 3 when the error is random. These figures clearly show that the sampling strategies produced using sample sizes obtained assuming that the error is random (when systematic should have been chosen) are non-conservative.

Conclusions

A new algorithm has been developed to determine sample sizes when two to three levels of measurement methods are available. Results are compared with an existing method when the error is random and the rejection limit is 3. In all cases that we analyzed, the new code produces sample sizes that meet the detection probability goal. In our extensive tests, the new code allows the use of fewer bias-defect measurements and is better at achieving the detection probability goals when compared to results produced by the existing method given the same parameters.

In addition, the new algorithm allows the use of flexible rejection limits and handles the case where error is systematic; the existing method allows only one fixed rejection limit and models only random error. In situations where the error type is systematic the existing method used in references 1, 2, and 3 has been shown to yield sample sizes which are non-conservative and would fail to satisfy the stipulated detection probability goals. The ability of the new code to reliably model flexible rejection limits and systematic error could assist in the development of effective inspection strategies that may be more representative of situations inspectors actually encounter.

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Figure 2a. Detection probability for the diversion of one goal quantity

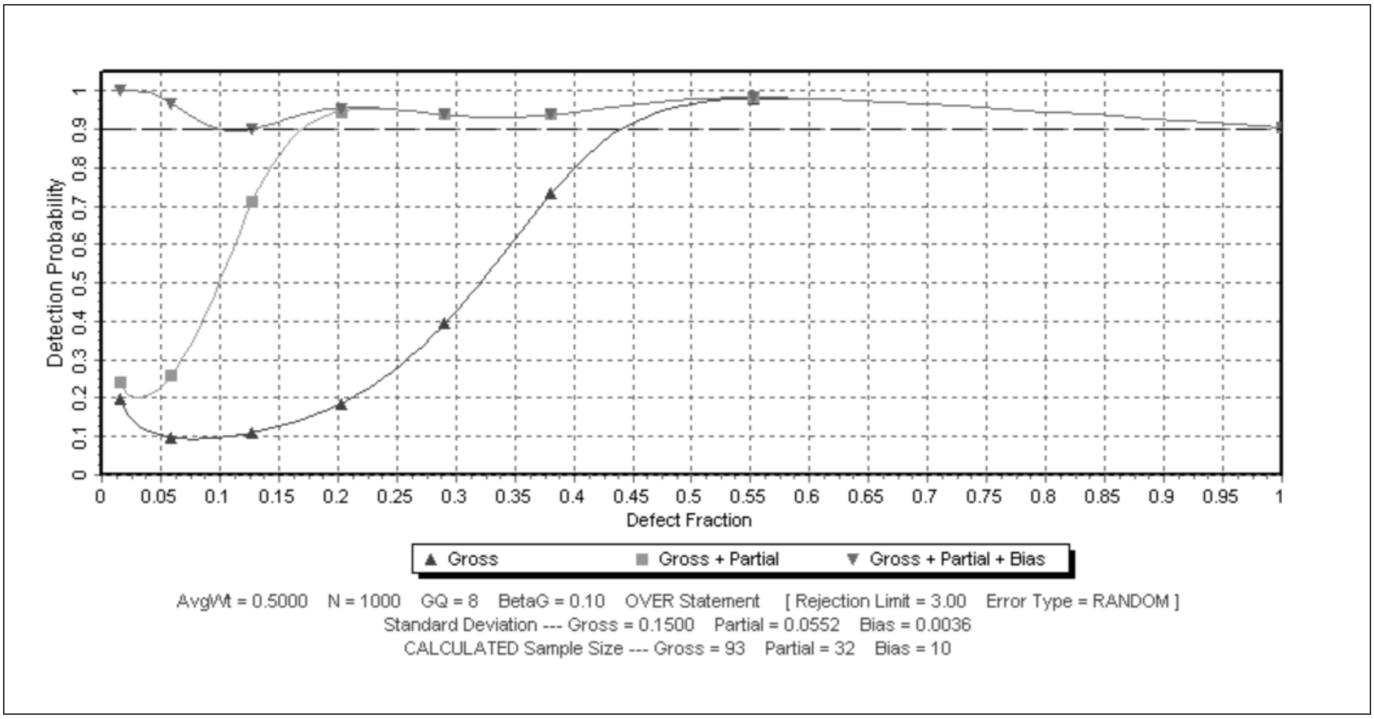


Figure 2b. Detection probability for the diversion of one goal quantity

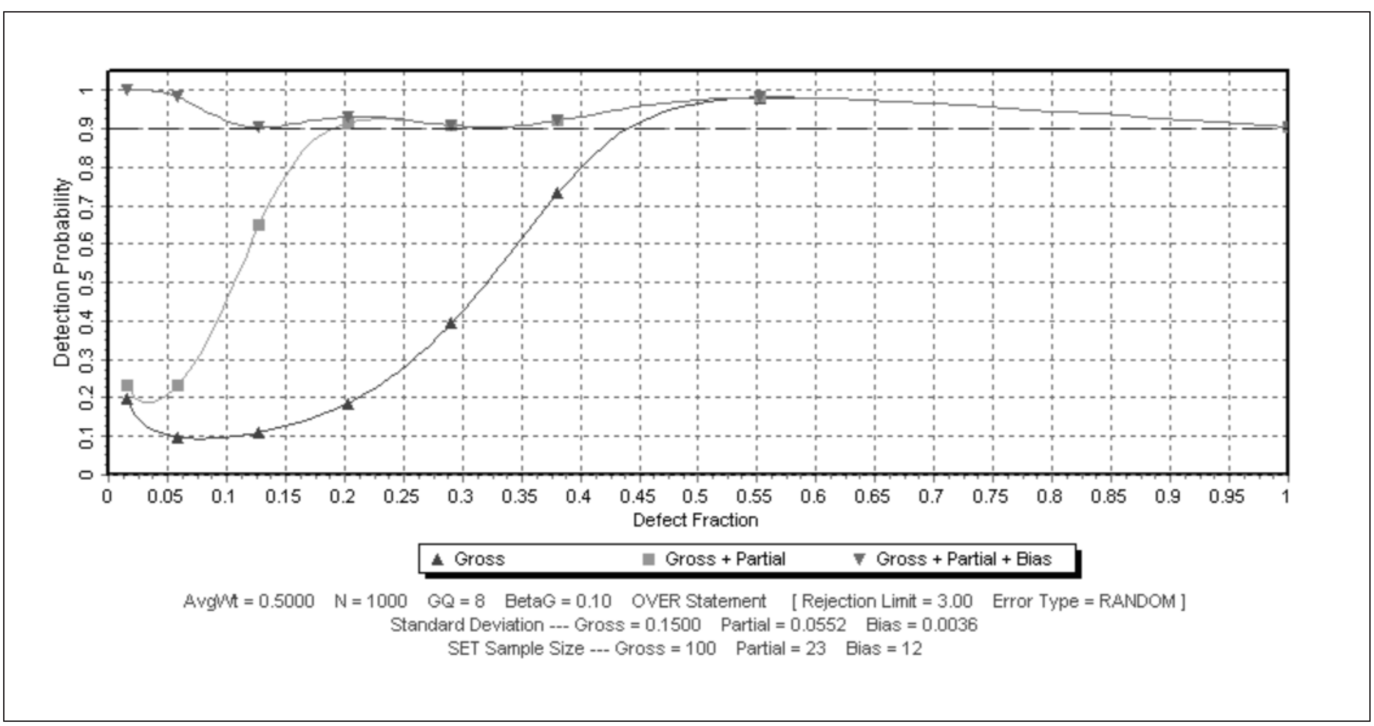


