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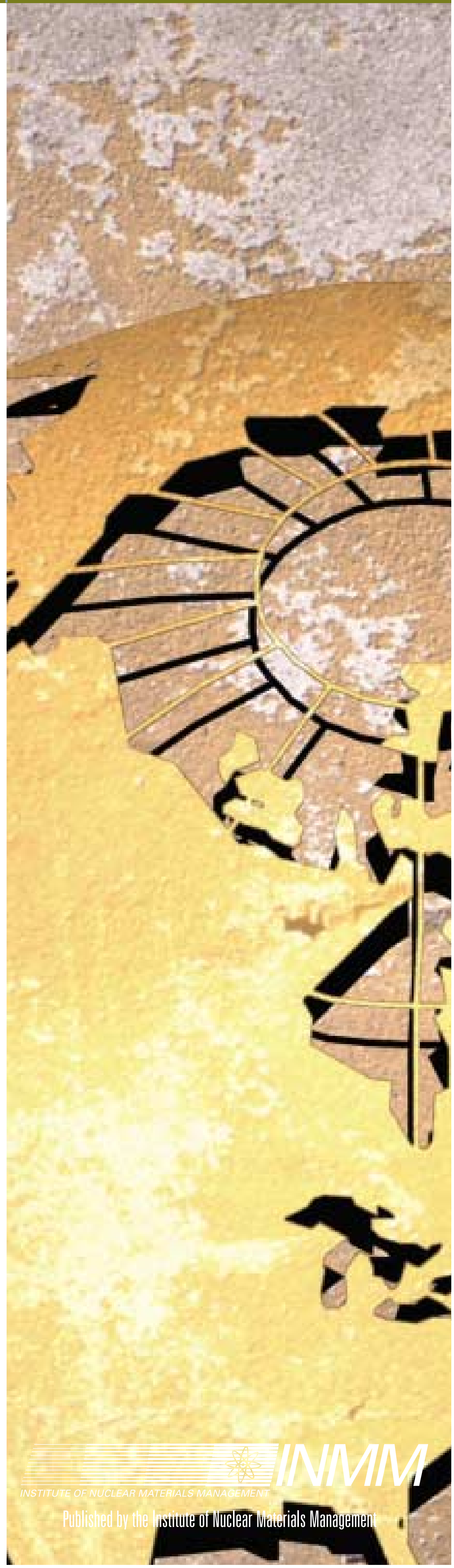

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JNMM Journal of Nuclear Materials Management

Fall 2004, Volume XXXIII, No. 1

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INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Taking a Look Back, Taking a Look Ahead

By Cathy Key
INMM President

On October 1, 2004, I feel honored to have begun my two-year term as the president of the Institute of Nuclear Material Management (INMM). I think back eight years ago as I became involved with the Executive Committee as the Communications Committee chair and realize the road to the position I am in today has been very fulfilling both personally and professionally.

Before I go any further I would like to recognize our previous president, John Matter. John has worked very hard during his presidential tenure and our professional society has benefited greatly from his contribution. One of the key areas John worked has been the student activities. As we have seen in the past ten years our industry continues to suffer from what has been termed *brain drain.* It has become a priority worldwide to make an effort to bring young people into the nuclear field. Under John's direction the INMM initiated a Student Activities Committee (SAC) in 2003 and John, accompanied by the newly appointed SAC chair, Mark Leek, participated in a career fair at the 2004 ANS Student Conference in April. INMM chapters and technical divisions also put forth an effort to increase student awareness and involvement during the past two years. This year's annual meeting also emphasized student presentations through the J. D. Williams Student Paper Award for best student presentation. Also, this year a student has been awarded the Robert Sorensen Student Award, which assists the student financially for their education. Student activities shall continue to be a priority of the INMM. The INMM's goal is to continue stimulating student interest in the nuclear field, nuclear material management and the INMM with an emphasis on assuring recruitment of young people into our field of employment. I would like to thank John for his contribution in this very important area of concern and promise to continue its thrust in importance.

As I previously mentioned, my involvement with the INMM has been rewarding both on a personal and a professional level. I have had the opportunity to meet and work with many people not only here in the United States but also all over the world. I truly believe this has enabled my career to thrive and grow to the point which would allow me the opportunity to serve in this position. Personally, my involvement with the INMM has provided a wealth of friendship and professional contacts/connections.

As I believe everyone is aware, the people who keep the INMM a viable professional organization are 100 percent volunteers. Everyone from the secretary to the technical division chairs to the chapter officers to the annual meeting registration personnel (and everyone in between) do this work on a purely volunteer basis. The INMM has continually grown stronger. Each year it seems as though there are more and more people willing to get involved and volunteer their efforts—which assures positive continuation of our professional organization.

I wish to thank everyone who has become involved in the INMM over the years and have provided (and continue to provide) unwavering time and effort to keep the INMM on a positive growth path. It is your volunteer work, your efforts, your loyalty that pushes our organization to higher levels.

In the summer of the year 2008, the INMM will host the 50th INMM Annual Meeting. This alone will be a major milestone in the organization's history. I request that all interested people please volunteer their time to assure the INMM's continued success. Take the time and make the effort to become involved and stay involved. This is our professional organization; it is only as good as what we put into it.

In closing I would like to say I feel privileged to serve as the INMM's president and will make every effort to meet or exceed the efforts put forth by my predecessors. I know that this is a tall order to fill but I am honored to have the opportunity to do so.

Thank you to all who have supported my involvement with the INMM through out the past years. And especially, thank you to those who support my future year's service. I am looking forward to a prosperous two year term working with my colleagues.

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

Technical Editor's Note

By Dennis L. Mangan
Technical Editor

Report of the 45th INMM Annual Meeting–Moving Forward to Meet the Challenges

By Charles E. Pietri
Chair, INMM Technical Program Committee

We all encountered some challenges at this year's annual meeting and also in the process leading up to its unveiling at the Renaissance Resort Hotel in Orlando, Florida, July 18 to 22, 2004. First, after six years as INMM's administrative director, then executive director, Rachel Airth resigned as of April 1 (no April Fools' joke, either!) right in the middle of the Technical Program preparation, to do gardening and perhaps pursue some further educational opportunities. However, John Waxman, president of the Sherwood Group, the firm that provides management services for INMM, stepped right in with a most suitable replacement, Leah McCrackin. We worried for a short while how this would impact the annual meeting but the transition was seamless and transparent. With Airth's tutoring and some exposure to the idiosyncrasies of the Technical Program Committee and its activities in the prior month, McCrackin picked up the lead most successfully. Many of you may not be interested in these details but only in the end result—an informative and successful annual meeting. I provide this information because major credit for the annual meeting outcome must be given to our INMM headquarters staff, which diligently works behind the scenes to make it a success. They even enjoy it!

So, that was one challenge we faced and came out smiling. Meeting attendees tell me that this 45th INMM Annual Meeting was highly successful—as in the past—and in some ways even better than most. INMM recognizes that the success of the meeting depends on all of us, the headquarters folks, the Technical Program Committee, opening and closing plenary speakers, 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 and, of course, the session chairs who manage the sessions. In his last meeting appearance as INMM president, and after two years of most commendable performance, John Matter, set the tone for the meeting and was ably supported by Vice President Cathy Key. And how would we ever function without Glenda Ackerman and her well-tuned Registration Committee. (She even recruited John Curts, Yvonne Ferris' husband, who made the mistake of looking for something constructive to do at the meeting.) The INMM staff, including Leah McCrackin, Lyn Maddox (our knowledgeable conference manager), Madhuri Carson, *JNMM* Managing Editor Patricia Sullivan, and the always-cheery Rose Lopez, worked diligently to keep the program rolling and helped to correct the few hotel problems that arose. Knowing all that, and applauding the contributions of our many speakers, we come to our second challenge this year in which forty-three papers were about to be cancelled a day before the meeting and about eighty planned participants of the 848 total meeting attendees were not going to be present. What a shock to realize that our carefully prepared meeting now looked as if termites had eaten large holes in the framework. It appears that because of some institutional matters at one of the national laboratories, employees were required to focus on the issues of concern there and most were not allowed to participate in other work activities such as presentation or attendance at professional activities. So how could this meeting then be called highly successful? Since this is our meeting, other knowledgeable colleagues including some from other laboratories volunteered to present many papers. In fact, of these 43 papers in potential jeopardy, fifteen were presented by colleagues while Norbert Ensslin became the hero of the meeting by presenting eight papers—undoubtedly a record! Other presenters were Chris Pickett, Pam Dawson, Denny Mangan, Hiroshi Hoida, Darryl Jackson, James Tape and Carlos Rael. (My sincere apology if I missed anyone who contributed.) We even had one presenter who came at his own expense and vacation time to present his paper. So, carpe diem once again! Our meeting was a hit because you salvaged it (applause, applause).

Our challenges were real this year (unlike the scorpion threat we heard about in Phoenix last year that never materialized). But we think we might have preferred the scorpions to program disruption even though we managed to survive—and well, too.

Despite our crisis, there were 848 total attendees including eighty-four companions. We had 289 papers actually presented including thirteen posters (a total of 360 abstracts were submitted with 35 withdrawals, or a net 325 papers available for presentations), and forty-nine sessions. (For comparison, in 2003 we had 774 total attendees including seventy-six companions, 281 papers including fifteen posters, and forty-three sessions.) This year the net number of papers submitted did not match the ones actually presented because of those Los Alamos papers not presented.

The keynote speaker, Jacques Baute, director of the Iraq Nuclear Verification Office of the International Atomic Energy Agency (IAEA), made a timely presentation, *Challenges and Lessons Learned from Nuclear Inspections in Iraq,* in which he described the IAEA's experience in Iraq over several years and how its activities (as well as those from other organizations) reached a turning point in March 2003 due to impending military operations. The many measures taken by IAEA, both technological and methodological, many even unprecedented, to cope with these challenges were outlined—some provided great success while others gave limited results. Our customary interview at lunch following the opening plenary session was conducted at the INMM Roundtable by *JNMM* Technical Editor, Dennis Mangan. It provided some additional thoughts on the global nuclear nonproliferation issues currently facing the world. Baute's complete paper will be found on page 9 in the *Journal* and in the *Proceedings of the INMM 45th Annual Meeting.* A transcript of the Roundtable begins on page 14.

Sunday afternoon is a traditional time for the six INMM Technical Divisions to meet and discuss issues 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.

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, in locations that give visibility to the exhibits and an opportunity for the meeting attendees to meet with these exhibitors.

INMM annual meetings are outstanding opportunities to meet colleagues and friends in the nuclear materials management community. The President's Reception on Sunday, July 18, provided such an occasion in an informal manner. (And this year, we were able to provide almost unlimited food and beverages to enhance the gathering—and pacify some hungry travelers.)

Avoiding Disaster: Perception and Reality, our Closing Plenary session, was addressed by Brigadier General Ronald Haeckel, of the National Nuclear Security Administration, Michael Brooks, of CNN; and Mary Alice A. Hayward, a senior policy advisor at the U.S. Department of Energy. Amy Whitworth, chair of the Government-Industry Liaison Committee, orchestrated the session. The speakers explored three different facets of national and global security all with a common linkage. Text of the talks will be found in the *Proceedings of the INMM 45th Annual Meeting* and on page XX.

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 third year of such an initiative and four of the six papers submitted for presentation competed for the J. D. Williams Best Student Paper Award. (Most unfortunately, another two students, Angela Thornton and Rohun Gholkar, both from LANL, were unable to make their presentations and participate in the competition but their papers will be published in the addendum to the *Proceedings*.) Many of our colleagues are responsible for making this student initiative a success: Yvonne Ferris, Nancy Jo Nicholas, Mark Leek, and about fifteen others too numerous to name. The winning paper was presented by Brandon O'Donnell, who received his master's degree in nuclear engineering this spring from the University of Michigan. His paper, which was his master's thesis, Calculating External Doses from Partial Loss of Lead Shielding in a Spent Fuel Cask, discussed original research. O'Donnell worked this past summer as an intern at Sandia National Laboratories in New Mexico. In addition to an award plaque, he will receive $1,000 and his paper is published in this issue of *JNMM* on page 29. Two other University of New Mexico student interns at Sandia, Jenny Tobin and Heidi Smartt, presented papers orally. Lalit Savalia, an engineering student at the University of Nevada in Las Vegas, participated in the poster session and submitted a paper for evaluation in the competition on spent fuel storage technologies. Both Tobin and Savalia were sponsored by INMM's Southwest Chapter. All four students will have their papers published in the *Proceedings of the INMM 45th Annual Meeting.* We encourage our membership to promote student activities through INMM. A prime purpose of the student paper award is to encourage younger professionals to opt for a career in nuclear materials management and to become members of INMM. Look for more information on students in the fall issue of the *INMM Communicator.*

Scott Vance, INMM's staunch chair of the Membership Committee, gleefully informs us that the Executive and Membership committees of INMM once again held a most successful New Member/ Senior Member Reception on Monday, July 19. The reception is an opportunity for the officers of INMM to meet and welcome members who have joined INMM since the last annual meeting as well as to congratulate those members who have been recognized for their contributions to the institute and promoted to the rank of Senior Member. It's an especially attractive combination: young, new members and, hopefully, more experienced folks who have been with INMM for a while. More than 100 individuals attended the reception this year, and were officially welcomed by INMM President John Matter and Vice President Cathy Key. They were also encouraged to make the most of their membership by becoming involved in the many activities of the Institute by longtime member Ed Johnson of JAI Corporation. Thanks to the hard work of INMM headquarters staff and the comfortable atmosphere and great food offered, most attendees stayed and enjoyed the opportunity to mingle with INMM officers, new members and senior members for the entire reception. Once again we examined the composition of the meeting attendees and note the broad range of those for whom this is their first meeting (31 percent), those who have attended two-three meetings (23 percent), those attending four to ten meetings (30 percent), and lastly the old-timers with more than ten meetings in their history (16 percent) based on the response level. So we continue to get new members to INMM and the annual meeting and their comments about the meeting are mostly laudatory.

The Awards Banquet took place on July 20, the food was better than most institutional dinners and the awards were worth mentioning: Debbie Dickman was awarded the Meritorious Service Award and Myron Kratzer received the Distinguished Service Award. 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 three of our deceased members were read: Cecil Sonnier, Hiroyshi Kurihara, and Dale Maul.

This banquet (and meeting) was the last for John Matter as president (and for Cathy Key as vice president) since his two-year term ends this September, and Cathy Key begins her term as president on October 1 (with First Gentleman Larry Key, who has some spectacular ideas for this role). Our thanks go to John and Kathy Matter for a most commendable performance; we look forward to the other Cathy in her new role.

Another evening event that some suspect was to keep the rest of us from getting out to see the Orlando surroundings was the student initiative open meeting chaired by Mark Leek, Student Activities Committee chair. The purpose of this gathering, a really worthwhile event (in addition to the pizza), was to solicit input to potential improvements in INMM's student activities program. We got an earful of good counsel to digest from both student and faculty that Leek will provide as additional feedback to us.

For the second year, and in response to our speakers' wishes, Paul Ebel continued with a speakers and session chairs tutorial following the speakers' breakfast each day. This year the emphasis was on presentation material—The Secrets for Giving Good Presentations. Also, there have been some suggestions that INMM hold a special tutorial session sometime before the actual start of the annual meeting—any comments? INMM members can see the article on Ebel's tutorial and his plans for next year in the fall 2004 issue of the *INMM Communicator.*

Now we come to the *gripe section* of this report where we try to address all the concerns and issues that arise at the annual meeting. INMM continues to take into serious consideration all the comments (even some of the trivial and nonsensical ones) made either verbally to us or through the formal evaluation form provided by e-mail to meeting participants. Many of the observations and suggestions provided to us have been used to make each annual meeting more effective and enjoyable. However, we don't usually get a very large response but it is improving—this year it was 31 percent versus last year at 28 percent and only 5 percent before we started the electronic evaluation system. We now feel we have a significant representation of INMM to use as a more solid basis for decision-making. And there was a truly remarkable decrease in the meeting onsite comments this year. Perhaps the real issues and traumatic consequences of our colleagues who could not attend the meeting or present their papers put all gripes in their proper perspective.

One real continuing issue is the withdrawal of papers and changes in speakers not only after the final program has been sent to the printers for publication (approximately four weeks before the annual meeting) but actually during the meeting! (I do not include the unusual circumstances arising from the LANL stand-down in this statement.) The issue of cancellation of papers and changes in speakers is so disruptive to the program that it is one of the most common complaints from our attendees. INMM recognizes that there are legitimate reasons for some authors to withdraw their paper from the program even at the annual meeting itself. We do strongly urge those who submit papers for presentation to do so after careful consideration of their ability to attend, the management and classification approvals required, and any other factors that might inhibit meeting their commitments to INMM and fellow colleagues. Further, I perceive that some of the folks who did not attend or changed speakers knew at least one month prior to the meeting and could have provided that information to INMM before the final program was sent for publication. We plead with you to get pertinent information to us as soon as you become aware of it and before our stated deadlines.

For example, as we noted previously, this year we received thirty-five withdrawals out of 360 abstracts originally submitted; nine were received after the Final Program was published (four weeks before the meeting) including one at the meeting itself! Although still an issue, it is somewhat of an improvement over last year's performance. (Gratefully, we had only one *no-show*—those folks who did not have the courtesy to their fellow colleagues to let INMM know in advance of their decision not to present or even attend the annual meeting. We still need everyone's cooperation to eliminate this unprofessional occurrence.) We also had numerous speaker and session chair changes (not related to the LANL issue) even during the meeting.

This year the Overall Annual Meeting process was rated almost exactly as it was last year's—mostly as good-excellent with especially good commendations for the online abstract and final paper submission process, preliminary and final programs, the online program, the pocket schedule-at-a-glance (a great hit again!), the registration process, and our terrific INMM headquarters staff. The Technical Information Exchange, Logistics, and Exhibits areas were also rated highly good-excellent. Once again, greater than 97 percent of the respondents indicated that the INMM Annual Meeting met their needs and expectations!