Figure 3a. Detection probability for the diversion of one goal quantity

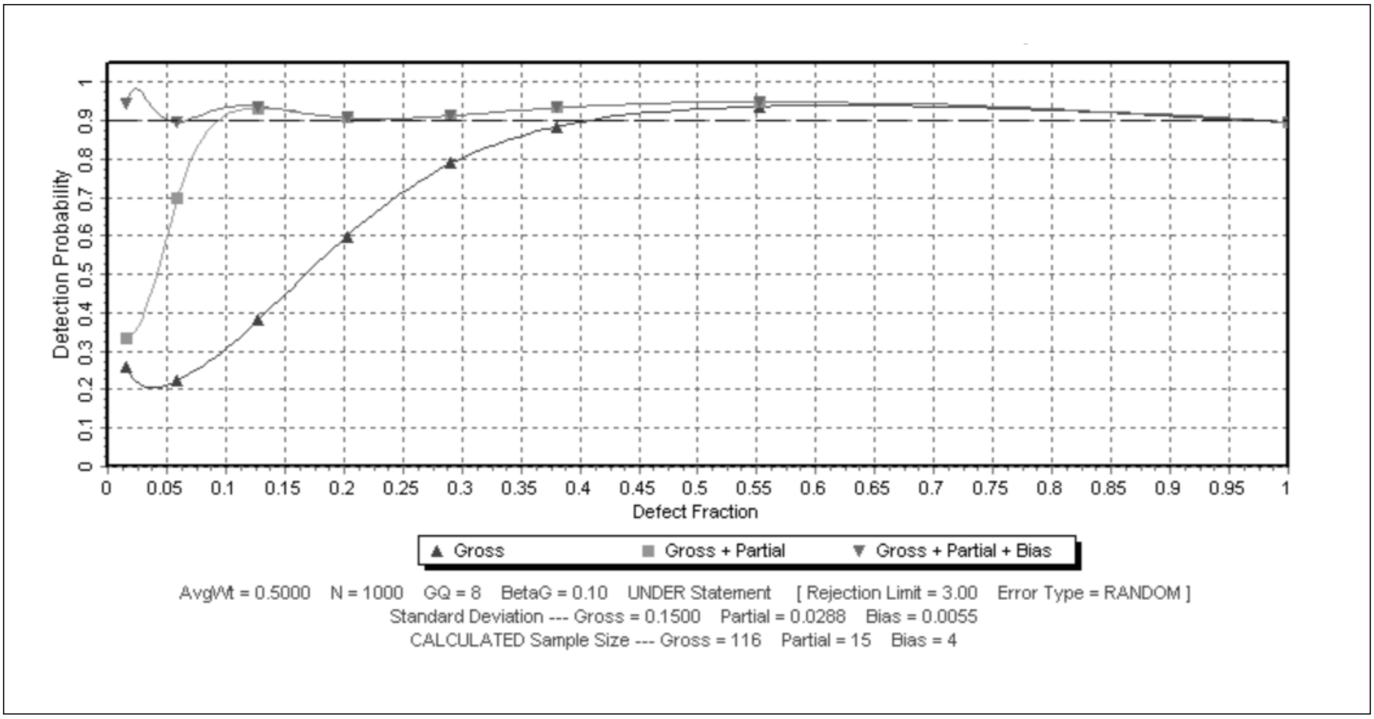


Figure 3b. Detection probability for the diversion of one goal quantity

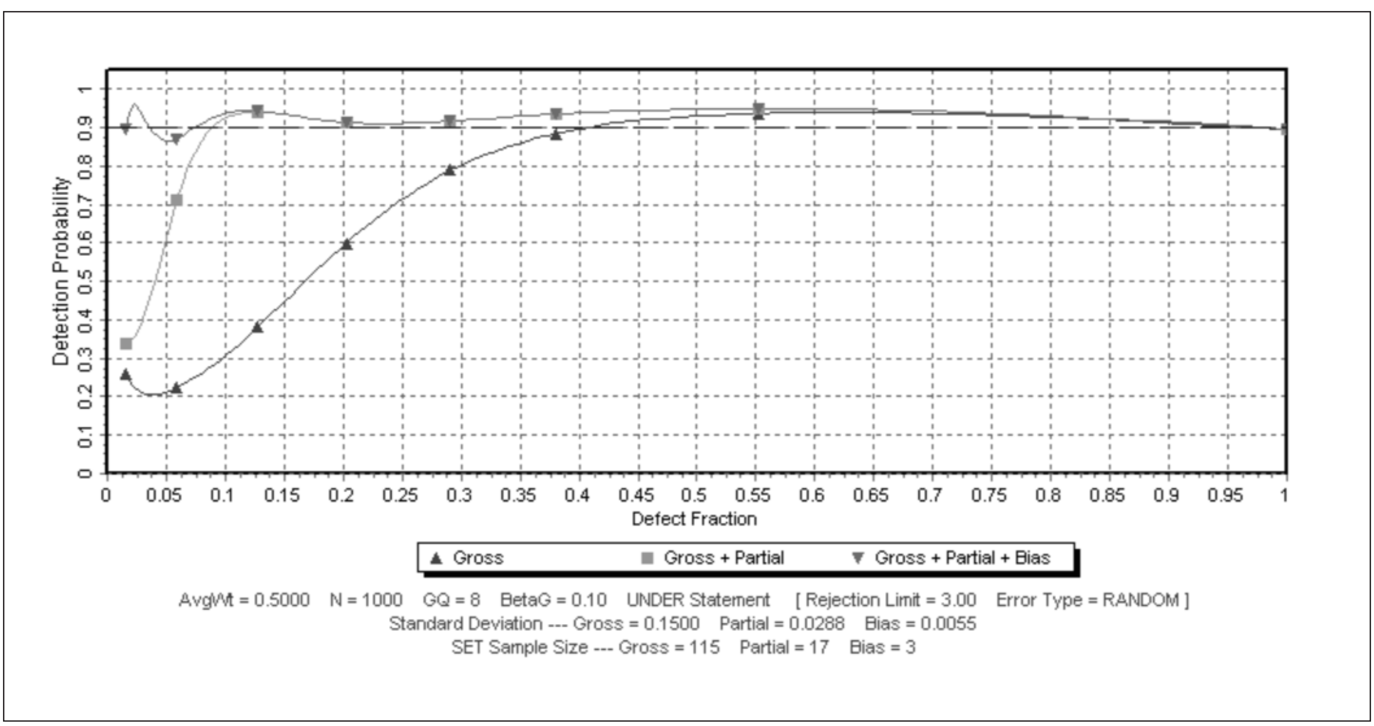


Figure 4a. Detection probability for the diversion of one goal quantity

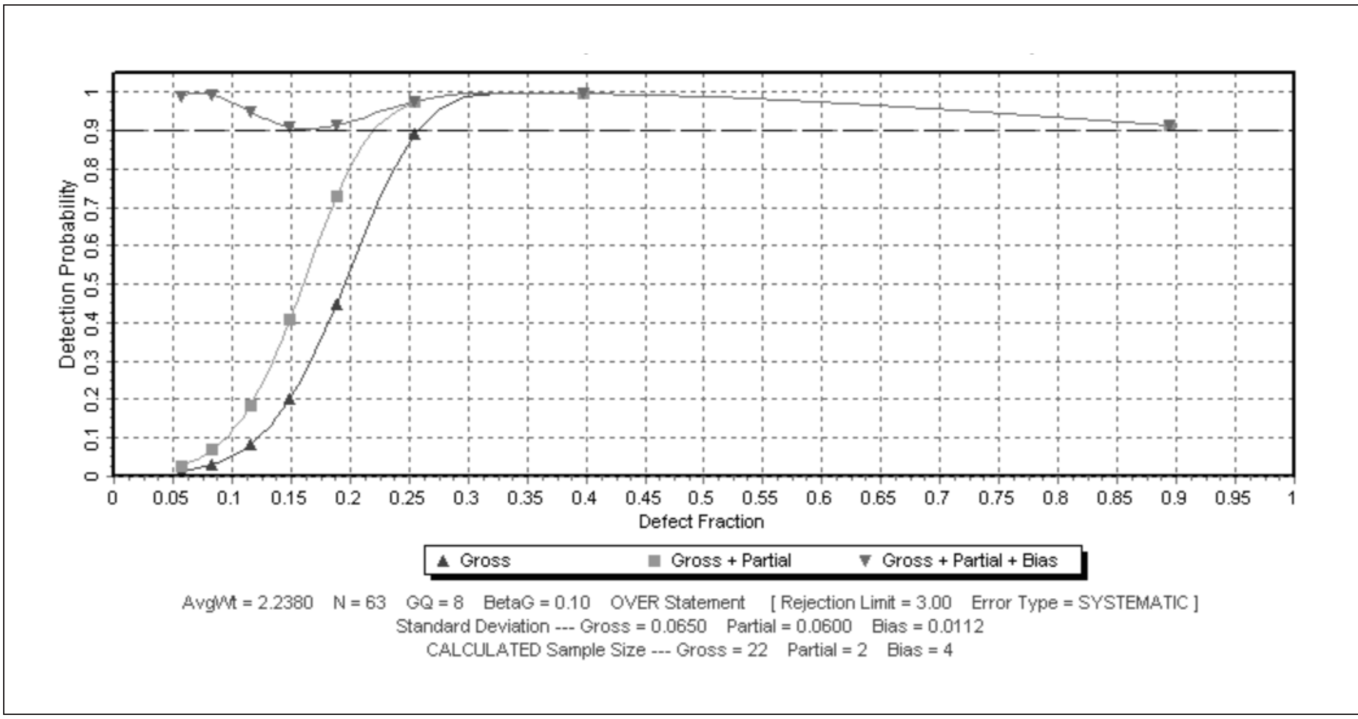


Figure 4b. Detection probability for the diversion of one goal quantity

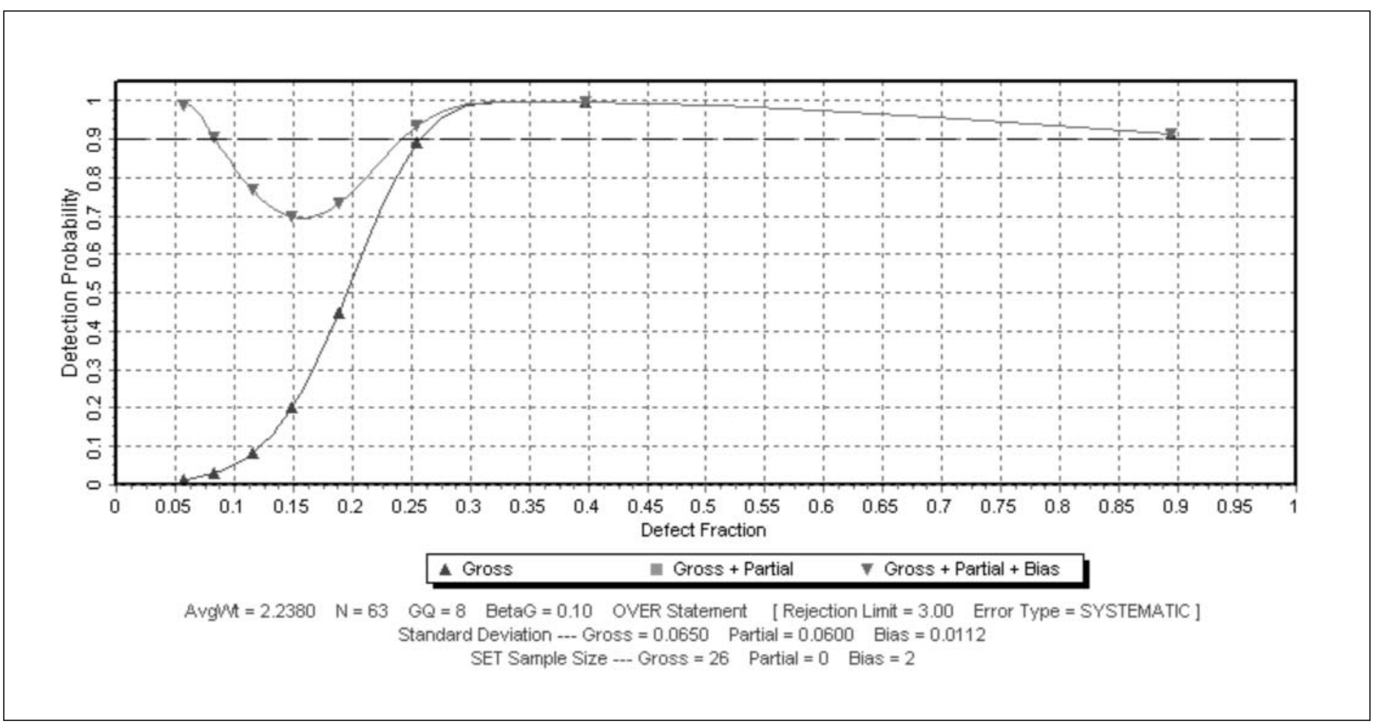


Figure 5a. Detection probability for the diversion of one goal quantity

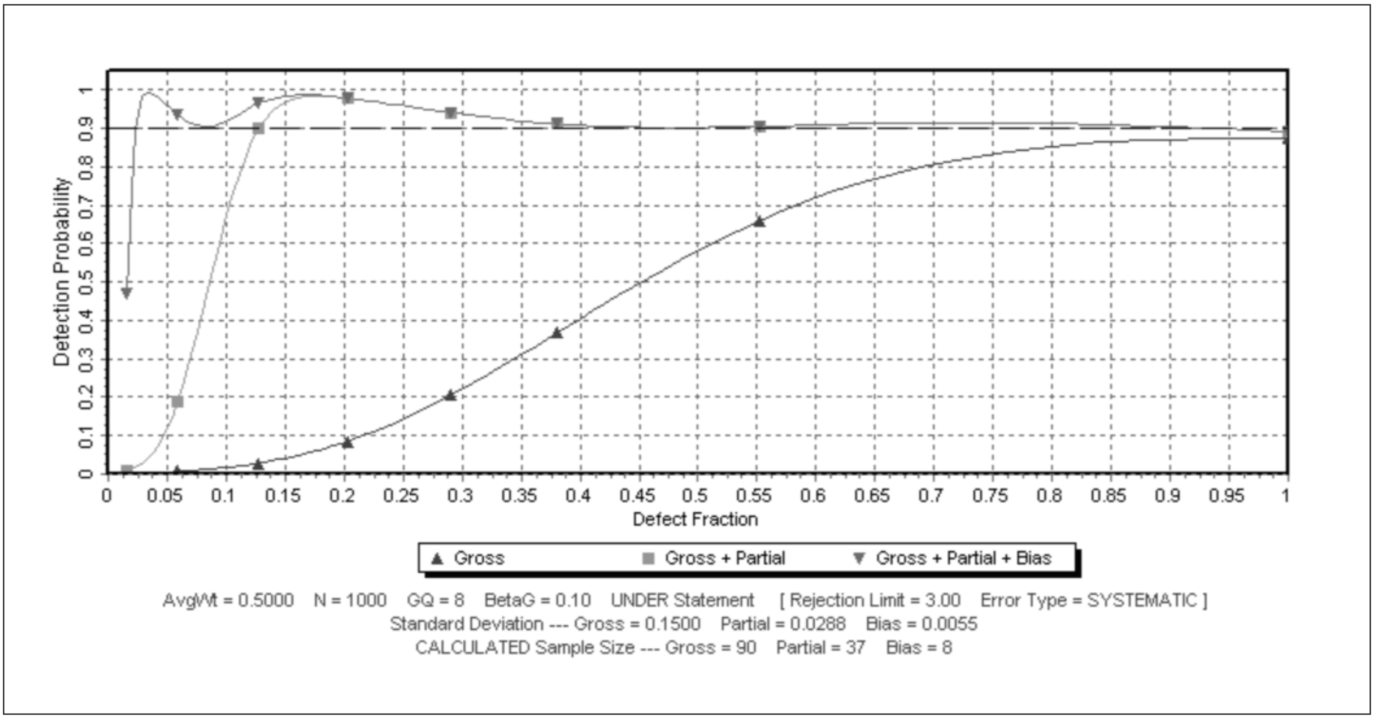


Figure 5b. Detection probability for the diversion of one goal quantity

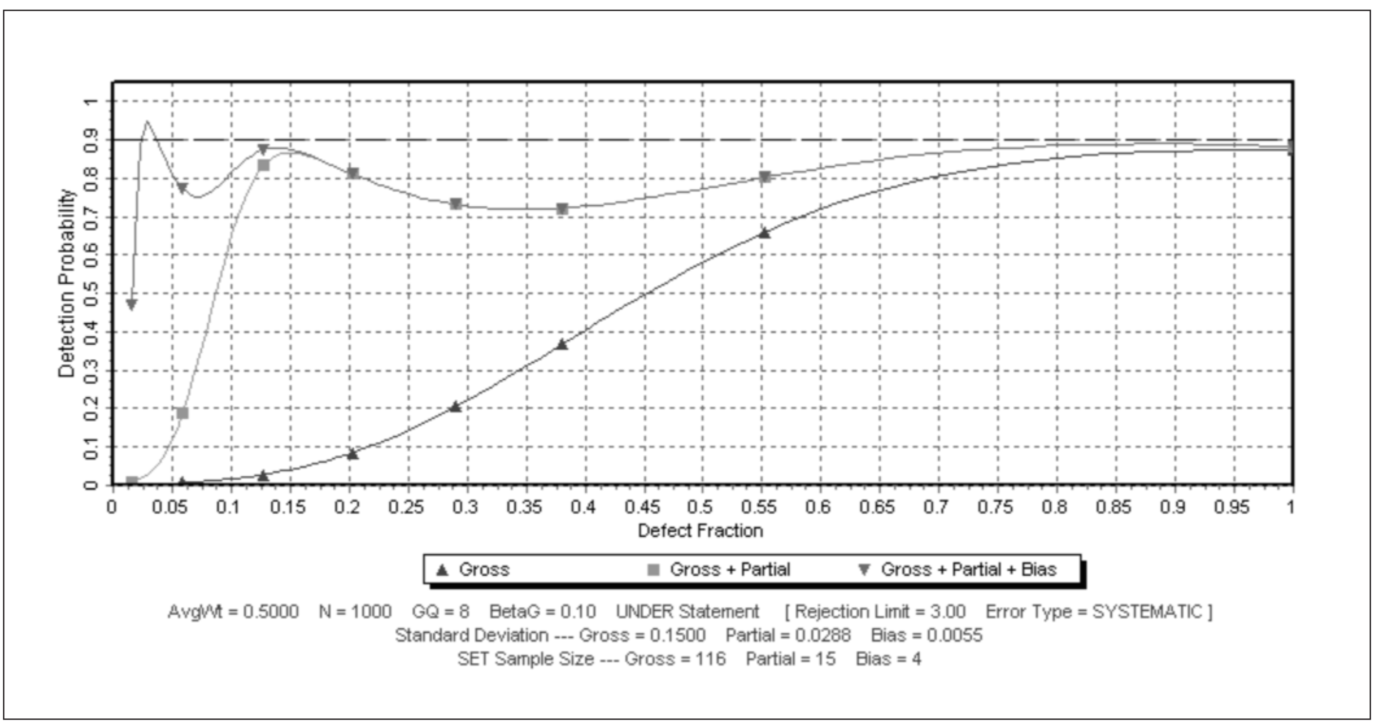


Figure 6a. Detection probability for the diversion of one goal quantity

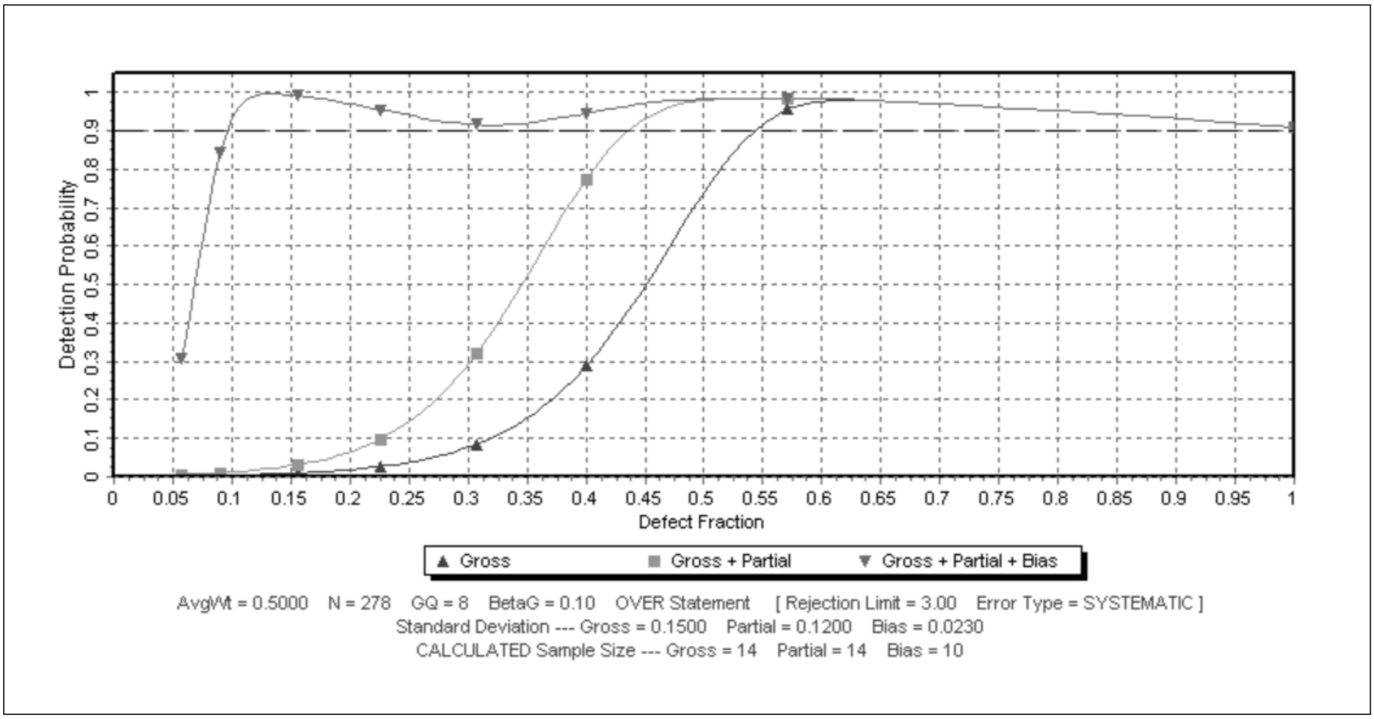
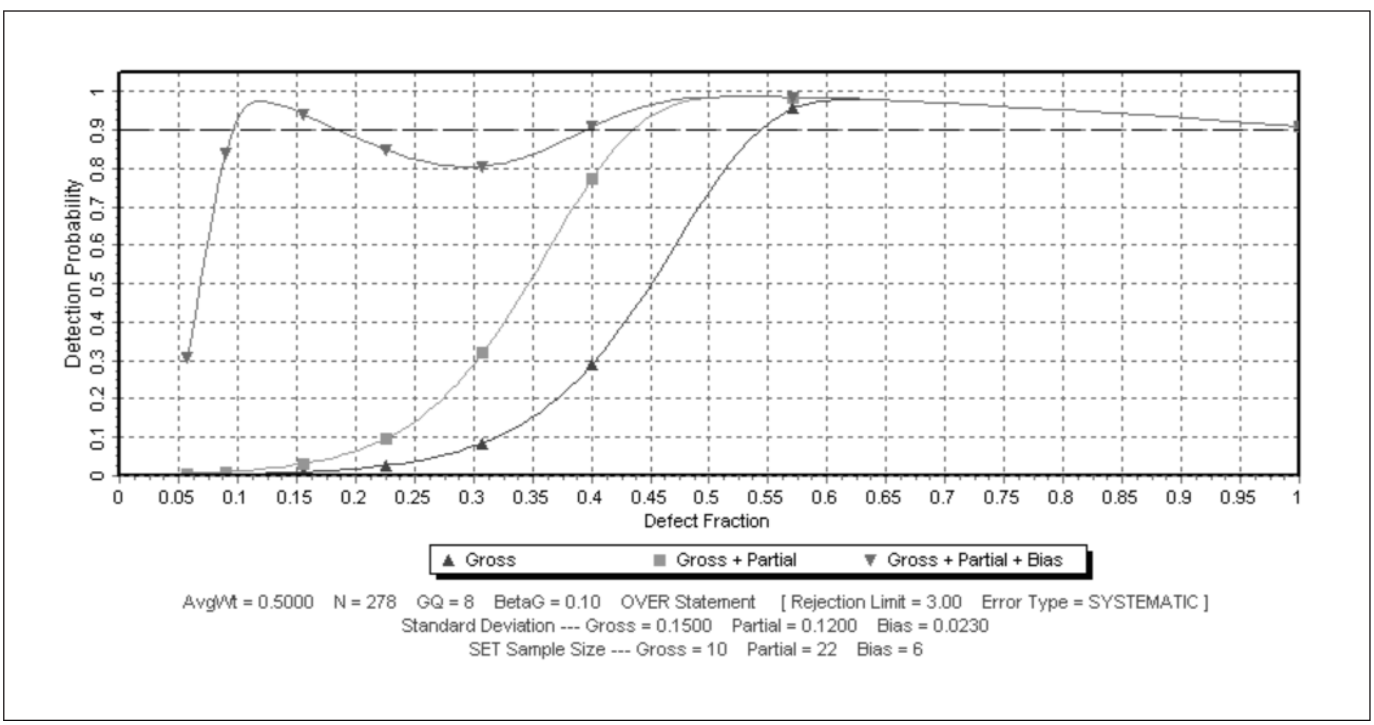