Despite the generally good meeting evaluation, there were also some significant issues that merit INMM's attention. Ordinarily, we would summarize them here but the evaluations provided us with more than 300 individual comments this year. INMM plans to review all the comments and provide a summary response later this year via the Web site and/or the *Communicator.* (Some of the problems we have in evaluating responses are the great diversity of these comments. For example, our respondents said: "Although not a member now I am preparing the documentation to have my organization become a sustaining member. I find that the INMM environment is very rewarding. Thanks for the good work"; "Weed out those talks that have no new material"; "Have less parallel sessions"; "Annual meeting is perfectly organized"; "Session chairs need to show up and stay on schedule"; "A superb meeting and have been a satisfied member of INMM"; "My only real problem was that I could not be in two places at once"; "Better speaker breakfasts—some protein (eggs, bacon, etc.)"; "Shorten sessions to three days. Plenary sessions are not very interesting. Better technical review—screen 'unfinished' papers and papers clearly seeking support for commercial products"; and "The variety of presentations offered was fantastic.") Below are some of the more relevant comments we received and our responses:

- *Speaker Tutorial:* "Too late to be useful for speakers who present their paper the same day." Correct (maybe). Ebel has explained that it may not be useful for the current day (or meeting) but should be a basis for next year's presentation. We have tried to schedule the session earlier but other meetings from Friday to Sunday conflict; besides we're not sure that folks would come in earlier even if we expanded the tutorial to an hour. (However, we'll review the scheduling for next year's meeting for any possibilities.) At the Speakers' Breakfast we capture 50 to 120 speakers each day—if we assume that many will be returning next year to present papers, they will have had some prior basic training. If they never present a paper at INMM the tutorial is good preparation for them for their next professional presentation elsewhere—at no extra charge.
- *Schedule Changes:* "Need a better way to inform attendees of paper presentation schedule changes." We have struggled with this issue every year. Our answer is to implore our contributors to provide us changes (even speaker) changes before the final program is published. We've seen some progress, discounting the unfortunate circumstances at one of the national laboratories this year, of course. To try to prepare a schedule daily was neither practical nor effective even this year with all the Los Alamos changes. The Technical Program Committee agonizes over proper placement of papers in the most appropriate session—even then we occasionally goof. So, to rearrange the schedule daily (or at any time) just to fill empty slots is counterproductive. (We did provide meeting addenda each morning that reflected the changes that we were receiving, some of which came in as late as the morning of the sessions for that day.) Further, INMM does not believe that deleting several papers in a session creates a lull too great so as to lose attendees for the remaining papers. More likely, the audience attended other papers that they probably would have anyway. It's a matter of individual choice not circumstance—the program is arranged to provide such flexibility. Several folks may not have taken the opportunity to hold discussions, as INMM has suggested, during the vacant schedule slots, or they may have had the opportunity to visit another session that they might not have been able to attend otherwise.
- *Focus of the technical sessions:* "Meeting very heavily focused on MC&A and international safeguards and there should have been more variety of INMM topics including supply and disposition of HEU and Pu." If one reviews the Call for Papers, there are about ninety subtopics listed as suggested (but not exclusive) areas for presentation. Contributors may use these as guidelines or submit abstracts in any other applicable area. Except for specially focused areas, INMM leaves the topical area to the individual author. The technical program is planned around the abstract submitted. INMM does encourage any individual who wishes to explore a specific topical area to contact any Technical Program Committee member for assistance in setting up a special session. There were three such sessions at the meeting this year.

Here's more of what happened at the Annual Meeting this year:

- LCD projection for PowerPoint© presentations continues to be of very high interest to INMM speakers. (For the background information and review of this issue that we made available last year, please refer to the *Report of the 44th INMM Annual Meeting* published in the fall 2004 issue of the *Journal of Nuclear Materials Management.)* INMM may have a viable process for 2005. Paul Ebel, BE, Inc., has volunteered to coordinate this process for INMM regarding equipment, schedule, operation and management. We are currently developing a procedure that addresses all of our concerns to provide meeting participants a cost-effective, more formal and highly reliable system for presentations. We will keep you informed of the progress and the process as our plan develops. (So stop complaining!)
- Current INMM policy is that authors submit final written papers two weeks before the annual meeting so that headquarters 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. Each year the response gets better; this year we only had three papers not submitted by the end of the annual meeting. (My infamous *Delinquent Final Papers Blacklist,* although disturbing to a few people, seems to be at least one way to attract attention to this serious matter—it has resulted in a modicum of success.) 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.*

Looking forward to next year: the practice we initiated last year to move to a smaller, more economical and more effective Preliminary Program that provides basic meeting information and eliminates the paper titles to be presented in each session is working out well. INMM continues to post the titles of these papers on the Web site and update them weekly. We're still meditating about reducing the Final Program to the pocket program alone (without abstracts) and, again, posting the abstracts on the Web site and/or some other attractive means of communication. Results of our survey were 59 percent for supporting that change and 37 percent against such a practice with the rest with other views; however, many significant questions were raised that need to be addressed.

At the beginning of this fascinating recap of the 45th INMM Annual Meeting (I can say that because I'm the author!), I reminded you that these meetings are your meetings. So, I also want to remind you that INMM encourages those interested persons, under the mentorship of a Technical Program Committee member, to actively participate in structuring the technical program by organizing special topical sessions of interest for the Annual Meeting. For the 46th Annual Meeting, special sessions like these need to be planned carefully and submitted in final form by February 1, 2005, for consideration and review by the Technical Program Committee. Let me hear from you very soon so that we can reserve space in the program for your special session

Every year I ask: How can we make the annual meeting better for you? Send any suggestions for INMM to improve meeting practices to me at cpietri@aol.com.

Also note that we are back at the JW Marriott Desert Ridge Hotel in Phoenix, Arizona, for INMM's 46th Annual Meeting, July 10–14, 2005. It's never too early to begin planning to attend the 2005 annual meeting. You can present a paper or a poster, chair a session or organize one, be a sponsor and/or an exhibitor, or just be there to be overwhelmed with the depth and breadth of all the valuable information made available by INMM every year. It's almost like a total immersion course in nuclear materials management—perhaps more than we can take at one time. Be there—everyone one else will!

Opening Plenary Address—
Challenges and Lessons Learned from Nuclear Inspections in Iraq

Jacques G. Baute
Director, Iraq Nuclear Verification Office
International Atomic Energy Agency

45th INMM Annual Meeting
July 19, 2004
Orlando, Florida USA

Abstract

The International Atomic Energy Agency's experience in Iraq certainly reached a turning point in March 2003 when its team, together with that of the United Nations Monitoring, Verification, and Inspection Commission (UNMOVIC) and the rest of the United Nations organizations operating in Iraq, had to withdraw in view of the announced military operations. Nevertheless, from the signature of Iraq's safeguards agreement in the 1970s until the implementation of UN Security Council resolution (UNSCR) 1441 in early 2003, the agency has accumulated invaluable experience in nuclear verification, addressing issues from the mine to the weapon.

Numerous technical and methodological measures, often unprecedented, were taken by the agency to cope with the challenges of the situation; some with great success, others with limited results. Such measures covered the fields of relations with supporting member states, interaction with the inspected state from the organizational to the individual level, selection and utilization of human resources, implementation of technological tools, development of the analytical effort needed to reach the proper level of assurance requested by the international community, and efforts in public information. Even if we keep the specificity of the "Iraq case" in mind, this experience has already been and certainly will be of value for nuclear verification for years to come, particularly in a context where international security has become an increasingly important issue.

The Limits of Traditional Safeguards: The Pre-1991 Era

Much is known in the nuclear verification community about the limitations of the early approach to safeguards and of the steps that were taken to correct them. The nature of the approach, then thought to be adequate by the international community, had enough loopholes for Iraq to begin a clandestine nuclear weapons program and remain undetected for a decade. It is unfortunate that, in some arenas, in particular when politically convenient, some like to portray the failure of the safeguards system in the 1980s as an indicator of the agency's inability to provide credible assurance of a state's adherence to its obligations under nonproliferation agreements. We should remember that, at that time, the international community was convinced that states that had signed the Nuclear Nonproliferation Treaty would remain committed to their engagements, and thus, the agency's role should be restricted to the verification of declared materials and installations. The mistake was to forget that there can be no meaningful verification without measures aimed at detecting whether a state is trying to deceive the system by conducting undeclared activities.

Addressing these loopholes—that is, developing the lessons learned from the initial discovery of Iraq's undeclared program—was the main objective of the 93+2 Program that led to the approval in 1997 of the Model Additional Protocol, meant to broaden the scope of information and access to be provided to the agency in the context of nuclear safeguards verification. For instance, Iraq would have not been able to develop most of its clandestine activities in undeclared buildings at its Tuwaitha Nuclear Research Center had the Additional Protocol been in the agency's tool kit prior to 1991. Had the agency been able to put together and analyse information from an extended declaration provided by the inspected country, drawing on open sources quite numerous in the late-1980s about Iraq's apparent intentions and supported by member states who, at that time, had not yet realized that the agency could make good use of sensitive information, the world would not have had to wait for the invasion of Kuwait to address the issue of a clandestine nuclear program in Iraq.

Mapping the Extent of a Clandestine Program Despite Deception (1991–1995)

A milestone in the discovery of Iraq's clandestine nuclear program was the adoption of Resolution 687 by the United Nations Security Council in April 1991. In this Gulf War ceasefire resolution, the agency was requested to map out and neutralize Iraq's nuclear program and to ensure Iraq's compliance with its obligations through an ongoing monitoring and verification system. Can a verification body dream of better conditions than being provided unconditional access to anywhere, at any time, to any individual, any documents, and any technology that would help strengthen the conclusions? No, these are dream conditions. Easy? Maybe not.

The challenge at that time started with a learning phase: learning about Iraq's covert program, including weapons development and its most sensitive aspects; learning how to make effective use of the tremendous rights provided by the resolution; and learning how to team with UNSCOM, the United Nations Special Commission, tasked with a similar mandate for chemical and biological weapons and missiles and requested to provide "assistance and cooperation to the agency."

Establishing the right organizational structure in size and composition was certainly a challenge. Starting with an action team consisting of three professionals reporting directly to the IAEA director general, relying on the roster of inspectors from the Department of Safeguards, and calling on member states to provide the expertise not readily available in-house was the first agency response. Was it too modest? It would certainly seem so, given that the team grew through the years to become the Iraq Nuclear Verification Office (INVO) in December 2002 with more than twenty full-time professional staff members, assisted at times by staff *borrowed* from other parts of the agency, as well as outside consultants, to meet the needs of identified challenges. Through the years that combination of thorough and experienced inspectors, skilled analysts, experts with sharp knowledge, and dedicated support staff (we should never forget their importance) led to the known achievements.

Perhaps the biggest misconception at the outset was the time the "Iraq file" was expected to remain open. The timeframe cited by the Security Council in UNSCR 687 was expressed in terms of days, as if the general expectation was that the entire exercise would not last more than a few months. As a result, the team went through a serious struggle when, at the end of 1993, a major turnover of personnel occurred, leaving only the action team leader as a continuing figure. Newcomers had to rebuild the institutional knowledge with an innovative attitude. Instead of using the traditional paper trail and unhelpful compartmentalization of information, a major effort was put into developing a team approach, with a high priority in securing vital information through advanced structured databases, avoiding unnecessary restriction of information circulation, unless its sensitivity demanded a strict need-to-know approach. That lesson, learned the hard way in 1994, was certainly a critical factor in the success of the agency when it resumed its Security Council mandated inspections in November 2002. By then, staff turnover had once again led to a situation where INVO's director was almost the only survivor of the team of senior staff involved in the previous four years of inspections, 1994–1998. But knowledge management worked!

In 1991, it was clear that Iraq's initial reaction certainly did not match the expectation of transparency set by UNSCR 687. During the first months of inspections, Iraq's obvious objective was to hide as much of its past program as possible. Unannounced intrusive inspections, in an attempt to defeat concealment actions such as Iraq's cleanup of enrichment facilities and its efforts to hide sensitive information from inspectors, became a powerful tool that forced Iraq to readjust its approach, and reveal some of its program components by summer 1991. This inspection approach—in conjunction with technical tools, such as particle analysis of swipe samples, one of the most effective verification tools in the nuclear area; the realization of member states that sensitive information provided to the agency can lead to dramatic discoveries; the right mix of selected staff; and the development of systematic and comprehensive analytical approaches, dealing in particular with understanding the depth of Iraq's procurement effort during the 1980s—led to uncovering to a broad extent Iraq's clandestine program well before Iraq's forthcoming declaration in 1995.

The agency's mandate under UNSCR 687 to destroy, remove, or render harmless Iraq's proscribed materials, equipment, and facilities was practically completed by early 1994 (and not in forty-five days as foreseen in UNSCR 687!). At that time, there was no weapons-useable material (plutonium and highly enriched uranium (HEU), that is uranium enriched to 20 percent or more in U-235) left in the country, no single use (that is, exclusively nuclear) equipment was still intact, and all buildings with dedicated features had been destroyed. Even pieces of dual-use equipment that were uniquely linked to the prohibited program were destroyed—as were, in some cases, facilities for which Iraq had not yet acknowledged the link with prohibited activities, such as Al Atheer, the weaponization center, denied to be such until the summer of 1995.

In August 1994, after having operated for three years on a campaign mode (sending teams of inspectors from headquarters for inspections finite in time), the agency began its permanent presence in Baghdad. Fully unannounced inspection then became the absolute rule. The agency could inspect any day, at any place—a far more effective regime than the previous system, which allowed some relief to our counterparts during the periods between fixed inspections, in particular to implement the damage control after each new discovery made during inspections.

Drawing Conclusions Despite Iraq's Lost Credibility (1995-1998)

August 1995 marked a big step forward for the action team when General Hussein Kamel, Iraq's president's son-in-law and the former supervisor of all weapons of mass destruction (WMD) programs, left Iraq. Iraq decided to anticipate what General Kamel could tell the agency and came forward with additional declarations. In particular, Iraq provided details on its attempt to recover HEU from reactor fuel, and handed over large quantities of documents related to the centrifuge enrichment and weaponization areas. Additionally, our Iraqi counterparts demonstrated a far higher level of transparency compared to what had been observed for years before.

Because we had previously been able to fully understand Iraq's documentation procedures, we completed our collection of original Iraqi documents by convincing the counterpart that providing the missing original reports was inescapable. Documents contemporary to the past activities being investigated have a tremendously higher value than declarations made for the circumstance. Managing to gather a quasi-comprehensive set of all reports ever published by Iraqi technicians was clearly a pillar of the credibility of the assessment.

Access to all relevant Iraqi personnel became possible, while, prior to August 1995, Iraq had had the tendency to grant access only to a *spokesperson* in the relevant technical areas. Preventing access to the right individuals who are able to deliver precise information on their actual work and instead proposing designated counterparts, who will always be imperfectly briefed on technical matters, is certainly one of the most damaging action an inspected country can take in terms of building confidence. It does not take long for a trained inspector to identify the shortcomings of such behavior. In Iraq, face-to-face interviews became a key tool for the agency's for refining its understanding of past achievements and establishing the remaining capabilities, including the evolution and state of the residual nuclear-relevant expertise.

The agency also followed up on Iraq's most damaging concealment action—the unilateral destruction of equipment and documents in the summer of 1991—and conducted a campaign of digging in the desert to recover and inventory what had been hidden. The support of technologies such as subsurface sensing and mapping equipment led, with the help of the counterpart, to effective determination of the locations of interest and the recovery of numerous concealed items.

Another technology, by sampling large trees, confirmed the timeframe during which Iraq dealt with tritium for weapon development purposes. Gamma surveys, handheld, car-borne, or heliborne, did not detect prohibited activities but located numerous contaminated areas and orphan sources worth some follow up. In the same way, the monitoring of Iraq's waterways (sampling of water, sediment, and vegetation) did not provide any indication of prohibited activities but demonstrated its power through the detection of iodine used for medical applications. The installation of air samplers, unfortunately for only a few months before the December 1998 evacuation, led to the identification of operational problems, such as the difficulty to maintain adequate filter conditions in a sand-polluted atmosphere. (Since then, the agency, with the support of several member states, implemented a series of field trials, from which we hope to refine the assessment regarding the effectiveness of atmospheric sampling for the detection of clandestine nuclear activities.)

On the outside information part, supporting member states, through those communities within member states that had been working closely on the Iraq case, had finally realized that we were strong in our technical approach and reliable in our handling of sensitive information, and that we had become the most knowledgeable organization on Iraq's past program and remaining capabilities. A tremendous amount of information of all kinds began to flow to us, allowing the team to become confident that, as all sources of credible information (original Iraqi documents, inspection findings, good quality third-party information, including details on past Iraq's imports of critical items, etc.) were showing consistency (in terms of compatibility between each other, presence of all expected program, program logic, etc.), we had reached an accurate detailed understanding of Iraq's nuclear past program and remaining capabilities.

The lesson of that period should have been as follows: provided that the inspection team is technically strong and thorough and has a detailed level of documentation and access to all relevant personnel, provided that it is focused on issues of importance and remains politically independent, (that is, relying on facts only, rather than bending to political pressure), provided that member states are supportive of the team's action, both politically through the support of the Security Council and technically through the provision of information and expertise, and provided that the inspected state fulfills the requests by the verification body, the international community can be provided with an accurate and comprehensive appraisal of the situation, past and present. Although, the accuracy can never be 100 percent, the world was given a clear and coherent picture of Iraq's nuclear program (as reported in S/1997/779 and S/1999/127).

Unfortunately, one of the key problems, in retrospect, was that the agency's approach and its results remained largely unpublicized. By 2002, after four years had passed, and after heavy turnover of the staff involved on the relevant files in most of the member state capitals, it was clear that the promoters of the "inspections do not work" line could easily surf on the majority's memory. The key lesson for the agency was that it should not only successfully fulfill its mandate, but also use the media more effectively to ensure that its achievements are conveyed to the public, including the decision makers.

When the International Community Goes Blind (1998-2002)

The world has certainly not yet measured the broad consequences of the fact that, after operation Desert Fox in mid-December 1998, inspections did not resume in Iraq for nearly four years. All possible speculations became possible, based on the most pessimistic interpretation of fuzzy intelligence or worst-case scenarios extrapolated from procurement attempts. The "experimental results" normally provided by field activities were no longer available. Four years without inspections is certainly of significance in the development of a nuclear program, especially considering what Iraq was able to do in the years between 1987 and 1990. On the other hand, it is clear that contrary to what was possible during the 1980s and early 1990s, the sanctions in place were having an effect, and there was no comparison in Iraq's available assets at the end of 1986 and its situation at the end of 1998.

In the absence of inspections, high-resolution commercial satellite imagery provided the only real opportunity to remain in contact with the reality in the field. Overhead imagery had been utilized by the agency in Iraq since 1991, in the form of photographs from a U2 plane. Unfortunately, while imagery allowed us to prepare well for inspections (and is now used extensively in the preparation of safeguards inspections worldwide), imagery also proved, as expected, to be far from sufficient to confirm the existence or absence of nuclear activities. The limits of the collection of human intelligence appeared even greater, as expressed in recent reviews. How many of the concerns raised by defectors' reports or as the result of imagery observations could have easily been resolved had inspectors been in the field? Moreover, while it is difficult to define a measurement of the deterrence induced by an inspection regime, the broad conditions provided by UNSCR 687 and other resolutions, together with their implementation aimed at optimizing inspection effectiveness, were certainly providing a level of deterrence quite effective in preventing any prohibited activity of significant scale.