Figure 6b. Detection probability for the diversion of one goal quantity



Final Transuranic Waste Shipment Leaves Rocky Flats

In July, the final remaining shipment of radioactive, transuranic (TRU) waste left the Rocky Flats Site in Golden, Colorado, on a truck bound for an underground waste repository at the U.S. Department of Energy's (DOE) Waste Isolation Pilot Project (WIPP) in Carlsbad, New Mexico. This milestone is a step toward the final conversion of the site to a national wildlife refuge managed by the U.S. Fish and Wildlife Service.

During the Cold War, components for nuclear weapons were made at the Rocky Flats site using radioactive and hazardous materials including plutonium, uranium, and beryllium. In fact, every U.S. nuclear weapon in the field today has a part or component that was produced at the Rocky Flats facility.

When operations ceased in the early 1990s, large amounts of radioactive waste and other hazardous materials, such as the TRU removed in July, remained behind. The materials shipped today consist of disposable items contaminated with radioactivity, such as clothing, tools, and rags generated during nuclear production and deactivation.

Since cleanup began ten years ago, workers have faced tremendous challenges in the removal of more than twelve metric tons of plutonium, the demolition of hundreds of aging and contaminated buildings, and the disposal of tons of radioactive and hazardous waste materials. The project, despite initial estimates predicting a cost of $37 billion over sixty years, is on track to be completed a year earlier than planned, at the end of 2005, at a total cost of about $7 billion.

Two U.S. University Research Reactors to be Converted From HEU to LEU

The U.S. Department of Energy (DOE) has begun to convert research reactors from using highly enriched uranium (HEU) to low-enriched uranium fuel (LEU) at the University of Florida and Texas A&M University.

This effort, by DOE's National Nuclear Security Administration (NNSA) and the Office of Nuclear Energy, Science, and Technology, are the latest steps under the Global Threat Reduction Initiative's Reduced Enrichment for Research and Test Reactors program. As part of this program, NNSA is minimizing the use of HEU in civilian nuclear programs by converting research reactors and radioisotope production processes to the use of LEU fuel and targets.