While the agency was not operating in the field, UNSCR 1409, adopted by the Security Council in May 2002, provided us with a new mandate, resulting in developing a new type of experience. The review of all contracts of exports of goods to Iraq (in order to identify what items might be of relevance for a hidden nuclear program) would allow the agency to build an understanding of procurement networks, reflect on what items would be choke points, and identify areas of possible concern based on the procurement of humanitarian or infrastructure rehabilitation goods.

Although only implemented to a limited extent, given that sanctions were in place, the import-export mechanism approved by Resolution 1051 (adopted in 1996), as part of the OMV system, was actually another opportunity for the agency to reflect on the advantage of getting access to information on ongoing or intended procurement as a tool to develop credible assurance on a country's respect of its obligations. In that mechanism, notifications related to items, single- and dual-use, are to be provided by both the exporting and the importing country. As part of its verification mandate, the agency would then be in a position to verify the end-use of sensitive equipment and materials. In a new context where current export control arrangements have demonstrated their limitation, this mechanism could be a starting point for a reflection on the establishment of the practical modalities for an improved worldwide export control regime, as advocated by our director general.

In the Spotlight: Inspections Under World Scrutiny

The last period of Security Council mandated inspections, between November 2002 and March 2003, was of a dramatically different nature in terms of the world's attention and what seemed to be at stake: some saw war or peace resting on the shoulders of the IAEA and UNMOVIC (UNSCOM's replacement since 2000). From our perspective, it was clear that the decision would not be in the inspectors' hands but in those of the of Security Council members. Still, the agency could not afford to allow such a decision to be made without having done its best to provide the Security Council with all possible facts and reliable conclusions in a timely fashion. Relying on our four years of preparation, including our comprehensive databases on sites, equipment, and personnel, our refined coherent picture, and the former inspectors we called back to benefit from experience accumulated before December 1998, the agency was able, within three months, to address most of the concerns raised by member states. On March 7, 2003, the director general told the Security Council that the agency had found no evidence or plausible indication of the revival of a nuclear weapons program in Iraq. However, he added that more time was still needed for the agency to complete its investigations.

As of July 2004, not one of the agency's conclusions had been contradicted, despite the changes that occurred in Iraq and the work done by the Iraq Survey Group, the organization set up by the Coalition Authority to complete the disarmament of Iraq, and the various investigations conducted by national commissions on Iraq. Final conclusions, however, should not be drawn before the agency can complete its assessment, after returning to Iraq when the Security Council revisits its mandate, as promised in UNSCR 1483 (2003) and 1546 (2004).

Perspectives

The results obtained by the IAEA in terms of annihilating the threat of nuclear proliferation in Iraq were the outcome of the combination of several positive factors. Inspections worked, as a consequence of constant pointed efforts developed by the agency, and, even if both were variable in time, the international community's support and the cooperation of the inspected country.

Since 1991, the agency has certainly demonstrated its adaptability to new challenges and that it could learn fast its lessons from the past. The methodologies developed in Iraq have served and will certainly serve as inspiration to develop more effective and efficient verification activities elsewhere, including by avoiding actions that proved to be unrealistic in Iraq. The use of all rights provided by the authority that member states have agreed to grant the agency, the search for any kind of relevant information to be consolidated with inspection results in order to derive independent credible assessment, and the maintenance of a dialog with the inspected party, acknowledging that nothing can be achieved without a significant level of constructive but uncompromising interaction, are among the key parameters for the success of a verification regime.

But the agency, as the only technical arm of the international community for nuclear verification, cannot operate on its own and make unilateral progress of its own. Improvements will be made through, for instance, the adaptation of internal modus operandi, a mandatory survival condition for any organization of the agency's size and responsibility. It is also the agency's management responsibility to promote the development of current staff for the efficient preservation of the continuity of knowledge and to generate the recruitment of new adequate staff, to adapt the organization's response to the new challenges. But this cannot happen without ongoing outside support. The worldwide nuclear verification community gathered for this INMM Annual Meeting can certainly help in this regard.

Funding should certainly not be forgotten. Although the agency has benefited from a spectacular increase of its budget in recent years, it was only spectacular as an international organization. Is it appropriate to the level of the increased number of issues to be addressed? It could never be overemphasized how important it is to properly think this through and avoid the mistakes of the past: for instance, no secure funding mechanism was in place for UNSCOM and the agency's UNSC mandate prior to 1996! And we need to highlight how low-cost the contribution of the agency was to international security (the annual expenditures for nuclear verification in Iraq remained at $3 million to $5 million U.S. per year for the result obtained).

It is not for an agency official to draw lessons on behalf of member states, but it is clear that, when the international community (in this case the Security Council) was unanimous to address the proliferation issue in Iraq, major progress was made in reducing that threat. Member states' responsibility is certainly, first, to set the political and legal basis of the verification regime, establishing the authority that the agency will have in its endeavour. As often expressed by the director general, this may require, for instance, making the Model Additional Protocol the global norm for nuclear verification and providing the agency with the actionable information from an effective export control system, as well as any other relevant information available to member states. It is also essential for the international community to constantly maintain its support to the inspectorate, to avoid the risk of becoming blind, like in Iraq in 1999-2002. That support should not be limited to the political, diplomatic, or information aspects but also include technical components such as the provision of improved expertise and technology, through the national efforts put in research and development of new verification tools.

The preservation of international security with regards to nuclear proliferation and associated threats is a tremendous current challenge for which the only solution is comprehensive team work. At the diplomatic and political level, this may call for multinational solutions for sensitive parts of the fuel cycle, as proposed by the director general, and multilateral answers to threats, as proven effective in Iraq after 1991. For us, at the technical level, the required credibility in addressing the problems come through the establishment of multi-expertise teams of inspectors, experts and analysts, as capable to dispute cutting edge scientific and industrial issues than to investigate and reach the core of the reality of a crisis despite limited transparency, including by understanding political and cultural sensitivities. When such a system is in place, as it was for nearly twelve years, unfortunately not on a permanent basis, it is for the benefit of the international community, in receiving the assurance it seeks, as well as being in the best interests of the inspected party, which is given the best opportunity to demonstrate the reality of its compliance.

INMM Roundtable

July 19, 2004
Orlando, Florida, U.S.A.

Opening Plenary Speaker
Jacques G. Baute
Director, Iraq Nuclear Verification Office, IAEA

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INMM Fellows Committee Chair

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INMM Constitution and Bylaws Committee Chair

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JNMM *Associate Editor*

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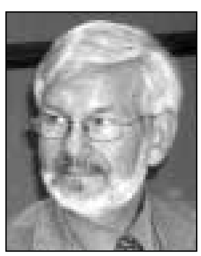
JNMM *Managing Editor*

James Tape
INMM Interim Past President

Scott Vance
JNMM *Associate Editor*

Dennis Mangan: I thoroughly enjoyed your plenary speech this morning and I'm sure the rest of this audience did too. You have a rich history with being involved with Iraq and I really enjoyed the way you put it in different time phases and how you brought to us the different activities that went on in different time periods. But as you made your presentation I kept saying to myself, how many times has this guy been to Baghdad? Why don't you give us some insights?

Jacques Baute: I started to go there in 1992 and then I joined the agency in 1994. My longest stay was about six weeks. I stopped counting at sixty trips.



Bernd Richter: Since you've been looking for a nuclear weapons program I wonder what role experts from non-nuclear weapon states could play in your team. For instance the Germans, since Germany is a non-nuclear weapon state and we can hardly have any experts in nuclear weapons.

Baute: But that's not a problem. The team has been looking for weapons programs—in other words understanding a program from the mine to the weapon, which means that the team needs a certain number of weapons state experts to deal with specific weapon development issues but the rest of the activity is dealing with enrichment, conversion, all the classic aspects. I can even say that in terms of some of the components of the weapon, you don't need to be specifically a nuclear weapons expert to have knowledge in high explosives for instance. So we almost always had a German in the team actually. So even in the search for nuclear weapons program, there is room for non-weapons experts.

Gotthard Stein: Some people say that the agency is a nuclear watchdog but as you nicely said you are dealing with an investigation with technical issues so it's always interaction with nuclear and missile, the biological, and the chemical issues. Because sometimes it would be an advantage to have some let's say some general verification expertise to deal with the complete complex.

Baute: You know, as I mentioned this morning, the agency was in charge of the nuclear program while UNSCOM was responsible for missiles, chemical, and biological weapons. I would say among the three topics, the one we had the most commonalities with is probably missiles for two reasons. One is that missiles are one of the possible delivery system for nuclear weapons; so, if we want to have a complete understanding, we need to look at the delivery aspect too. Second, missile programs might have lots of tools in common with nuclear weapons R&D. For instance, high explosives and solid propellants for missiles need pretty much the same type of facilities. If you find mechanical workshops in the country used for short-range missiles, they may also have the capabilities to be used for the fabrication of centrifuge components. So these are examples where there is a certain synergy between nuclear weapons and missile programs. Do we need to have a unique body of inspectors dealing with the four topics? I'm not sure. And I actually feel that what was done in Iraq, having the agency fully responsible for the nuclear aspect from A to Z, has proven its effectiveness. What would be the advantage of having some nuclear inspectors isolated in New York? I'm not sure that I can really identify any positive aspect. Is there a need to have closer cooperation between the agency in charge of nuclear weapons and the agency in charge of chemical weapons, and whatever body may one day deal with missiles or biological weapons? Certainly, as very often, regimes that develop one type of weapons of mass destruction (WMD) explore the other ones too.

Jim Tape: Sort of following on to this, what I see as a theme of looking beyond the boundaries of the usual IAEA mandate, and also looking beyond the experience in Iraq to the future, you mentioned this morning that perhaps as a normal part of safeguards analysis, the agency should pay more attention to the weaponization aspects of proliferation and I wonder if you'd comment further on that and also on the desirability of institutionalizing within the department of safeguards the experience that you and your colleagues have had.

Baute: Considering that the agency needs to look at the weaponization aspect is simply addressing properly the problem of how to assess the completeness of a country's declarations. If the agency remains totally blind with regards to what may be happening in terms of weapon development-related activities, which are the only indicators for the ultimate use of undeclared weapons-grade nuclear material. What would be worse for the agency than concluding on the absence of indications of clandestine activities with regards to the production of weapon-grade nuclear material, simply because the country has acquired otherwise the nuclear material? So I think that it's one of the strong arguments that would make us look at that part of a potential nuclear program. It's true that it's definitely an extension of the way things developed, even as part of the original Additional Protocol. It is also clear that some countries are not very keen on having us deal with that. There were some question marks for a few weeks regarding our involvement in that aspect in Libya.

There were some remaining questions the same day we were flying. Finally, the Libyans gave us access to the weapons-related documents and we were able to identify what type of activities we should focus on. The key argument was for us to have an understanding of what was there, what is on the market in terms of a nuclear device that you can buy with your checkbook. Having had access to this information clearly helped us focus our investigations. So, I think it's above all an issue of enhancing the effectiveness of agency's verification. We certainly are fully aware of the proliferation risk. Someone this morning raised the issue of how you handle that type of information. When you come from a weapons lab, you have a pretty good idea what is the required level of classification, and so put in place the measures so that no one without proper background would in fact have access to sensitive information.

Steve Dupree: You mentioned the Additional Protocol. It would seem Iraq is in a unique position to adopt and implement the Additional Protocol after all the effort that the agency has put into the country. Do you foresee that happening? Is this something that is going to be discussed with the new government in Iraq?

Baute: It's clear that everybody hopes that, at some point in time, Iraq would be again a normal country, and it will be clear that with regard to nuclear nonproliferation verification, the Additional Protocol will be the standard. Between now and the moment when that can happen, it is in the hands of the Security Council. If the council decides to revisit the mandate with an outcome, which is cancellation of the agency's Security Council mandate, then things will go directly to an Additional Protocol. If the council decides that there is the need, given Iraq's past history, given Iraq's current uncertainty, for a system that is based on the ongoing monitoring and verification (OMV) system that was implemented in the past, or something slightly different, maybe with some limitations on our rights of access, then we will adapt. As I said this morning, we'll always use our rights reasonably but in an uncompromising way, and come with the assessment that we need to provide to the council. When will the council revisit the mandate? I have no idea. I don't think we've got any frustration out of that political delay, simply because, even if the council had told us "you can return now and within these conditions," the security situation is currently too bad to conduct any meaningful verification activities of the type we were used to conduct since 1991.

So we'll have probably something of the order of six months to one year before the council solves the political issues of the return of inspectors. Iraq will have elections in December or January 2005. Hopefully the administration of Iraq will have time to get organized, in order to support the resumption of nuclear verification, be it in terms of OMV system or in terms of the Additional Protocol. From a practical point of view, the way we are considering reshaping our ongoing monitoring system is simply in a mode which can be characterized as "Additional Protocol plus," so that we get from Iraqi declarations the same information as defined out of the monitoring plan implemented since 1994, but in a format that we'll be usable after return to normality.

Richter: I felt there was some contradiction in statements you made this morning. On the one hand you showed on your slide that you found well-trained scientists and engineers in Iraq but on the other hand I have the impression that the quality of the Iraqi nuclear program was rudimentary, not very well advanced, and given the facts that a Korean colleague told me recently that in South Korea they find many Arabs now studying nuclear engineering, I ask myself what is the real potential of nuclear education in Iraq and what do you guess could it be in other Arab countries, given the fact that we have political problems with many Arab countries.

Baute: It's a politically difficult question. There has been one problem with Iraq, that's clear. Libya was another problem but it has been addressed since last December. Given its worldwide responsibility and mandatory neutrality, it is out of question for the agency to point the finger in one specific direction.

About the first part of your question, no, there is no contradiction in the sense that Iraq had many scientists, engineers who were trained, particularly in the 1970s and later on in the 1980s, in all the best Western universities, but, of course, there was no possibility to build up expertise that would cover the whole of a nuclear program. Just to give you one example, there aren't many universities that deal with weaponization-related activities. For instance, the team that was dealing with the very preliminary high explosive testing was actually a team of people who were previously working on experiments on a research reactor. Of course, there were people dealing with experiments. But that is not the same, and we have some memos that clearly display their lack of competence. It is also worth looking at the difference between Iraq and Libya. Libya is a small country, almost an order of magnitude less in terms of population, which means an order of magnitude less in terms of experts that would be available. So Iraq certainly could have a critical mass of technicians in many areas, and as I said earlier, there are many areas where they made progress in the direction of their objective. But they had also big holes that led to the fact that they sometimes got stuck on problems for many months, if not years, because they didn't have the basic expertise, the training, and didn't find the help that they would have needed.

Debbie Dickman: My question concerns the agency and the agency inspector's job and the importance of the role in the world. You stated in your talk this morning that the IAEA needs new blood, needs to have more inspectors. And of course the brain drain in this industry is what everybody faces whether it's the laboratories or the nuclear facilities. I was wondering what, if anything, the IAEA is putting in place to assure that you're able to obtain these inspectors to keep this job going?

Baute: Among the actions put in place is, for instance, having a section head of the division of personnel here, this week, to explain to whoever is interested what the agency can offer in terms of professional perspectives. I know that she was in Germany with one of the German directors about two weeks ago. So there are ongoing efforts to find new blood. I also believe that increasing the profile of the agency in the media should be something, which will help bring quality candidates. The more people know the agency, the more people, I hope, will consider that the agency is a serious organization, with a tremendously challenging mandate, worth being considered in a professional career. But the key question is: are we going to get the needed spectrum of expertise? That's the reason why I put in my presentation, which was aimed to address a technical audience, this call for help. I think that it's within the national communities that there can be measures taken to help people preserve and develop the needed expertise. The agency cannot do a lot alone.

It can try to promote itself, and be attractive enough to bring new comers. The best way to get promoted is actually doing its job in a reliable manner and finding people who will report that, and an adequate audience to hear it. I think that in the 1990s we were too silent. But clearly, without national help, we won't solve the problems. I know, coming from a national nuclear community, that the issue of the lack of popularity of nuclear matters in general in the 1990s is now a problem in terms of recruiting people who have had enough experience. It's a challenge but I think we can address it. The second way to address it will be to develop adequate training of the already available staff. But we need to work together, the agency and member states, and probably training will have to become an even more important factor in the life of every single inspector.

Dickman: That of course is where my question is coming from as well. As we discussed last night, the problem of continuity of knowledge and how we give the next generation the right tools to solve these problems, whether it's one as an agency inspector or a facility operational manager. My foreign colleagues all say the same thing. With regard to what you've observed in terms of the inspectors and other professionals that come into the agency that work nonproliferation issues, have you thought about it enough that you could offer comments on what as international bodies, where we could focus on efforts? We've been trying to raise the awareness of our membership but specific comments or thoughts would be really helpful to us as we're trying to look at ways that we can help make a difference.

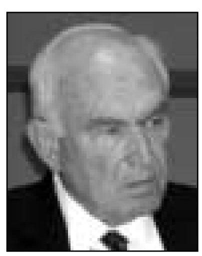
Baute: One of the key elements for effective investigation in the case of difficult verification problems is to really have top experts on each topic that needs to be addressed. The problem is that, ideally, we need top experts who have the expertise that is being developed now by would-be proliferators.

This means that sometimes you need to go back quite a lot of years and find experts who were involved in R&D conducted decades ago in advanced nuclear countries. The years going by is a problem, because modern experts think modern labs, modern computers. The Western expert often has a superiority complex and a technical bias: if you don't have the same nice laboratory conditions, the same supercomputers, you cannot do anything. Wrong. The first application of nuclear technology toward nuclear weapons was done in the 1940s. So let's look at technologies of the 1940s, or at least a few decades ago. This is actually where the profile of the effective inspectors might start to be disconnected from experts in a modern running nuclear program.

Then there is the whole aspect of handling information. Having an analytical mind, an investigative mind is mandatory for effective inspections. And there is no instant training for that. Often, people either are born with it or do not have it. But there are certainly ways to identify what types of past activities help enhance such skills. I am used to say, for instance, as I think I'm not too bad in terms of analytical skills, that I developed them in my former professional life by being in charge of a section aimed at improving the simulation of nuclear weapons. Nothing to do with verification investigations but what is worse, in terms of analytical problem, than finding a bug within a newly developed simulation code? Although analytical skills are key, we have to take care not to be flooded with analysts who are non-technical generalists. That's a big danger to let the assessment of proliferation-relevant information issues to political science generalists, for instance, who have only seen theoretical problems based on geopolitics and keywords. That can lead to dramatically wrong conclusions. So we need top technical experts first, with proper analytical skills, but supported by a broader spectrum of other expertise and skills! As I said this morning, nonproliferation investigations is team work, or it can't succeed.

Stein: Safeguards are complex and the research is very important. Due to the huge support by the member states, the agency has an excellent standard. But on its research we have to go on and I think research is becoming more needed as are other ideas to restructure research support in general but especially the scientific part of research to build up more efficient networks that might be multinational. Are there some ideas for making research more productive and results more productive?

Baute: I'm outside of the Department of Safeguards, hence I'm not sure that I'm fully aware of what's happening there, and so my answer would be probably be not reliable. What I know for sure is that the agency has multiple countries to deal with, assesses the proliferation relevance of multiple technologies, and reflects on and develops new verification methodologies. The key for me is: think synergy, avoid duplication of efforts. When something is done for the Comprehensive Test Ban Treaty (CTBT) for instance, an immediate question should be can that be applied or adapted for enhancing safeguards verifications too? Because everybody is short of money, that's a way to save money for any state and organization.



Ed Johnson: I would like to hear some comments on pre-March 2003. What does an inspector go through? In Iraq for example, where do they live? Where do they eat? Do you have any problem with the Iraqis trying to find out what you've found and what you've concluded? Can you give us a feeling for an example day of a team of inspectors, what they face.

Baute: Let me just describe the first day of resumption of inspections on November 27, 2003. We had chosen our destination, the first site to inspect. The team members are usually informed the day before of that destination, in order to prepare and coordinate the inspection in advance, and to avoid leaks. The way we proceed is that, even if we are in a UN building that is supposed to be secure, we do not speak loudly about the site we're going to visit. All relevant information can be retrieved through dedicated computer systems, designed so that inspectors virtually know the site before inspecting it. To enhance the team preparation, we would favor speaking with our hands on layouts or write on a piece of paper so that we could not be heard through listening devices. The result expected is that, the following morning, the counterparts don't know where we're going. We climb in our cars and they follow us to our destination. Of course, for the first day of inspections, there were probably about 200-300 journalists at the gate of the BOMVIC, our base in Baghdad, with thirty to forty cars ready to go and follow us. The usual rule was always, since day one, that there would be one Iraqi car for one inspector car, at least, sometimes more during crisis times. That day we were about three cars of ours, and about three or four Iraqi cars. But there were so many press cars that some crashed.

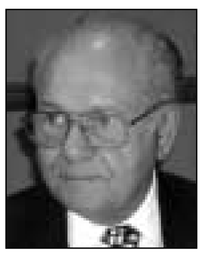
As I said earlier, our way to implement the right of "access anytime" was not saying anything to the counterpart with regard to the destination. We have our own driving instructions that allow us to reach any site without asking for help. That day, the mess was such that we initially lost our senior counterpart car, who started to follow an UNMOVIC team. We had to make a U-turn. The day after some even reported that we got lost. That was not the case but we would never inspect sites without our counterpart being with us. Then, you arrive at the gate, you simply say "that's the place I'm going to inspect today." Depending on the plan of inspection, your team may split into sub teams and go to selected buildings, according to the inspection tactics agreed. Sometime, you want to have the minimum time between the warning that your implicitly give to the counterpart at the gate and the access to a workshop from which you want to evaluate what it is used for. When you are there, you just observe the activities, review available documents, such as the technical drawings of a piece being machined, and interview the technicians there. The most intrusive type of inspections, as we did late February, early March, included full searches of offices, from paper to computer files. We had put together a team made of nuclear experts with various backgrounds, including weapons experts, together with customs officers used in searching papers and all kinds of files, "professional hackers," from law enforcement organizations, who are able to extract everything out of a computer.

At the end of the day, you go back to the base, in a secure area, and you start to put together your notes and preparefor following day. We were used to work pretty much seven days a week while we were in Baghdad.

With regard to security, we always considered that we were spied on. After you've been at a site, unless you made an observation that you want to keep to yourself, the counterpart knows what you've seen, so there is no big secret in the inspection report usually. It's the preparation that matters. However, we would preferably communicate with the headquarters in Vienna with a secure telephone, fax, or encrypted mail. Security was always something that we had in mind.

Rebecca Horton: I had a little bit more interest in the topic of the training and especially in light of your comments this morning on bringing together a team. The ultimate team that you pull together is from across nations, across expertise. Can you comment on techniques or programs that would help capture the knowledge from those experts as have they gone through experience in Iraq or in other cases and how you might utilize that? Are there programs that you'd like to capture that information to help future teams that you send out?

Baute: Sure. I would say it is certainly one of the key focuses of INVO today, but we've made less progress along this line than I had expected a year ago, simply because a significant proportion of my division is being used on other priority topics for the agency, Iran and Libya for instance. Right now, for the significant portion of our funding, which is coming from the UN, our activities include lots of actions aimed at securing the lessons learned and make proposal to enhance the agency's future verification activities in Iraq and elsewhere. The international community cannot loose the experience accumulated through the years in Iraq.



Charles Pietri: I'd like to explore further your knowledge of the scientific expertise say in Iraq. Was it significant? Were there any foreign contributions to their scientific posture there?

Baute: The foreign contribution was not big in the sense that if you disregard the university education and some training that anyone would get when one buys a piece of equipment, the foreign contribution was very limited, particularly for the Electromagnetic Isotopic Separation Program and weapons development. As I said this morning, that was essentially fully indigenous action, even if initially based on the declassified Manhattan Project documents. In the weapon area, for instance, some of the ideas in early documents are really jokes, indicating that the Iraqis started from scratch, without outside help.

The area where they got the most direct support was actually in the centrifuge enrichment area. Everybody knows the role of Karl-Heinz Schaab for instance, this former employee of MAN, subcontractor of URENCO, who provided some significant contributions to help Iraq move fast in this field. But these contributions were certainly not state's contributions in the sense that these individuals were in legal breach of their commitment with their former employers and main customer. But overall, that was quite limited.

Pietri: Now can you extend that thought to Iran, Libya, and North Korea?

Baute: For North Korea, the case is quite simple. I insisted a lot this morning that for four years, the world was blind in Iraq. I think that in North Korea, in the absence of meaningful inspections, blindness has started far longer before and might continue for a long time.

Iran I'm not involved in personally at all, so it's difficult for me to comment.

Libya was certainly the shock of 2003. Because, clearly, I think that until then, most of the verification approach was developed to address an indigenous program. Certainly, what we had in front of us in last December was a program essentially relying on buying quasi-turnkey facilities and detailed information, actions practically undetectable with the current verification means. How far after Libya had started to assemble a significant centrifuge cascade and conversion facilities would we have been able to detect them, I don't know. But clearly, this is the big novelty, the change in order of magnitude of the proliferation problem. Complicated by the fact that anyone seems to be able to buy weapon design and fabrication information. Fortunately, the package that I saw is not complete. But does a second package that will make it complete exist on the market? And who else got that information? Between the unsolicited offer apparently made to Iraq in 1990 and the findings in Libya in 2004, how many potential customers were offered this type of information and how many were ultimately provided with it? Today, these are the main questions. I don't know what will come out of the current reflections on how to increase the effectiveness of nuclear nonproliferation measures. But we're in the middle of a river right now, and honestly, there is an urgent need to be creative to prevent future unwelcome discoveries.

Scott Vance: I really have a follow-up on question to Charles' and to Bernd's earlier questions. I was fascinated in your talk about the miscalculation that was made on how quickly you could do your work, which was reflected by an original request for a report in forty-five days that eventually took three years to complete. In relation to that I wonder if you believe that the Iraqi government also severely miscalculated how long it would take them to develop a weapon?

Baute: Absolutely!

Vance: Following onto that, if other countries are in the same situation, does the possibility that they would not realize "results" in the timeframe anticipated increase the possibility that they would simply try to buy the technology and not develop a clandestine program?

Baute: Like always, there was in Iraq some overconfidence from technical people who were convinced that they had the solution, when actually unexpected technology problems would appear when moving to the industrial scale. For instance in the EMIS area, the Iraqis were not only happy to have all the declassified Manhattan Project information but I think that the head of the project himself was convinced that he could significantly improve that. But they had not solved all technical problems, particularly for the production level, after nearly a decade of development. We have all the documents that show how, in 1988, they saw the program evolving. They certainly were not in 1991 where they expected to be three years before. So they miscalculated the progress of the program. They also miscalculated the power of inspection process. I really think that at the beginning, Iraq thought they would easily escape. I will always remember my first high-level meeting in New York with a senior Iraqi counterpart, Dr. Gafoor, at that time the chairman of the IAEC, nearly a year after inspections had started. Dr. Gafoor was asking to Dimitri Perricos, then head of operations of the IAEA Action Team in Vienna: "Can you guarantee that inspection IAEA 11 (which was going to take place in April 1992), will be the last inspection?" And of course, nothing like that was guaranteed. But that was the Iraqi state of mind.

It probably explains why they thought they were going to save a certain number of assets, that they would be able to use later. But the feeling we got was that nuclear ambitions were abandoned after the 1995 defection of Hussein Kamel. We then really started to see the teams of scientists vanish.

Tape: Toward the end of your talk you were wrapping things up very nicely I thought by talking about preventing proliferation as a team effort. You talked about multi-talented technical teams and multilateral efforts and so on. In the last year, we've heard a number of initiatives relating to nonproliferation efforts broadly. One coming from your boss last October, the director general in his op ed piece in the *Economist.* This February from President Bush, we got the proliferation security initiative that is part of the Bush proposal but was already ongoing. Which of these ideas do you think will present significant barriers to the next Iraq?

Baute: It's too early to know which of these ideas will bring the most significant results. I think that many ideas, starting with the director general's ideas, are things to reflect on, in order to review the practicality and define the modalities of implementation. For instance, the proposal for multinational arrangements for critical elements of the nuclear fuel cycle is something that needs to be further discussed, and its feasibility assessed. A working group has been created, headed by the former head of the Department of Safeguards Bruno Pellaud, and more work is going to be done. Clearly, I share the director general's feeling that after what we've seen in Libya, we need to be creative. We need to have an approach that goes far beyond what was done before. The issue for information on nuclear related exports is something that is essential. We definitely learned to deal with that with Iraq and it worked well. The export-import mechanism that I mentioned this morning was never really implemented because sanctions were in place and were more restrictive. The fact that inspections were successful in Iraq is not independent from the fact that there was also a strong export control regime, actually sanctions in Iraq's case, which was also effective. The combination of the two could be effective in particular taking into account our inspection access rights, in other words the possibility to implement a control of the the end usage of an exported item. That is why it is essential for the agency to be provided with that type of information. Now, how does that fit with countries' interest in terms of economical development and exports competition? This is where again there is the need to refine the model: what can really be done and what cannot. The 1051 export-import mechanism for instance requires both Iraq and the exporting countries to notify us of the intention. Forget about that. It is out of question that when millions are at stake, anybody is going to notify the agency of intention. But what about the notification when the contract is finished, when everything is in place? What about the issue of denials? State denials are certainly interesting. But there is even more that is interesting, and we discovered that talking to companies at the time when we were seeking information about Iraq, in the timeframe 2000-2002. Often companies receive requests that they just discard because the inquiry looks too strange. That is a type of information we would like to have access to. No economic value, but great interest for us in terms of the identification of areas of concern. Overall, we need now to reflect on the big ideas and turn them into practical measures.

Jim Lemley: You mentioned this morning the assurance that the IAEA offers to the world community through its international safeguards undertakings. I would like to ask you to tie several things together. What would a state such as Iran have to do in order to provide assurance that it was operating a nuclear program strictly for peaceful purposes? And how could the IAEA provide credible assurance to the world community that that was the case? Is there a way to do that?

Baute: First of all, there is the issue of consistency and I'm not sure that, right now, the agency has a consistent or fully coherent picture of what is happening in Iran. And that is certainly a problem that will need hard work to resolve. When the consistency is pretty much reached, then the remaining part is trying to fill the smaller gaps, what we called in Iraq "questions and concerns." We managed to make significant progress in Iraq by convincing them for instance that we should have access to the real technical staff, not spokespersons, convincing them that they should provide us with all sorts of reports, even those that had nothing to do with a nuclear program, for instance to demonstrate that the former members of the nuclear program were doing something other than prohibited activities after 1991. So, even if I cannot and I do not want to speak for the Department of Safeguards, my Iraq and Libya experiences today make me feel that if a country wants to show that it has nothing to hide, it should invite the agency to come anywhere and demonstrate that, for instance, there is no activity of concern in places where there is suspicion, and not hide behind the fact that this is a military site and so it will take two months to get approval. Of course we cannot ignore the issue of local or internal sensitivity. Can the government lose face in providing the type of access beyond normal verification practice, even if it is the best way to display good faith? There is the question of why Saddam behaved the way he did if he had nothing to hide? But what about losing face vis-‡-vis his own people, his neighbors? I think that one of the tendencies we have is to assess the behavior of the other side with our own criteria. But again, this is where a multilateral organization helps because it has already integrated lots of multicultural parameters that help to better understand the inspected side patterns.

Mangan: I want to ask one more question and then we'll close out. In your talk you had a quote that said, "but we remain nonexistent in the media." Would you explain that more fully?

Baute: You know, I really think that in the timeframe 1997-1998, there was only one of the two organizations on TV and in the newspapers: that was UNSCOM and actually mostly Scott Ritter and his "concealment mechanism investigations." So it was not only the agency but also the technical parts and achievements of UNSCOM that were not in the media. Then all the technical work that had happened in terms of understanding the pre-1991 programs, destroying the remaining capabilities, implementing a credible monitoring program, etc., were totally forgotten. So, when in 2002, there was a certain line of communication aimed at discrediting inspections, it was easy for everybody to remember these publicized UNSCOM's problems and forget what was actually achieved at the more "boring" technical level.

Mangan: I want to thank you so much for participating and we hope that the outcome is going to be very positive. Thank you.

Avoiding Disaster: Perception and Reality

A Summary of the Closing Plenary Session of the 45th INMM Annual Meeting

Amy Whitworth
Chair, Government Industry Liaison Committee

In choosing this year's closing plenary session theme, the Government Industry Liaison Committee examined drivers for our community. Sometimes our motivators are real-world events like 9/11 or the NASA shuttle disaster. Sometimes our motivators are public perception and our knowledge of what a terrorist act or an accident can result in when overlaid on our nuclear world.

This year's closing plenary session presented a cross section of these motivators. We were fortunate to have three very distinguished individuals presenting this year: Brigadier General Ronald Haeckel, U.S. Department of Energy Office of Defense Programs; Michael Brooks, CNN correspondent; and Mary Alice Hayward, senior policy advisor to the U.S. Secretary of Energy on national security matters. Haeckel discussed lessons learned from the NASA shuttle disaster and their application to the NNSA; Brooks discussed the roles and responsibilities of the media in events involving weapons of mass destruction; and Hayward discussed the Global Threat Reduction Initiative.

In this issue of the *Journal,* we are publishing summaries of two of the speeches. This was our first experience with having an active member of the media speaking and we have learned that there is a very stringent clearance process for publishing Brooks' comments. So, unfortunately, we will have to wait until his summary is cleared by CNN. We anticipate publishing his summary in the winter issue of the *Journal.* However, it can be said with confidence that anyone attending the closing plenary session is not likely to forget Brooks' energetic and enthusiastic presentation and his invitation to come to Atlanta and visit CNN headquarters.

CNN Correspondent Michael Brooks, Senior Policy Advisor Mary Alice Hayward, GILC Chair Amy Whitworth, and Brigadier General Ronald J. Haeckel

Attendance at this closing plenary session was at a record high with more than 300 people present. There were a plenitude of questions for the speakers from the audience, so interest and participation were high. It is the goal of the Government Industry Liaison Committee to maintain this high level of quality for future closing plenary sessions.

NNSA Review of the Findings of the Columbia Accident Investigation Board Report

Brigadier General Ronald J. Haeckel
Associate Deputy Administrator for Defense Programs, National Nuclear Security Administration

On September 9, 2003, following review of the Columbia Accident Investigation Board (CAIB) report concerning the loss of the Space Shuttle *Columbia,* Ambassador Linton Brooks, administrator of the National Nuclear Security Administration (NNSA) of the U.S. Department of Energy (DOE), directed Brigadier General Ronald J. Haeckel (USAF), principal assistant deputy administrator for defense programs, NNSA, to lead an NNSA team to address a number of questions concerning the NNSA organization. Brooks realized that the CAIB report likely contained valuable lessons that could be used to develop recommendations to improve the "NNSA of the Future". The exceptionally well-detailed and analytically thorough CAIB report contained succinct recommendations to NASA for improving the organization and minimizing the chances of another disaster of equivalent scale.

Accordingly, Brooks directed Haeckel to address some key questions: Is NNSA's management and safety culture appropriate for an organization managing high technology, high-risk activities? Are there issues raised in the CAIB report that should be considered in implementing NNSA's new organizational model? Will the re-engineered NNSA provide for the necessary technical capability for properly executing NNSA's safety management and regulatory responsibilities? What changes should NNSA consider adopting in light of the lessons learned by NASA?

The CAIB had focused its review on NASA's high-risk, high-consequence activities related to human space exploration. Similarly, the NNSA team focused its review on potential high-consequence activities internal to NNSA, specifically, the operation of nuclear facilities at NNSA sites and the nuclear weapons production program. The most important outcome from the review was recognition of the need to understand and shape NNSA's safety culture through leadership, organizational alignment with safety requirements and policies, and the maintenance of adequate technical capability.

The NNSA team found striking similarities between NASA and NNSA when comparing their safety systems and cultures. Both organizations were built on Cold War rivalry with the former Soviet Union and both suffered similar uncertainties in their missions with the collapse of the Soviet Union. Both organizations also have a tradition of scientific and technical excellence.

The NNSA team believes that to be effective, NNSA's senior leadership must fully and actively support NNSA's safety culture. The NNSA team also emphasized the importance of NNSA senior leadership's being able to judge the status and effectiveness of NNSA's safety culture as it exists today and, for the future, to be able to identify and track trends in its effectiveness.

DOE and NNSA have invested many resources in integrated safety management (ISM). The NNSA team believes that ISM has demonstrated its value as a systems model that has survived multiple changes of leadership in DOE and NNSA. However, without robust and active support by NNSA's senior leadership, ISM will not lead to an enduring NNSA safety culture. Furthermore, ISM is not specifically designed to improve an organization's safety culture.