The Global Threat Reduction Initiative, announced in May 2004, aims to identify, secure, remove, and/or facilitate the disposition of high-risk, vulnerable nuclear and other radiological materials and equipment that pose a threat to the international community.

DOE has targeted twenty-five research reactors in the United States for conversion, and of those, eleven have already been converted to the use of LEU fuel. The planned completion date for the conversions of the University of Florida and Texas A&M University reactors is in late 2006. DOE's goal is to complete all remaining conversions by 2014.

DOE Announces Preferred Alternatives For Moab, Utah, Uranium Mill Tailings

The U.S. Department of Energy (DOE) has announced the department's preferred alternatives for remediation of the Moab, Utah, Uranium Mill Tailings Remedial Action Project site: active groundwater remediation, and offsite disposal of the tailings pile and other contaminated materials to the proposed Crescent Junction disposal site.

These preferred alternatives will be included in the DOE Final Environmental Impact Statement (EIS). The DOE had not identified a preferred alternative in its draft Environmental Impact Statement on the remediation of the Moab, Utah, Uranium Mill Tailings Remedial Action Project.

The preferred alternatives do not indicate that the department has reached a final decision on remediation of the Moab site. The DOE continues to review comments it has received from the public on the site.

A final EIS on the Moab, Utah, Uranium Mill Tailings site and the remediation of the site is in preparation, and the final department Record of Decision will be issued following the release of the final EIS for the Moab site.

Honduras Becomes 100th Country to Sign Additional Protocol

The Republic of Honduras became the 100th state to sign an Additional Protocol to a safeguards agreement with the International Atomic Energy Agency (IAEA). Additional protocols strengthen the Agency's safeguards system by giving IAEA inspectors greater rights of access to information about a country's nuclear program and to nuclear sites. They also grant inspectors added authority to use advanced technologies to track that nuclear materials are not being diverted, and that there are no clandestine, proscribed nuclear activities in a state.

IAEA Director General Mohamed ElBaradei has referred to additional protocols as *a sine non qua* for effective verification and invited all states to conclude additional protocols. Similar calls have been made by the UN General Assembly, the Nonproliferation Treaty state parties, and the IAEA General Conference. Additional protocols grant the IAEA complementary inspection authority to that provided in underlying safeguards agreements, typically concluded pursuant to provisions of the global Nonproliferation Treaty. This authority facilitates the IAEA's task to verify that all nuclear material in the country has been declared and remains in peaceful nuclear activities. Last year the IAEA was able to draw this broader conclusion for nineteen states, as outlined in the 2004 Safeguards Statement.

The Model for Additional Protocols was agreed in 1997. For the past few years the IAEA and several member states have been encouraging countries to conclude safeguards agreements and Additional Protocols, primarily through consultations, information seminars and training.

G8 Leaders Endorse IAEA's Work for Nuclear Safety, Security, Safeguards

Leaders of the Group of 8 leading industrialized countries (G8) reaffirmed their full support of the International Atomic Energy Agency (IAEA) at their annual summit in July in Gleneagles, Scotland. In a six-page statement, the G8 endorsed IAEA efforts in the fields of nuclear nonproliferation and measures to improve the security of radioactive sources worldwide.

G8 countries include Canada, France, Germany, Italy, Japan, the Russian Federation, United Kingdom, and the United States. The European Union also participates in the summit.

The G8 pledged to redouble efforts to uphold and strengthen the Nonproliferation Treaty (NPT), declaring it remained the cornerstone of nuclear nonproliferation. The IAEA is the verification authority of the NPT, inspecting nuclear and related facilities under safeguards agreements with more than 140 countries. The G8 endorsed IAEA safeguards as "an essential tool for the effective implementation of the NPT."

G8 nations welcomed the continued cooperation with the IAEA in the area of nuclear and radiological safety and security, including the effort to strengthen regulatory infrastructures. It urged countries to sign the Joint Convention on the Safety of Spent Fuel Management and Safety of Radioactive Waste Management.

The G8 nations pledged to strengthen cooperation to improve the security of radioactive sources globally. They welcomed the fact that more than seventy countries had committed to implement the IAEA Code of Conduct on the Safety and Security of Radioactive Sources.

States Agree on Stronger Physical Protection Regime

Delegates from eighty-nine countries agreed in July to fundamental changes that will substantially strengthen the Convention on the Physical Protection of Nuclear Material (CPPNM).

The amended CPPNM makes it legally binding for state parties to protect nuclear facilities and material in peaceful domestic use, storage, and transport. It will also provide for expanded cooperation between and among states regarding rapid measures to locate and recover stolen or smuggled nuclear material, mitigate any radiological consequences of sabotage, and prevent and combat related offenses. The original CPPNM applied only to nuclear material in international transport.

The new rules will come into effect once they have been ratified by two-thirds of the 112 state parties of the convention, expected to take several years.

The IAEA's Nuclear Security Fund, set up after the events of 9/11, has delivered $19.5 million in practical assistance to 121 countries since 2001. Under this program fund, countries have been aided in carrying out the tasks that are called for under the amended CPPNM, such as helping states identify their vulnerabilities, training their staff, and carrying out physical protection work.

The IAEA will also actively assist member states in their efforts to ratify and implement the obligations under the CPPNM.

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