Brigadier General Ronald J. Haeckel

The majority of the NNSA team believes that NNSA as a whole has an adequate concern for safety for potentially high-consequence programs, such as nuclear facility operations and nuclear weapons design and production, including adequate systems to ensure that operations are proven safe before initiation or deployment. But, additional cultural change is needed to maximize the assurance of safety in those high-risk activities. NNSA needs to actively encourage a diversity of views, accept outside criticism, and avoid oversimplification of technical information. Additionally, NNSA's management must be vigilant in guarding against the organization's becoming conditioned by past successes.

The CAIB concluded that within NASA, the loss of a truly independent, robust capability to protect the system's fundamental requirements and specifications inevitably compromised those requirements and therefore increased risk. The CAIB concluded that it was critical to separate the authority of the program managers (who, by nature, must be sensitive to costs and schedules) from the authority of the "owners" of technical requirements and waiver capabilities (who, by nature, are more sensitive to safety and technical rigor). The ability to operate in a centralized manner or a decentralized manner, as appropriate, is the hallmark of a high-reliability organization. However, complex organizational structures—such as NASA—that mix centralized and decentralized functions or that split functions into centralized and decentralized pieces can hinder effective operations and result in severe consequences. The CAIB determined that NASA failed to operate effectively in either the centralized or decentralized modes, based on the roles, responsibilities, authorities, and relationships that developed over time. As a result, the organizational complexity of NASA created artificial barriers to effective communications throughout the organization. Assigning individuals to multiple, and in some instances, competing places in the organization, further complicated the problem.

Confusion about decision-making processes within NNSA, the attenuation of technical information, and the lack of clear accountability created by redundant management activities were previously significant concerns within NNSA. The "NNSA of the Future" model, with its line management responsibility for safety, eliminates much of the complexity and confusion that previously existed. Now site office managers are clearly held accountable for the operational safety and security of their sites. The NNSA Safety Functions, Responsibilities, and Authorities Manual (FRAM), published on October 15, 2003, was an important step in eliminating any remaining confusion about those responsibilities. NNSA has intentionally optimized its organization for decentralized risk acceptance decision-making to ensure that risk acceptance authority is delegated to the technically competent senior managers who have access to the most accurate and current information—the site office managers. NNSA's new organizational model depends heavily on decentralized decision making by site office managers. As NNSA's risk acceptance officials, the primary responsibility of site office managers is operational safety and security. However, some confusion still exists regarding the role of centralized decision-makers with respect to operational safety oversight, given that NNSA has a limited independent safety organizational construct.

The CAIB concluded that changes in NASA's organizational structure, which were designed to improve efficiency, undermined the redundancy essential to successfully operating a high-risk enterprise. NASA's contractual arrangements, organizational structure, and downsizing, taken together, undermined the adequacy of federal oversight of the contractor and resulted in the transfer of too much authority for safety to the contractor.

The NNSA team concluded, that for NNSA, redundancy and the level of oversight should be proportional to the risk (i.e., higher risk = more redundancy). No hazardous facility or operation that presents a risk to the public or co-located workers should be without redundancy in oversight processes. NNSA site managers have multiple, although not necessarily redundant, federal sources of technical information to support risk acceptance and safety assurance decision-making, including authorization basis professionals, facility representatives and subject matter experts. Additionally, the DOE Office of Independent Assessment (OA) provides the NNSA administrator with an independent audit function, although OA has no day-to-day safety assurance function. However, the NNSA team believes that NNSA can further enhance the levels of redundancy in its oversight processes.

Finally, the CAIB determined that NASA's complex and often hierarchal organizational structure diffused and confused responsibility, essentially leaving no one person accountable. NASA's culture also lent greater technical credence to communications that originated from higher in the organization and the organizational structure often stifled or blocked communications.

The NNSA team agreed that NNSA should consider establishing the position of chief of defense nuclear safety (chief) in lieu of an environmental, safety & health (ES&H) advisor. The chief would be responsible for developing, maintaining and overseeing corporate technical ES&H policies and standards and for reviewing and approving any waivers to those policies or standards.

The NNSA team concluded that a careful balance in the combination and interrelationships between contractors and their respective Site Offices should be maintained, as well as between contractor and Site Office self-assessment and headquarters oversight. The careful balance between organizational efficiency and the adequate assurance of safety through redundancy and oversight must be maintained. With regard to the implementation of line oversight/contractor assurance systems (LO/CAS), the adequacy of these new assurance systems should be verified before reducing existing oversight, particularly in high-hazard operations. NNSA should consider re-instating headquarters line management oversight practices to address self-assessment and external review of federal and M&O contractor operations until LO/CAS is fully implemented.

The NNSA team believed that NNSA as a whole should embrace the importance of fully evaluating and considering minority opinions—something that the naval reactors program has embraced as part of its culture from the beginning. It may be necessary to provide a new or revitalized organizational conduit, along with revised decision-making processes, as a means to encourage the airing of minority opinions and the effective evaluation of their input into NNSA's decision-making.

The CAIB concluded that years of workforce reductions and outsourcing had culled NASA's layers of experience and hands-on systems knowledge that once provided a capacity for safety oversight. NASA became increasingly dependent on contractors for technical support, accompanied by increased contract monitoring requirements. The CAIB also concluded that NASA did not have a recurring training program, was not aggressive in training, and did not institutionalize lessons learned into training. The CAIB was appalled that the Navy had trained more personnel on the root causes of the loss of the *Challenger* than had NASA.

The CAIB found that while NASA had a number of information systems for reporting and capturing information with potential safety significance, the captured information was not consistently analyzed, tracked, trended, or acted upon to resolve underlying causes. The CAIB concluded that this failure was one of many root causes in both the *Challenger* and *Columbia* accidents.

After studying the CAIB report, the NNSA team highlighted three items with regard to adequate technical capability including: workforce reductions, outsourcing, and loss of organizational prestige can cause an erosion of technical capability; technical capability to track known problems and manage them to resolution is essential; and a quality technical training and qualification program is vital for the success and safety of high-risk operations.

The NNSA team considered that the erosion of ES&H technical capability might be a serious issue within NNSA. As the organizational transition progresses (e.g., establishment of the Albuquerque Service Center), it is not clear whether the site offices have sufficient ES&H support. Consolidation of personnel into the Service Center has already resulted in a large loss of ES&H nuclear safety expertise. More than 50 percent of nuclear safety experts within the ES&H department have taken other positions or declined the directed re-assignment. Headquarters, the

Albuquerque Service Center and the site offices must establish clear mutual expectations of each other's technical capabilities and support plans. Although each recently completed and validated individual staffing plans, a deeper integrated review may be useful in ensuring that adequate technical capability is maintained and that sufficient capacity and processes are in place for the recruiting, training and career development of technical personnel.

Like NASA, NNSA needs the ability to capture, analyze and share safety information, but has limited capability to do so in some areas. NNSA may need to consider establishing an analysis/trending function for complex-wide issues at either HQ or the service center to be periodically reviewed by NNSA senior leadership. Additionally, NNSA needs a process to identify and evaluate operational experiences outside of itself and DOE, such as the *Columbia* disaster and the near-miss at the Davis-Besse nuclear power plant, to disseminate the lessons learned from those experiences, and to develop and implement recommendations resulting from those lessons learned.

Finally, NNSA requires a cadre of technically trained personnel in order to properly perform its mission. This includes key senior management positions, such as site office managers, whose responsibilities include safety of nuclear and other hazardous facilities and operations. Formal qualification and experience requirements, training, and/or compensatory measures must be identified for those individuals within NNSA.

Haeckel concluded by stating that there were many important lessons learned from the NASA shuttle disaster that can be applied to the NNSA. Serious consideration is being given to the recommendations from Haeckel's review and some, most notably the designation of a chief of defense nuclear safety, have been implemented.

Mary Alice Hayward

Global Security for Nuclear Materials

Mary Alice Hayward
Senior Policy Advisor on National Security Matters to the Secretary of Energy

Hayward identified the task of securing nuclear materials around the globe as one of the most urgent challenges the civilized world faces today. Citing the terrorist attacks on September 11 and at Bali and Madrid, she stated that there are no questions concerning the goals of terrorists and the fact that they continue, on an ever-increasing scale, to seek terrorism as a means to achieve their aims. Given black market activities, the United States must work even harder to control the proliferation of nuclear designs and expertise, and to reliably safeguard the manufacture and sale of high-tech components, such as centrifuges and super-strong rotor tubes. Accordingly, the department is focusing on the element that makes nuclear weapons nuclear; locating, identifying and securing nuclear and radiological material.

A decade ago, in the wake of the Cold War, the nonproliferation programs were narrowly focused on securing nuclear weapons and weapons-grade material made vulnerable by the collapse of the Soviet Empire. Since 2001, the Bush administration broadened and accelerated these nonproliferation programs.

As a result, the relationship between the United States and Russia is stronger. This close association has translated into great progress on many fronts:

First is substantially increased nonproliferation spending. The president's most recent DOE budget request to the U.S. Congress sought a nonproliferation budget of $1.35 billion—a nearly 75 percent increase over the last—and largest—budget request of the previous Administration. Second, a number of important nonproliferation programs have been accelerated and expanded, such as the efforts to secure 600 metric tons of weapons-usable material in Russia. Third, a number of key new initiatives have been launched to address the evolving nuclear security threat:

In June 2002, the United States proposed—and the G-8 leaders established—the Global Partnership Against the Spread of Weapons and Materials of Mass Destruction. This ten-year program brings important new resources to bear on nonproliferation, disarmament, counter-terrorism, and nuclear safety and will engage countries that previously had not been involved

In spring 2003, the DOE began a new program with Russia to upgrade security for its strategic rocket forces sites. By the end of this year two sites will have been secured, with the remaining 15 sites secured by the end of 2008.

On May 31, 2003, the president announced the establishment of the Proliferation Security Initiative, a program of counterproliferation partnerships to allow the United States and its partners to interdict weapons of mass destruction (WMD) proliferation shipments on land, at sea, or in the air.

Last year, the DOE created the MegaPorts program to place radiation detection equipment at the world's major seaports. This summer, installation of radiation detectors will be completed at the largest seaport in Europe, the Port of Rotterdam. Other agreements and work with Sri Lanka and Spain are in process.

Last year, Russia and the United

States established a joint process to allow upgrades to security at Russia's most sensitive sites without compromising Russian security interests.

In 2002, at the annual IAEA General Conference, Secretary Spencer Abraham called upon the member nations of the IAEA to establish a new international effort to account for, secure, and, where appropriate, dispose of radioactive sources that could be used in a radiological dispersal device. In spring 2003, the DOE launched this effort by co-hosting, along with the Russian Federation and the IAEA, an international conference for more than 120 nations. This conference set the stage for our new Radiological Threat Reduction program, which is working in more than 40 countries to prevent the acquisition of radiological dispersal devices by terrorists.

And, finally in June of this year, the G-8—under U.S. chairmanship—endorsed a nonproliferation action plan that will further aid our progress. The G-8 partners actively affirmed their support to eliminate the use of highly enriched uranium (HEU) in research reactors, and to secure and remove fresh and spent HEU fuel. And they also spoke strongly in favor of controlling and securing radiation sources, as well as strengthening export controls and border security. The strong and growing G-8 support for this work is extremely important and will no doubt facilitate work in these areas.

Hayward cautioned that as the global proliferation threat continues to evolve, it is clear that an even more comprehensive and urgently focused effort is needed to respond to emerging and evolving threats. She acknowledged that while the efforts expended by the DOE are significant, there is always more that the DOE can and should do. Accordingly, Abraham with IAEA Director General Mohammad ElBaradei announced the Global Threat Reduction Initiative (GTRI) to secure, remove, or dispose of an even broader range of nuclear and radioactive materials around the world that are vulnerable to theft.

GTRI is a comprehensive initiative to protect, collect, and secure materials not satisfactorily dealt with by existing nonproliferation or threat reduction efforts. Specifically under the initiative:

- The United States will first work in partnership with Russia to repatriate all fresh and spent Russian-origin nuclear fuel that currently resides at research reactors around the world.
- The United States will take whatever steps necessary to accelerate and complete the repatriation of U.S.-origin research reactor spent HEU fuel – about 20 metric tons in all—from more than forty locations around the world.
- The third major feature of the GTRI will be the conversion of the cores of 105 targeted civilian research reactors that use HEU that will continue to operate using low-enriched uranium fuel instead.
- The final pillar of GTRI will be to work to identify other nuclear and radioactive materials and related equipment that are not yet covered by existing threat reduction efforts. Once identified, these materials and equipment will be secured, removed, relocated, or disposed of in the fastest and safest manner possible. The most vulnerable facilities will be addressed first, to ensure that there are not any gaps that would enable a terrorist to acquire these materials.

Obviously the GTRI is a very expansive, robust undertaking. Its success will require several things. First, a single organization is needed whose sole purpose is to make sure it is done on time. Such an office has been established with the NNSA. Second, resources are needed. The United States is prepared to spend the resources necessary to guarantee success, but heightened international cooperation is needed to finish the job. Dedicated as the United States is to such an undertaking, it is clear that a truly effective nonproliferation regime is made up of the collaboration of efforts by as many nations as possible, not just a few. This is particularly true with the collection of materials that are not of Russian or U.S. origin, or that may be located in locations that pose certain challenges that the United States and Russia cannot address alone.

This is why Abraham proposed the Global Threat Reduction Initiative Partners' Conference. This conference will build support for international efforts to identify, secure, recover or facilitate disposition of high-risk nuclear and other radioactive materials that pose a threat to the international community. It will also focus on material collection and security of other proliferation-attractive materials not of U.S. or Russian origin, such as those located at conversion facilities, reprocessing plants, and industrial sites, as well as the funding of such work.

Hayward stated that the GTRI is precisely the vehicle needed to take the necessary action now. It is ambitious, but realistic. It is bold, yet practical. It builds on previous successes and positions us for new ones and it's the strategy best suited to dealing with the defining threat of the 21st century.

Calculating External Dose Increase from Partial Loss of Lead Shielding in a Spent Fuel Cask

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Abstract

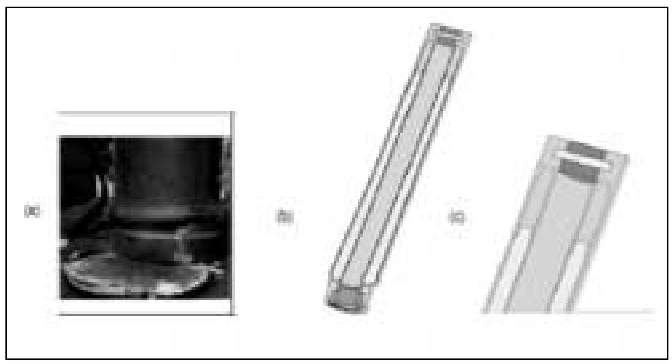
In this work, a stainless steel-lead-stainless steel (SS-Pb-SS) transportation cask containing spent nuclear fuel is assumed to be damaged with a consequent loss of some lead photon shielding. One possible scenario is a collision during transit that subjects the cask to a severe impact on its end, which causes the lead layer to *slump,* thus leaving a gap in the lead shield layer. The factor by which the external photon dose rate increases due to the partial loss of shielding is calculated. This analysis compares the effective shielding of damaged and undamaged casks and estimates this factor *F* (increase in dose rate) at receptor points away from the cask. The analysis uses analytical point-kernel methods with radiation buildup factors and dose response functions to approximate the increase in dose rate. Representative values of *F* are computed and presented as functions of position relative to the cask.

Introduction

Since 1977, the risks of transporting radioactive materials have been estimated using the RADTRAN code.[1,2] RADTRAN includes a module for calculated doses to the public in the event of a transportation accident that results in release of radioactive material from the transportation package. However, accidents that could result in increased radiation dose to the public, but that did not result in a radioactive release, have not been included. One particular type of accident, in which shielding from photon emissions is decreased, has only recently been considered.[3, 4] The model described below allows the analyst to calculate doses to the public from such an accident.

If a stainless steel-lead-stainless steel (SS-Pb-SS) transportation cask containing spent nuclear fuel is damaged in transit, some loss of lead photon shielding could occur. For instance, the cask may be involved in a collision that subjects it to a severe impact on its end, which causes the lead layer to *slump,* thus leaving a gap in the lead shield layer, as shown in Figure 1. The factor by which the external dose rate (or dose) is increased due to the partial loss of shielding is necessary when estimating the consequences of such an accident. In this paper, a conservative analytical model compares the effective shielding of damaged and undamaged casks and estimates the dose increase factor at receptor points outside the cask.

Figure 1. a. Photograph of the text cask showing a bulge from lead slumping resulting from an impact (see Reference 3). b. Image taken from finite element analysi for a lead-lined truck cask involved in a 90-mph corner impact (bottom of image) without impact limiters. The void in lead shielding on the end away from the impact is shown clearly(5). c. Blow-up view of the void shown in Figure 1b.



With only the physical dimensions of the cask, receptor point locations, the degree of lead slumping from an impact, and the information related to radionuclide inventories in the spent fuel as input, most longitudinal impact scenarios can be analyzed.

The Two-Dimensional Cask Model

Assuming that the spent fuel can be modeled as an isotropic, photon-emitting line source (i.e., only photons contribute significantly to dose), all calculations are performed on a two-dimensional model for an undamaged cask and for a damaged cask with some amount of lead shielding missing. Figure 2a illustrates the model used for the undamaged cask, and Figure 2b shows the model used for the damaged cask that has lost some lead shielding (described by void height *d* in the lead layer). Only half of the two-dimensional axial cross section is analyzed because of symmetry, and its total thickness is denoted by *x0,* which is the outer radius of the layer of stainless steel surrounding the lead shielding. The length of the spent fuel assemblies that emits radiation (fueled length) is *L,* which will be referred to as the length of the cask. Z_{FOV} (in which the subscripts stand for *field of view*) is the length of a line including all possible receptor points outsidethe SS-Pb-SS shielding. The line is parallel to the long axis of the cask, and is centered with respect to the length of the cask (there are as many receptor points above the top of the cask as below the bottom of the cask). Because of rotational symmetry, this line represents a cylindrical shell of receptor points enclosing the cask. The dose rate at points along this line is equivalent to the dose rate at points on the cylindrical shell. As illustrated in Figure 2, $D_{FOV} > 0$ is the perpendicular distance from the line containing the receptor points (Z_{FOV}) to the outside of the stainless steel layer surrounding the lead shielding of the cask. The lengths Z_{FOV} and D_{FOV} are sufficient to describe the field of view to be analyzed. Also, *z* is the coordinate on the line source, and *z.* is the coordinate along Z_{FOV}. The combination of coordinates *z* and *z'* describes the emission point of a photon, the direction the photon is traveling, and the receptor point receiving the dose that results from the photon.

Calculation for Monoenergetic Source

The dose rate to a receptor point is calculated by integrating the point-kernel fluence Equation 6 over a range of possible source points $zmin \leqslant z \leqslant zmax$, where $zmin \geqslant 0$ and $zmax \leqslant L$, and multiplying by a suitable factor to convert fluence to dose rate. Thus, for a receptor placed at an arbitrary point z' outside the cask, the dose rate from an isotope emitting photons with energy *E0* will be approximately given by

$$D(z')_{mono} \cong S_L R(E_0) \int_{z_{min}}^{z_{max}} \frac{B(E_0, \mu_{Pb} x_{Pb}) \exp\left[-\mu_{Pb}(E_0) x_{Pb}(z,z') - \mu_{SS}(E_0) x_{SS2}(z,z')\right]}{4\pi r^2} dz, \quad (1)$$

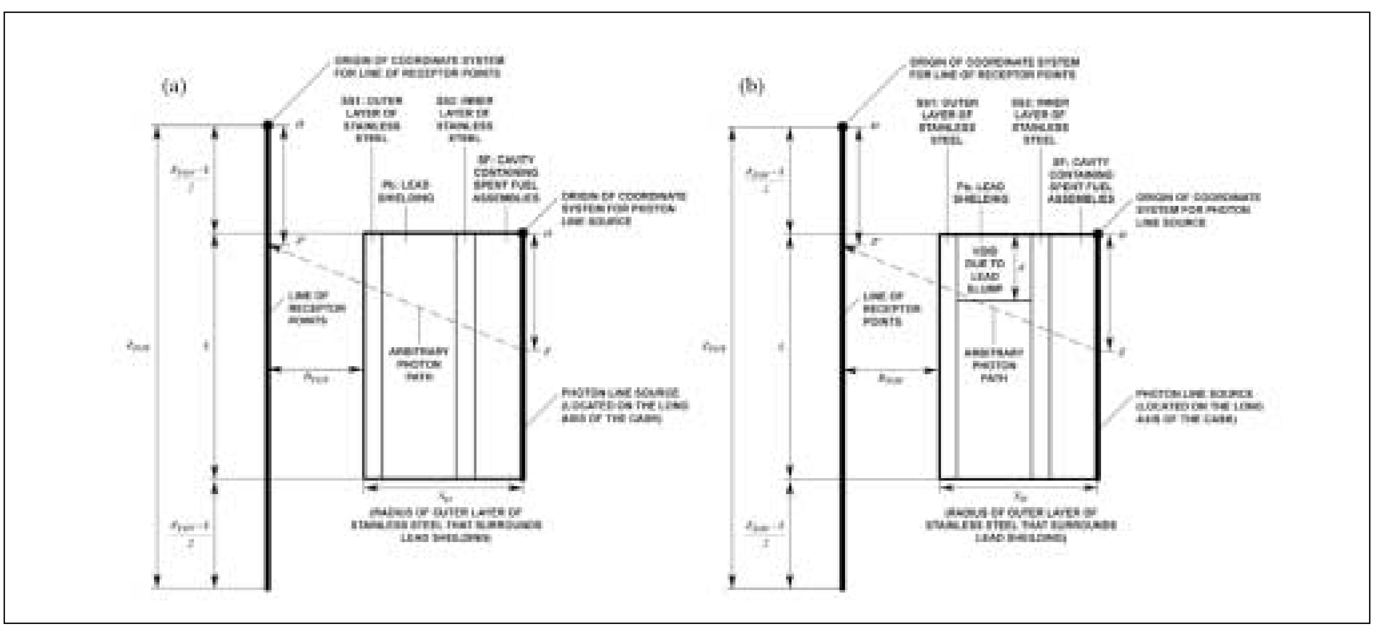
where $D(z')_{mono}$ is the dose rate to a receptor located at *z'* from the monoenergetic source, SL is the source photon emission rate per unit length of spent fuel (assumed constant over the shielded length of spent fuel assemblies), *R(E0)* is the dose response function (explained later in this section), *B(E0, μPbxPb)* is the buildup factor for photons in lead, μ (with the appropriate subscript, e.g. SS for stainless steel) is the attenuation coefficient for each material, and *x* (with the appropriate subscript, e.g., SS2 for the inner layer of stainless steel) is the photon path length through each layer to be considered in the calculation.

The distance from arbitrary point *z* on the line source to receptor point *z'* is

$$r = \sqrt{\left(\left[\frac{Z_{FOV} - L}{2} + z\right] - z'\right)^2 + (x_0 + D_{FOV})^2}. \quad (2)$$

Implicit in (1) are the assumptions that buildup is only significant in the lead (Pb) shielding, and that the outer layer of stainless steel (SS1) shielding is effectively transparent to photons. Buildup is only taken into account in the lead shielding because the lead layer is much thicker and has a higher attenuation coefficient than either of the two stainless steel layers. The inner layer of stainless

Figure 2 *a. 2D representation of undamaged cask model. b. 2D representation of damaged cask model.*



steel (SS2) was accounted for by constraining the limits of integration (z_{min} and z_{max}) such that the only photons considered are those that traverse the entire thickness of SS2 (i.e., photons do not travel through the corners of SS2). This results in a single equation for the photon path lengths through SS2 in the integration, which makes it simple to account for this layer. However, placing this same constraint on the outer layer of stainless steel (SS1), along with the constraint already placed on SS2, could often result in the limits of integration (z_{min} and z_{max}) being so close together that not enough photon source points are sampled for receptors beyond the ends of the cask (because SS1 is farther from the source than SS2). Thus, SS1 is neglected for simplicity. This will not produce significant errors because SS1 will attenuate much less than the lead layer. The dose response function is assumed to be that for the monoenergetic photons of energy *E0* emitted from the source. However, because of buildup, a spectrum of photons with unknown energy range *E* will emerge from the cask. The expression for dose rate D actually fits the form

$$D(z') = \int_{\Delta E} R(E)\Phi(E,z')dE, \qquad (3)$$

where *R(E)* is the continuous energy dose response function, and $\Phi(E, z')$ is the photon fluence rate per unit energy as a function of energy (spectrum) at the receptor point of interest. Since the continuous energy response function and the spectrum are both unknown quantities, an expression for dose rate that fits the following form is desired

$$D(z') = A\int_{\Delta E}\Phi(E,z')dE \cong AS_L\int_{z_{min}}^{z_{max}} \frac{B(E_0,\mu_{Pb}x_{Pb})\exp\left[-\mu_{Pb}(E_0)x_{Pb}(z,z') - \mu_{SS2}(E_0)x_{SS2}(z,z')\right]}{4\pi r^2}dz, \qquad (4)$$

where *A* is a constant factor quantifying the dose response. Thus, from (3) and (4), *A* is given by

$$A = \frac{\int_{\Delta E} R(E)\Phi(E,z')dE}{\int_{\Delta E}\Phi(E,z')dE}. \qquad (5)$$

Therefore, with no approximation, the constant *A* is given by the fluence-weighted average of the continuous energy response function. Since the continuous energy response function and the emerging photon spectrum are both unknown, the constant *A* is approximated by assuming that the fluence is very small at every energy except for the photon source emission energy *E0* and that *E0* does, in fact, fall within the energy range *E*. Making these assumptions, the integrands in Equation 5 are very small at every point except

E0, and the expression for *A* becomes

$$A \cong \frac{R(E_0)\Phi(E_0,z')}{\Phi(E_0,z')} = R(E_0). \qquad (6)$$

Figure 3. F(z') for a representative truck cask at variable distances DFOV from cask (ZFOV=10m, L=426.72cm=fueled length of assembly for a representative 17x17 PWR assembly (Reference 9, Table 4.1-1) d=10cm, burnup=57,469.5 MWD/ MTHM, cooling time=ten years); obtained from model presented in this analysis.

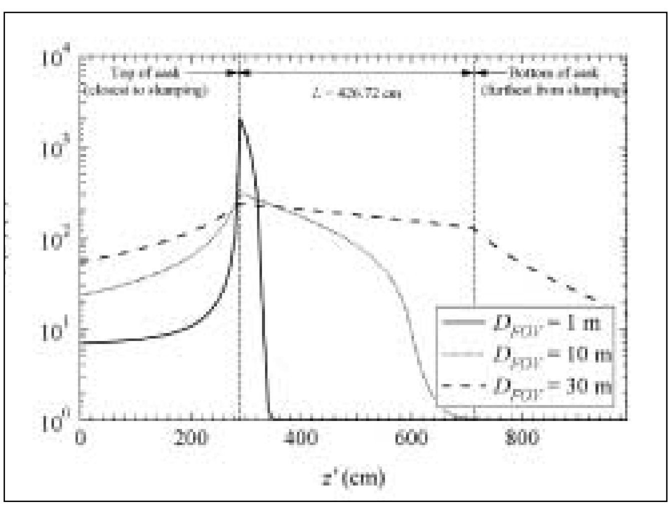
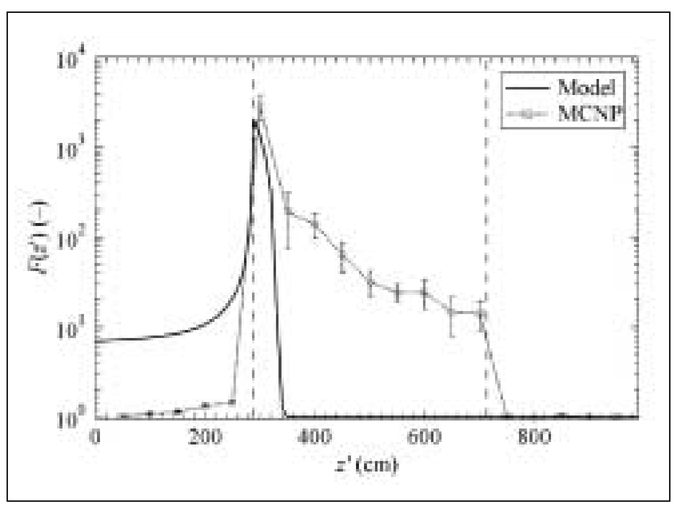


Figure 4. F(z') for the representative truck cask at distance DFOV=1m from cask (ZFOV=10m, L=426.72cm, d=10cm, burnup=57,469.5 MWD/MTHM, cooling time=ten years); compares result obtained from model presented in this analysis to result obtained from MCNP model.



$$F(z')_{mono} = \frac{D(z')_{mono,\,damaged}}{D(z')_{mono,\,undamaged}}$$

$$= \frac{\left(S_L R(E_0) \int_{z_{min}}^{z_{max}} \frac{B(E_0, \mu_{Pb} x_{Pb}) \exp\left[-\mu_{Pb}(E_0) x_{Pb}(z,z') - \mu_{SS}(E_0) x_{SS2}(z,z') \right]}{4\pi r^2} dz \right)_{damaged}}{\left(S_L R(E_0) \int_{z_{min}}^{z_{max}} \frac{B(E_0, \mu_{Pb} x_{Pb}) \exp\left[-\mu_{Pb}(E_0) x_{Pb}(z,z') - \mu_{SS}(E_0) x_{SS2}(z,z') \right]}{4\pi r^2} dz \right)_{undamaged}}, \quad (7)$$

and since S_L and $R(E_0)$ are the same in both cases,

$$F(z')_{mono} = \frac{\left(\int_{z_{min}}^{z_{max}} \frac{B(E_0, \mu_{Pb} x_{Pb}) \exp\left[-\mu_{Pb}(E_0) x_{Pb}(z,z') - \mu_{SS}(E_0) x_{SS2}(z,z') \right]}{4\pi r^2} dz \right)_{damaged}}{\left(\int_{z_{min}}^{z_{max}} \frac{B(E_0, \mu_{Pb} x_{Pb}) \exp\left[-\mu_{Pb}(E_0) x_{Pb}(z,z') - \mu_{SS}(E_0) x_{SS2}(z,z') \right]}{4\pi r^2} dz \right)_{undamaged}}. \quad (8)$$

Combining equations 4 and 6 gives 1. So far, several assumptions have been made, including that the spent fuel radiation source is well-approximated by an isotropic, photon emitting line source. As will be discussed later, these assumptions will be tested for multiple cases by comparing results obtained from this analysis to much more accurate shielding simulations. The factor F by which the dose rate from the monoenergetic source is increased by due to shielding loss from lead slumping is shown in equations 7 and 8 above.

The only parameters needed for the monoenergetic treatment are those describing the physical dimensions of the undamaged and damaged casks, the source energy, and the receptor location.

Calculation for Source Emitting Multiple Photon Energies

A model was developed to estimate F at an arbitrary receptor location for a source emitting multiple photon energies (to account for the key isotopes present in the spent fuel). To do this, the equation for dose rate, which is Equation 1 from the monoenergetic treatment, is averaged over the multiple emission energies using activity fractions for a set of key isotopes and branching ratios for the photon energies emitted by each isotope. Some results for a representative truck cask (single assembly SS-Pb-SS cask) [Reference 3, Table 4.1] are shown in Figure 3. The calculations were performed using approximate radionuclide inventories (from ORIGEN) for a single 17x17 PWR assembly with 57,469.5 MWD/MTHM burnup, a beginning of life enrichment of 4.236 percent, and a cooling time of ten years.[7] The key set of isotopes in the fuel was specified such that it comprised greater than 99 percent of the total activity calculated for the ten year cooling time. For this set of isotopes, activity fractions were calculated and branching ratios for all photon energies emitted by each isotope were tabulated[8] to perform the overall calculations.

The model suggests that if the line of receptor points is close to the cask (within 1m), the increase in dose is very large for points near the shielding gap created by the lead slump, but very rapidly drops off to unity for points near more shielded locations (e.g., near the bottom of the cask). However, as the distance from the cask increases, the dose increase begins to converge to a value greater than unity for receptors within the bounds of the cask. This is explained by the fact that as the line of receptor points moves away from the cask, more and more receptor points experience dose contributions from photons traveling through at least some portion of the gap in the lead shielding. In other words, the receptors have more of a view of the source through the gap. Overall, the model suggests that when one is very close to the cask, the dose increase is quite large near the gap in the lead shielding, but not at other points. However, when one is far from the cask, the dose increase is moderate at many points.

Benchmarking with MCNP

To test the assumptions made, the results obtained from the model presented here will be compared against Monte Carlo N-Particle (MCNP[10]) calculations for multiple cases (i.e., different types of casks and variable distances from those casks). The MCNP calculations employ a much more detailed model accounting for self-shielding within the spent fuel and the three-dimensional nature of the real problem, and will therefore be regarded as much more accurate representations of the cases to be analyzed. Furthermore, for most photon dose calculations, it has been shown that MCNP agrees to within ±20 percent of actual dose measurements.[11]

The representative truck cask has been analyzed in MCNP for a distance D_{FOV} from the cask of 1m. In the MCNP model, the fuel assembly lattice was constructed according to specifications for a generic 17x17 PWR assembly containing twenty-five non-fuel elements [Reference 9, Table 4.1-1 and Figure 4.3-4a]. Each fuel rod was modeled as a volumetric, isotropic photon source emitting all of the photon energies for the set of key isotopes with appropriate emission probabilities determined from the calculated inventory and branching ratios. All other parameters are the same as those used to obtain the results shown in Figure 3. Figure 4 shows the MCNP result for this case along with the analogous result obtained from the model presented in this analysis, which is also shown in Figure 3.

As shown in Figure 4, the results agree well near the gap in the lead shielding, but not too well elsewhere. This is most likely a result of the line source assumption used in this analysis, whereas in the MCNP calculation, the source is modeled volumetrically. The promising feature of the comparison in Figure 4 is that the maximum value obtained from the model presented here is within one standard deviation of the maximum value from MCNP. The spent fuel assembly will behave more like a line source for receptors farther from the cask, so the results will agree at more receptor points as D_{FOV} is increased beyond 1m. Currently, MCNP calculations for larger D_{FOV} values with the representative truck cask model and a similar representative rail cask model are being performed, but the complete set of results has not been obtained yet.

Conclusion

A model has been developed for a stainless steel-lead-stainless steel (SS-Pb-SS) transportation cask containing spent nuclear fuel that was assumed to be damaged with a consequent loss of some lead photon shielding. A method was developed for estimating the increase in external dose rate (described by the factor *F*) due to the partial loss of shielding at arbitrary receptor points for a monoenergetic photon source. In addition, a method built upon the monoenergetic source treatment was developed for computing *F* for a source emitting several photon energies (to account for key isotopes present in spent fuel). Finally, results were obtained for a SS-Pb-SS for several cases, and one such case was compared against a more accurate shielding calculation. For current and future work on this problem, correction factors for truck and rail casks will be extracted from the shielding calculations for mean and maximum F values to be used in RADTRAN.

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Evaluation of Risk of Security Failure of Protected Object

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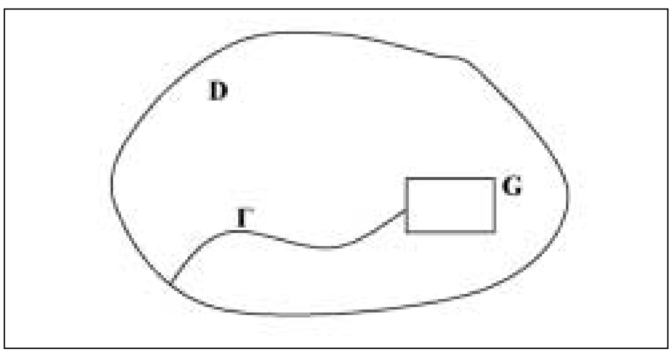
Abstract

The problem of evaluating the risk of security failure of a protected object, and optimization of a security system, is defined. An approach to solving this problem using probability theory and variational calculus is proposed and an analytical solution is given in a special case.

Problem Definition

The protected area *D* containing the protected object *G* is considered, as shown in Figure 1. There is the resource of a means of detection (recognition, elimination) of the object called violator, assumed to be penetrating into the area *D* .

Figure 1. *Definition of areas D and G*



The presumed aim of the violator is the object *G*. After reaching the boundary of *G* it is assumed the violator can make a diversion. This results in the following three levels of problems:

Problem I. Calculating the probability, P_r, of the violator being detected along the known trajectory Γ of violator movement from the boundary of the area *D* to the boundary of the area *G*.

Problem II. Finding the curve with the minimal probability of violator detection under the given means and position of detection. This probability will be the *effectiveness* measure for a given method of object security.

Problem III. Finding the most effective position in which to place a security device, i.e., that position of violator detection that maximizes the minimal along all of possible curves of violator intrusion. Note: This problem is similar to the whole class of problems that describes the real situations and certain spheres of human and natural activities. For example, it can be the problem of security of displacement or inhabitancy in any territory, evaluation of accident and catastrophe probabilities, etc.

Thus the proposed solution given below is suitable for all similar problems. The interpretation of relevant concepts such as the phase space and risk function (and its arguments), are determined by each specific problem. However, we will use the terms corresponding to the problem set given above.

Risk Function

The protected area *D* is considered *s* the area (possibly infinite) of a finite-measure Hilbert space $R^n(x_1 \ldots x_n)$ with some metric (e.g., following from its determination of space). This space is called the *phase space.*

Every point $M \in D$ has a corresponding *risk function* $p(M;t_0;\tau)$ defined as the probability density function of violator detection at the point *M* during the time interval $[t_0;\tau]$, where t_0 is the time of violator appearance at the point *M*. The risk function possesses the features of the probability density function:

1. The function $p(M;t_0;\tau)$ is defined in $D\text{x}(-\infty;=\infty)\text{x}[0;=\infty)$;
2. The inequality $p(M;t_0;\tau) \geq 0$ is true for all vlaues of the arguments;
3. The correlation $\int_{t_0}^{\infty} p(M;t_0;\tau - t_0)d\tau \leq 1$ is true for all M, t_0.

Thus the integral $F(M;t_0;S)= \int_{t_0}^{t_0+s} p(M;t_0;\tau - t_0)d\tau$ is understood to be the probability of violator detection at the point *M* during the time *S* beginning from the moment t_0.

Area *D* is called the *risk area*. Generally speaking, we can suppose not just one but several risk function areas in the area *D* corresponding to different reasons of security failure. However, the analysis of these options will be made in another paper.

For simplicity the value of the risk function at the given point is considered to be independent of the time of violator appearance at this point. Consequently, the meaning of the risk function is simplified and we may regard $p(M;t)$ as the probability density function of violator detection at the point *M* during the time *t*.

Probability of Violator Detection on the Given Curve

Consider the violator movement along any curve Γ with non-zero velocity in risk area *D*. We will find the value of the functional *P*r, the probability of violator detection moving along Γ. To do this the value of non-detection probability 1-*P*r is easier to calculate than *P*r itself.

The curve Γ is divided into *k* small segments. The non-detection of the violator on all segments are independent due to the theorem of probability multiplication:

$$1 - P_\Gamma = \prod_{i=1}^{k} (1 - p_i),$$

where p_i is the probability of violator detection on the *i-th* curve segment.

Finding the logarithm of this equality results in

$$\ln(1 - P_\Gamma) = \ln \prod_{i=1}^{k} (1 - p_i) = \sum_{i=1}^{k} \ln(1 - p_i).$$

Since the probabilities p_i are small due to the small segment divisions then 1n(1–pi) ≈ – p_i. Neglecting smaller addends results in

$$\ln(1 - P_\Gamma) = -\sum_{i=1}^{k} p_i.$$

Under the continuous variations of the risk function along the curve, the value p_i. can be approximately substituted by the probability of violator detection at any point M_i. during the time t_i. of the movement on the *i-th* segment:

$$p_i = \int_0^{t_i} p(M_i, \tau)\,d\tau$$

As the segments are small, the movement time along the segments is small and the integral can be approximated by the multiplication:

$$p_i = p(M_i; 0) \cdot t_i = p(M_i; 0) \cdot \frac{dS_i}{V},$$

where dS_i is the length of the *i-th* segment, and *V* is the movement velocity along the segment. Hence

$$\ln(1 - P_\Gamma) = -\sum_{i=1}^{k} p(M_i; 0) \cdot \frac{dS_i}{V}$$

In the limit of small segment lengths all our approximate equalities become exact and we have:

$$\ln(1 - P_\Gamma) = -\int_\Gamma p(M; 0) \cdot \frac{1}{V}\,dS \quad (1)$$

Thus the problem of determing the probability of violator detection on a given curve is reduced to the calculation of line integral (1). This probability is given by:

$$P_\Gamma = 1 - \exp\left(-\int_\Gamma p(M; 0) \cdot \frac{1}{V}\,dS\right).$$

Notes: 1. The movement velocity *V*, in general depends on the point and movement direction, e.g., it is more difficult to move through the marsh (up to the hill) then on the road (down the hill):

$$V = V(M; \vec{a}),$$

where the point, $\vec{a} = \vec{a}(M)$ is the movement direction determined by the direction of Γ at the given point. The value depends on the landscape conditions (natural and artificial), violator equipment, and so on. The value $V(M;\vec{a})$ is considered to be given. Furthermore, for simplicity we only consider the case in which the velocity depends on the point and is independent of the movement direction, i.e., $V=V(M)$.

2. In addition to the segments in which the violator can move continuously (although with different velocities), he may reach points along the trajectory Γ where he needs to stop. These points can be coincident with fences, obstacles, watchmen, doors,or safes and the violator needs time to surmount these obstacles. These points are considered to be known together with the time required for surmounting them.

We now consider the case when the violator reaches these points (obstacles) on the trajectory Γ. We note there are a finite number of such points on Γ because otherwise the entire Γ time would be infinite. The probability of violator detection near an obstacle is given by

$$F(P_i; T_i) = \int_0^{T_i} p(P_i; \tau)\,d\tau$$

where T_i is the time required for surmounting the ith obstacle. Taking into account all of the above mentioned points, the correlation (1) takes the form:

$$\ln(1 - P_\Gamma) = -\int_\Gamma \frac{p(M; 0)}{V(M)}\,dS + \sum_{i=1}^{L} \ln\left(1 - \int_0^{T_i} p(P_i; \tau)\,d\tau\right) \quad (2)$$

where the first integral is the sum of integrals along the segments between the obstacles.

Problem of Determing Effectiveness of Detection Means

We are looking for the ways a violator will most probably be successful. So we must find the curve Γ, where the probability of detection P_{Γ}^{-} is minimal. Consequently, the value $1n(1-P_{\Gamma}^{-})$ has to be maximal (and negative because $1-P_{\Gamma}^{-} \leq 1$). Taking the modulus[??] of this value we obtain the problem of optimization of the value:

$$I(\Gamma) = \int_{\Gamma} \frac{p(M;0)}{V(M)} dS - \sum_{i=1}^{l} \ln\left(1 - \int_0^{T_i} p(P_i;\tau)d\tau\right) \to \min \quad (3)$$

Thus, as formulated earlier in this paper, problem II is reduced to a typical problem of the calculus of variations. The selection of means is determined by the calculation particularities and risk function definition (but this function is known!), the view of boundary conditions, and so on.

In our case the curve Γ is constrained to the problem boundary conditions: one end of L belongs to the boundary $\delta(D)$ of the risk field D, the other to the boundary $\delta(G)$ of the protected G object .

So the problem of variations is the problem with one (if the protected object is pointlike) or two (if the object is extensive) movable ends.

Risk Function Dependence on Disposition of Detection Means

Let $C_1 \ldots C_n$ be the points where the detection means are located (we call them briefly *guards*). Then the risk function depends on $C_1 \ldots C_n$:

$$p(M,t) = p_{C_1 \ldots C_n}(M,t)$$

We assume that the guards $C_1 \ldots C_n$ work independently. Then the probability of violator detection at the point M during the time t is equal to the product of the probabilities of violator non-detection by each of guards:

$$1 - \int_0^t p(M,\tau)d\tau = \prod_{j=1}^{n}(1 - \int_0^t p_{c_j}(M,\tau)d\tau)$$

where $p_{cj}(M,t)$ is the probability density function of violator detection at the point M by the j-th guard during the time t. Elaborating on the calculations we made for probability of violator detection on a given curve, we obtain the correlation for the independent guards:

$$I(\Gamma) = \sum_{j=1}^{n} I_{C_j}(\Gamma),$$

where $I_{cj}(\Gamma) = -1n(1-p_j(\Gamma)), p_j(\Gamma)$ being the probability of violator detection by the j-th guard on the curve Γ. The correlation for $I_{cj}(\Gamma)$ follows from the relation (3) substituting the function $p_{Cj}(M;t)$ instead of function $p(M;t)$. Due to the linearity of the integral, the integral addend in (3) may be seen to be

$$\int_{\Gamma} \frac{p(M;0)}{V(M)} dS = \int_{\Gamma} \sum_j \frac{p_{c_j}(M;0)}{V(M)} dS.$$

Thus, we obtain the following important statement: The risk function at t=0 created by the group of independent guards is the sum of the risk functions at t=0 created by each of the guards:

$$p(M;0) = \sum_j p_{c_j}(M;0)$$

Problem of Determing the Most Effective Disposition of Detection Means

The value $I(\Gamma)$ depends on the disposition of guards $C_1 \ldots\ldots C_n$

$$I(\Gamma) = I_{C_1 \ldots C_n}(\Gamma).$$

Let's assume this value has the minimum along some curve under the given disposition of guards $I_{C_1 \ldots\ldots C_n}$. Problem III, defined above, can be formulated as:

Determine disposition of guards $C_1 \ldots\ldots C_n$ for which the value $I_{C_1 \ldots\ldots C_n}$ becomes minimal.

This is the problem of finding the extremum of a function of a finite number of variables (guard disposition coordinates).

Problem Solution with One Guard.

We will consider the particular case of the formulated problem by making certain simplifying assumptions

1. Solving the problem with one guard and violator movement without obstacles, the probability of violator detection along the curve is found be the formula (1) and depends only upon the value of the risk function at t=0. We consider the case when this risk function depends only upon the distance from the guard and the movement velocity $V(M)$ in the area D is taken to be constant (equal to 1).

Regarding the polar coordinates $(r;\varphi)$ with the origin at the position of the guard (during the movement of the guard the coordinates of other objects change), we have $p(M;0)=f(r)$.

2. The violator movement trajectory with the minimal probability of detection will be found by minimizing the function $\varphi(r)$. Then the problem in variations (3) will be:

$$\int_{r_0}^{r_1} f(r)\cdot\sqrt{r^2\cdot\varphi'^2+1}\cdot dr \to \min \qquad (4)$$

with the boundary conditions $\psi_0(r_0,\varphi(r_0))=0$ and $\psi_1(r_1,\varphi(r_1))=0$– the equations of the object and area boundaries. The violator moves from the protected object ($r=r_0$) to the boundary of the protected area ($r=r_1$).

Since the value $L=f(r)\bullet\sqrt{r^2\bullet\varphi'+1}$ does not explicitly depend on φ then $L'_\varphi=0$ and $\frac{d}{dr}(L'_\varphi=0$, i.e. L'_φ is constant and the Euler-Lagrange equation can be written as

$$L'_\varphi=\frac{f(r)\cdot\varphi'(r)\cdot r^2}{\sqrt{r^2\cdot\varphi'^2+1}}=C_0 \qquad (5)$$

Writing φ' we have:

$$\varphi'=\frac{C_0}{r\sqrt{(rf)^2-C_0^{\,2}}}, \qquad (6)$$

and φ can be found with two integration constants with help of the boundary conditions.

3. Let's consider the case when the probability of violator detection decreases with increasing distance from the guard according to

$$f(r)=\frac{a}{r}.$$

The constant a is taken out from the integral (4) to be minimized. It follows from (6) that

$$\varphi'=\frac{C_0}{r\sqrt{1-C_0^{\,2}}}.$$

Including the new constant

$C=\frac{C_0}{\sqrt{1-C_0^{\,2}}}$ we have

$\varphi'=\frac{C}{r}$ and

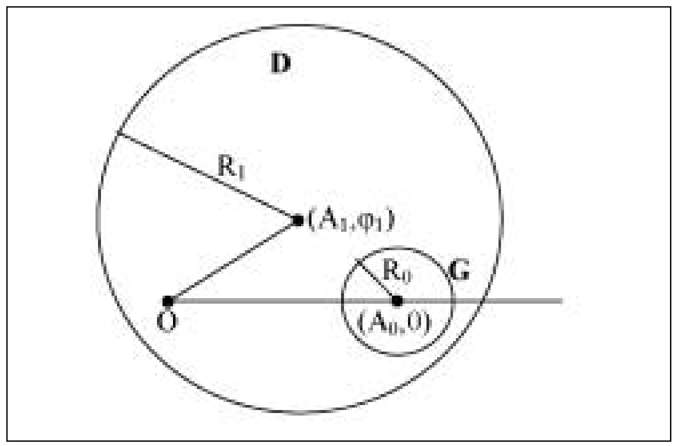
$$\varphi=C\ln(r)+C_1. \qquad (7)$$

Thus in this problem the available extremals will be logarithmic spirals or (with $C=0$) segments directed toward the guard.

The constants C and $C1$ at the integration boundaries r_0 and r_1 (the points of penetration into protected area and approach to the protected object) are determined from the boundary conditions.

4. Let us consider the case when the protected area and object are circles with radii R_1 and R_0($R_1>R_0$). The coordinate axes are chosen such that the center of the protected object is located at the point (A_0;0) on this axis. Let us assume the center of the area D is located at the point (A_1;φ_1) (see Figure 2).

Figure 2. Coordinates for circular areas D and G



The boundary conditions are:

$$A_i\cdot\cos(\varphi(r_i)-\varphi_i)-\frac{r_i^{\,2}+A_i^{\,2}-R_i^{\,2}}{2\cdot r_i}=0 \quad (8) \qquad (8)$$

(i=0, 1, φ_0=0)).

Simultaneously we consider the case when the protected object is pointlike (R_0=0). Then the problem in variations has one instead of two movable boundaries, and the equation with r_0 is $\varphi(r_0)=\varphi(A_0)=0$, i.e.

$$\varphi=C\ln(\frac{r}{A_0}).$$

For the movable boundaries, the transversality condition is:

$$\lambda\cdot L'_\varphi(r_i)=\lambda_i(-1)^i\cdot(\psi_i)'_\varphi(r_i,\varphi(r_i)),$$

where $\psi_i(r_i,\varphi(r_i))$ is the left-hand part of the boundary conditions of the problem (4). From (5) and (7) we have

$$\lambda\frac{C}{\sqrt{C^2+1}}=(-1)^{i+1}\lambda_i 2A_i r_i\sin(\varphi(r_i)-\varphi_i) \qquad (9)$$

The stationarity condition gives:

$$\lambda \cdot L(r_i) = (-1)^i \lambda_i ((\psi_i)'_{r_i} + (\psi_i)'_{\varphi} + \varphi'(r_i)).$$

Thus

$$\lambda \frac{\sqrt{C^2+1}}{r_i} = (-1)^i \lambda_i 2(r_i - A_i \cos(\varphi(r_i) - \varphi_i) + A_i C \sin(\varphi(r_i) - \varphi_i)) \tag{10}$$

Here we have i=0 in the problem with two movable ends and i-1 with one movable end.

If $\lambda=0$, then from (9) it follows that either $\lambda_i=0$ or $\varphi(r_i)=\varphi_i$. But from (5) we have $r_i=A_i$, which is not suitable for us. Thus we have either $\lambda=\lambda_1=\lambda_2=0$ or $l\neq0$. Taking $\lambda=1$ the relations (9) and (10) results in the correlation without λ_1 and λ_2

$$(\cos(\varphi(r_i) - \varphi_i) - \frac{1}{C}\sin(\varphi(r_i) - \varphi_i)) \cdot A_i = r_i \tag{11}$$

Using these expressions for r_i in the corresponding boundary conditions (8) we have

$$(A_i \sin(\varphi(r_i) - \varphi_i))^2 = \frac{C^2 R_i^2}{C^2+1} \tag{12}$$

The boundary conditions (8), combined with the relations (12), create four equations with four variables $C, C_1, r_0 r_1$, if the object is extensive (circle); or two equations with two variables C, r_1, if the object is pointlike.

The system of equations (8) and (12) can be simplified by putting the second addend in (8) in the right-hand part, squaring both parts and adding with (12). Thus we have:

$$\frac{C^2 R_i^2}{C^2+1} = A - (\frac{r_i^2 + A_i^2 - R_i^2}{2r_i}). \tag{13}$$

And so we obtain the relationship between C and r_i:

$$C^2 = \frac{(R_i + r_i + A_i)(R_i + r_i - A_i)(R_i - r_i + A_i)(A_i + r_i - R_i)}{(R_i^2 + r_i^2 - A_i^2)^2} \tag{14}$$

In particular, if the object is pointlike the substitution of this relationship into one of the equations (8) or (12) gives one (transcendental) equation with r_1 that can be solved numerically.

5. We consider the case when the object and the area are concentric circles ($A_1=A_0$, $\varphi1=\varphi_0$-0). It is easy to check that the system (8), (12) then has the solution

$C=0, r_1=R_1+A_0, r_0=R_0+A_0$

The trajectory of violator movement in this case will be the segment of the line $\varphi=0$ leading from the point most distant from the guard directly toward the guard. Intuitively, this trajectory will be the extremal and will reduce the functional to the minimum: the violator moves along the shortest way in the area of minimal probability of detection.

We note that we did not prove even in this simple case the minimum of the curve $\varphi=0$ and the absence of other possible extremals. In more complicated cases the problem seems to be solvable only by the numerical means.

Along the path $\varphi\equiv0$ the functional $I(\varphi)$ takes the value

$$I = \int_{r_0}^{r_1} \frac{a}{r}\sqrt{r^2 0^2 + 1}dr = a\int_{r_0}^{r_1}\frac{dr}{r} = a\ln(\frac{r_1}{r_0}) = a\ln(\frac{R_1 + A_0}{R_0 + A_0})$$

The probability of violator detection is found from $I=-1n(1-P)$, i.e.,

$$1 - P = \left(\frac{r_0}{r_1}\right)^a, \text{ or } P = 1 - \left(\frac{r_0}{r_1}\right)^a$$ which means

$$P = 1 - \left(\frac{R_0 + A_0}{R_1 + A_1}\right)^a$$

The probability increases as the guard approaches the center of the object. If the guard is located in the center the probability will be minimal. In particular, if the object is pointlike, then P=1 and the guard is sure to detect the violator. That will be the solution of Problem III in this particular case.

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Summary of Plutonium Oxide and Metal Storage Package Failures

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Abstract

This article compiles available documented information on failures of containers used to store plutonium-bearing oxide and metal materials within the context of the U.S. Department of Energy (DOE) stabilization, packaging, and storage standard DOE-STD-3013. Relevant information was obtained from published DOE-wide plutonium storage safety evaluations, workshops, technical reports, scientific journal publications, and direct discussion with many subject matter experts. This article focuses on the past two to three decades of plutonium oxide and metal storage, during which package failures were reasonably well-documented. Storage of residues and wastes is not covered in this study.

Based on the documented information examined, this report identifies two dominant modes for plutonium oxide and metal storage package failure:

- Metal oxidation due to non-airtight packages
- Gas pressurization from radiolytic and thermal degradation of inadequately stabilized materials and organic constituents

Four key considerations for safe storage of oxide and metal are identified:

- Adequacy of the calcination process
- Container resistance to pressure
- Container sealing requirements
- Container resistance to corrosion and radiation

The evaluation shows that rational explanations exist for all documented failures and that the associated conditions are well addressed by the requirements of DOE-STD-3013, for materials applicable to this standard. Since vulnerability studies were conducted in 1994 and appropriate corrective actions were taken, only one significant DOE actinide storage container failure for plutonium oxide or metal is known, and that resulted from an inadequate closure weld in a singly contained package.

Introduction

Storage of plutonium oxide and metal has been necessary since the inception of large-scale nuclear materials processing more than fifty years ago. However, it largely has been within the last twenty to thirty years that significant quantities of plutonium-bearing materials have been stored for extended periods at U.S. Department of Energy (DOE) facilities outside of nuclear weapons and components. The plutonium environment can be hostile with regard to package integrity. A number of package failures involving plutonium metal, oxide, and residues have been well documented in a series of summary reports, reviews, and popular articles. Examples are given in references 1-8. Factors that contributed to failures include container corrosion, gas pressurization, and volume expansion due to metal oxidation. Safety concerns about such vulnerabilities led to the issuance in 1994 of Recommendation 94-1 by the Defense Nuclear Facilities Safety Board (DNFSB).[9] In response, DOE prepared an implementation plan to address the vulnerabilities.[10] The implementation plan was revised in 1998.[11] Related recommendations on uranium-233 (DNFSB 97-1) and plutonium (DNFSB 2000-1) have been issued more recently.[12,13]

The five major plutonium sites in the DOE complex have been Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), the Hanford site, the Rocky Flats site (RFS), and the Savannah River site (SRS). While some notable operationally significant package failures of plutonium oxide and metal have occurred at these sites, it is also noteworthy that tens of thousands of packages did not fail during decades of operation, despite the lack of standardized stabilization and packaging protocols in the past. Valuable lessons were learned in assessing the storage successes as well as the many fewer failures. Improved surveillance procedures also were implemented. In general, a reduction in failure frequency and consequences resulted complex-wide. Indeed, since vulnerability studies were conducted in 1994 and appropriate corrective actions were taken, only one significant DOE plutonium oxide or metal storage container failure is known. That failure resulted from an inadequate closure weld in a singly-contained package. The recently approved plutonium stabilization, packaging and storage standard DOE-STD-3013-2000 (referred to hereinafter as STD-3013) and its predecessors used these lessons learned to specify criteria for safe fifty-year storage.[14-17]

The purpose of this article is to consolidate the well-documented reports of package failures and to place them in the context of overall storage success and requirements of STD-3013. This analysis is restricted to materials categorized as oxides (> 30 wt. percent plutonium) and metal applicable to this standard. Not comprehensively addressed in this study are failures of unstabilized plutonium-bearing residues and wastes that are not directly pertinent to safe storage of oxide and metal or STD-3013. A number of failures of this type are cited in references 1-8. A recent example of the failure of a package of unstabilized residue is the August 5, 2003, event at the LANL plutonium facility. That event involved unstabilized cellulose residues bearing plutonium-238 in a slip-lid can/plastic bag storage configuration. Details are provided in a type B accident investigation report issued by DOE in December 2003.

For the purpose of this report, container failure is defined as compromise of the package's main safety function, specifically containment of radioactive material. Tables 1 and 2 summarize all well-documented instances of plutonium oxide and metal storage package failures from our information search. In this report we also discuss some documented cases of unusual storage occurrences, such as collapsed (*paneled*) or bulged rim-sealed food-pack cans, where an unusual condition was noted but contamination was not released. Examples of such cases are summarized in Table 3.

In the past, long-term storage of oxide and metal generally was not a practical concern due to the demand for plutonium. For package failures and unusual occurrences before about 1970, documentation is sketchy at best and very little written record exists. Undocumented failures undoubtedly occurred in this early period but are lost to history. In the present study, subject matter experts were surveyed in an attempt to capture early significant failure incidents that may not have been documented. Documentation has improved dramatically since the 1970s and has continued to improve to the present day. We believe it is unlikely that any major failure within the United States or United Kingdom since the mid-1970s would have been missed in the information search. The authors are keenly interested in being apprised of any relevant incidents that may have been overlooked.

In 1994, DOE adopted a consensus standard for packaging plutonium metal and oxide materials that contain greater than fifty weight percent plutonium.[17] The objective was to avoid container failures during a storage period of fifty years, with minimal surveillance. In 1996, 1999, and 2000, revisions were issued.[15-17] The latest revision is referred to as STD-3013 in this discussion. Among other changes from the earlier standards in this sequence, the current STD-3013 lowers the acceptable minimum actinide content from fifty to thirty weight percent, eliminates any constraint on maximum material temperature and reduces the maximum acceptable wattage per package from thirty to nineteen watts. Appendix A of STD-3013 outlines the technical basis for these changes. This report further supports the technical basis by evaluating documented plutonium storage incidents within the context of requirements of the standards.

Discussion of the dominant failure modes and safe storage considerations form the focus for the remainder of this report. A 1999 Los Alamos report provided a preliminary account of this work.[18]

Sources of Information

Valuable information for this report was obtained from direct discussions with many active subject matter experts at DOE's five principal plutonium-handling sites. Subject matter experts from other DOE sites, retired personnel, and knowledgeable managers from the United Kingdom's Atomic Weapons Establishment (AWE) also were engaged. Some of these subject matter experts are identified at the end of this report. Published information that was surveyed included DOE-wide plutonium storage safety evaluations, *grey literature* technical reports, and the peer-reviewed scientific literature. A literature search was conducted using the following keywords: plutonium, storage, package, failure, metal, oxide, compounds, and residues. The following databases were searched: INSPEC, Engineering Database, and DOE Energy Science and Technology Database.

A search of DOE's Occurrence Reporting and Processing System (ORPS) electronic database also was conducted. The ORPS database search produced no information not acquired through the other means mentioned above.

Container Failure Events and Mechanisms

The information search revealed documented plutonium storage package failures relevant to STD-3013, presented as case studies in tables 1 and 2. Table 3 lists examples of documented unusual occurrences that did not result in release of contamination from the storage package. Photographs of some failed or off-normal containers are shown in figures 1-5. Figure 6 shows a cutaway view of a STD-3013-type package. Two dominant observed failure modes were noted (more details are included later in this paper) and are discussed in this section. A few examples of each failure mode are highlighted in the discussion.

Metal Oxidation in Non-Airtight Packages.

The largest number (nine) of well-documented package failures involved storage of plutonium metal in containers that were not air-tight (Table 1). In most cases, in-leakage of air led to oxidation of the metal to the dioxide, accompanied by a large increase in material volume that eventually caused mechanical failure of the container. Excellent descriptions of several events of this type are

TABLE 1. Failures from metal oxidation or corrosion

Case Number (Reference)	Year/Facility	Case Details	Cause of Failure	Failure Avoided by STD-3013?
SEAL-1 Reference 5	1969 Hanford	A fuel-grade plutonium metal button weighing 2 kg oxidized and ruptured the food-pack can after 13 months in storage due to radial growth of oxide. Vault was grossly contaminated and personnel were contaminated upon entering the vault.	Leak in the sealed can allowed air in-leakage. The metal oxidized, resulting in radial pressure that caused container failure.	Yes. Container sealing requirements (leak tested welded closure) and redundant barriers prevent air entry.
SEAL-2 Reference 5	1970 Hanford	A fuel-grade plutonium metal ingot weighing 2.2 kg oxidized and ruptured food pack can after about two years in storage vault. Can configuration was sealed can-plastic bag-taped slip lid can. Oxide formed in the can and the radial growth caused failure of can sidewall. Vault was grossly contaminated and personnel were contaminated and received internal uptake upon entry into vault.	Leak in the sealed can allowed air in-leakage. The metal oxidized, resulting in radial pressure that caused container failure.	Yes. Container sealing requirements (leak tested welded closure) and redundant barriers prevent air entry.
SEAL-3 Reference 5	1972 Hanford	Plutonium metal oxidized and the food-pack can split open in glovebox. Powder accumulated outside can but contamination was confined to glove box.	Leak in the sealed can allowed air in-leakage. The metal oxidized, resulting in radial pressure that caused container failure.	Yes. Container sealing requirements (leak tested welded closure) and redundant barriers prevent air entry.
SEAL-4 Reference 19	1982 Rocky Flats	Two out of twenty-seven 3-kg alpha plutonium cylinders breached their containers. Packaging was in aluminum cans with steel-crimp lids and stainless steel overpack. The overpack closure was a close tolerance fit lid sealed with silicone polymer sealant. These assemblies were submerged in water in experiments. The handling area was contaminated. Upon opening one of the ruptured containers for inspection in an air glovebox, the plutonium and corrosion products spontaneously ignited and the metal burned completely.	Leak in the sealed can allowed air in-leakage. The metal oxidized, resulting in radial pressure that caused container failure.	Yes. Container sealing requirements (leak tested welded closure) and redundant barriers prevent air entry.
SEAL-5 Reference 20	1992 Livermore	A seamless aluminum can with screw type lid was filled with 1,108 g of Pu metal in 1989. This can was bagged out of the glovebox and placed in a one-gallon can for storage. After 32 months, the package was retrieved for processing and the contents of the gallon can transferred into a glovebox. Upon removal of the plastic bags, the aluminum can as found to have split lengthwise due to oxidation of the metal. Approximately 622 g of metal had oxidized.	Leak in the sealed can allowed air in-leakage. The metal oxidized, resulting in radial pressure that caused container failure.	Yes. Container sealing requirements (leak tested welded closure) and redundant barriers prevent air entry.
SEAL-6 Reference 19	1992 AWE	A Pu metal button packaged in 1985 inside a screw-top aluminum can was bagged from a glovebox and placed in a metal food pack can with crimp sealed lid. By 1990, the Pu had gained only 3 g of oxygen but by 1992, the plutonium was totally oxidized. The increase in volume of the oxide exerted a radial pressure that destroyed the aluminum can and ultimately caused the food pack cans to rupture, contaminating the storage bin.	Leak in the sealed can allowed air in-leakage. The metal oxidized, resulting in radial pressure that caused container failure.	Yes. Container sealing requirements (leak tested welded closure) and redundant barriers prevent air entry.
SEAL-7 Reference 53	1993 Los Alamos	In 1979, 2.5 kg of cast Pu metal was enclosed in a 2-inch-diam vessel made of steel tubing with welded end caps. The cylinder was bagged out of the glovebox and stored in an 8-inch-diam by 15-inch-tall steel can with taped slip-lid closure and stored in a vault. Upon movement of the item to a processing area 14 years later, the handler's protective clothing and a transfer cart became contaminated. The inner welded steel vessel had one end torn away. Evidence was not seen of plutonium metal; only yellow-green oxide powder was observed. Hydride-catalyzed Pu corrosion was suspected. Faulty weld on stainless steel container caused leak in the sealed can.	Faulty weld on stainless steel container allowed air in-leakage. The metal oxidized, resulting in radial pressure that caused container failure.	Yes. Container sealing requirements (leak tested welded closure) and redundant barriers prevent air entry.

TABLE 1. Failures from metal oxidation or corrosion (continued)

Case Number (Reference)	Year/Facility	Case Details	Cause of Failure	Failure Avoided by STD-3013?
SEAL-8 Reference 19	1993 Los Alamos	In 1984, 5 kg of plutonium metal was removed from a glovebox in a plastic bag and placed in a second plastic bag inside a lead-lined can with a taped lid seal. Radiolysis of the plastic produced hydrogen, which reacted with the plutonium to form plutonium hydride and/or nitride. The container was opened inside a hood in 1993. Disruption of the brittle plastic caused a massive breach and spontaneous ignition occurred. Both the operator and hood were contaminated.	Comingling of incompatible materials (plastic and plutonium metal) led to formation of pyrophoric hydride. Inappropriate containment and handling led to release of the plutonium material.	Yes. The standards prohibit the presence of plastic materials in the storage package.
SEAL-9 References 22 and 23	1999 Savannah River Site	In 1998, a button of metal was placed in a stainless steel can, sealed with a weld and placed into storage without secondary containment. The weld was defective and the poor seal was not detected by the weld testing/inspection procedure. During storage, substantial metal oxidation occurred. When the can was handled more than a year after initial containment, extensive vault contamination occurred and plutonium intake by seven workers resulted.	A defective closure weld was not detected and the container was stored without secondary containment. Air-inleakage led to formation of easily suspendible oxide, which was released through the defective weld when the container was subsequently handled.	Yes. Container sealing requirements (leak tested welded closure) and redundant barriers prevent air entry.

given in references 4 and 19-21. The roles of moisture, hydriding, nitriding, and atmospheric pressure cycling in accelerating oxidation rates are elucidated in these reports.

To illustrate the metal oxidation failure mode, we cite an incident at LLNL which was discussed in detail by Dodson and summarized as Case SEAL-5 in Table 1.[20] In this instance, air entered an inner aluminum can through incomplete sealing of the container, followed by conversion of the plutonium metal to oxide and mechanical failure of the container. Failure occurred within three years of packaging. The can was found to be split along its entire length as a result of expansion of the oxidized metal. Figure 1 shows a photograph of a container that failed similarly at RFS in 1982 (Case Seal-4, Table 1).

A September 1999 event at SRS (Case SEAL-9, Table 1) provides a special case of metal oxidation in non-airtight packages. To the author's knowledge, this is the only example of a significant failure of an actinide metal or oxide storage package since vulnerability assessments were published in 1994. In this instance, a defective closure weld was made on a stainless steel container enclosing a metal button.[22, 23] A photograph of the defective weld

Figure 1. Photograph of a rim-sealed aluminum container that ruptured due to excessive mechanical pressure from oxidized plutonium metal, due to a faulty seal. This event occurred at Rocky Flats in 1982 and is described as case Seal-4 in Table 1.

Figure 2. Photograph of a defective closure weld on a stainless-steel storage container that led to an incident in September 1999 at Savannah River, causing intake of plutonium by seven workers and extensive vault contamination. This event is described as case Seal-9 in Table 1.

is shown in Figure 2. The weld inspection and testing process failed to detect this defect. The non-airtight container was placed into vault storage without secondary containment. Fifteen months later when the container was handled, extensive vault contamination and plutonium ingestion by seven workers occurred. Inspection of the container contents showed that extensive oxidation of the metal occurred during storage, generating easily suspendable oxide in the container that moved through the weld defect when the container was handled.

Gas Pressurization

As indicated in numerous technical reports and publications, failures of packages containing plutonium oxide have occurred because of excessive gas generation. Examples are given in references 2-4. Table 2 lists the seven documented cases of this failure mode. The root causes stem from radiolytic and thermal degradation of inadequately stabilized material or the presence of organics including plastic. Figure 3 shows a photograph of a Hanford container that failed in 1980 by gas pressurization (Case Pressure-5, Table 2).

The gas pressurization failure mode also is illustrated by incidents at the Hanford Plutonium Finishing Plant (PFP) in 1975 and 1984 (Cases PRESSURE-1 and 2 in Table 2). These incidents involved unstabilized glovebox sweepings packaged in rim-sealed cans. In both cases, gas pressurization and rupture of the containers occurred. In one case the container was ejected from its storage position and gross contamination of the storage vault resulted. The other failure occurred inside a shipping container and resulted in gross contamination of the interior of the shipping container.

Figure 3. Photograph of a slip-lid can that ruptured due to excessive gas pressure. This event occurred at Hanford in 1980 and is described as case Pressure-5 in Table 2.

An example of failure due to organics degradation is the 1980 SRS incident listed as Case PRESSURE-6 in Table 2. In this case, an oxide storage package ruptured due to overpressurization, resulting in contamination of a large area of a storage vault. The stored material consisted of glovebox sweepings and reject pressed compacts containing plutonium dioxide in contact with an aluminum stearate-dodecanol die lubricant. Inspection of similar packages indicated pressurization from buildup of hydrogen and methane due to radiolytic and/or thermal degradation of the organic material.

Unusual Storage Occurrences Without Failure

Table 3 tabulates examples of documented cases in which unusual conditions were noted but storage package failures did not occur, i.e., no contamination was released. *Bulging* due to internal gas pressure and *paneling* due to partial vacuum of food-pack cans dominate this category of events. Figure 4 and 5 show photographs of paneled and bulged food-pack cans.

Figure 4. Photograph of a paneled rim-sealed Hanford container of plutonium metal that did not release contamination. Several examples of the paneling phenomenon are listed in Table 3.

Figure 5. Photograph of a bulged Hanford rim-sealed container of plutonium oxide that did not release contamination. Other examples of the bulged can phenomenon are given in Table 3.

In a 1994 example from SRS (Case PRESSURE-11, Table 3), several food-pack storage cans were observed to be slightly deformed from small internal pressure buildup. The most probable cause of the pressurization was postulated to be a combination of thermal and radiolytic degradation of the PVC bag enclosing the inner container, with a possible small contribution from heating of the can atmosphere. At the United Kingdom's Aldermaston Weapons Establishment, pressurization of food-pack containers of plutonium oxide has only been observed for two containers in recent years, and these were packaged elsewhere under uncertain conditions.[29]

As Table 3 indicates, partial sidewall collapse (paneling) or inward lid deflection of food-pack cans has been observed at PFP and SRS during storage of alpha-phase fuels-grade plutonium metal. An observation at SRS in 1998 (Case PANEL-6, Table 3) apparently involved scrap mixed oxide with high-burn up plutonium metal containing incompletely calcined carbide. Likewise, paneling has been observed at Aldermaston only with high-burn up plutonium metal, but not with oxide or weapons-grade metal.[29] A number of reports describe creation of vacuum from reaction of oxygen and nitrogen from air cover gas with plutonium metal (e.g., see references 4, 31, and 32 and references cited

TABLE 2. Failures From Gas Pressurization

Case Number (Reference)	Year/Facility	Case Details	Cause of Failure	Failure Avoided by STD-3013?
PRESSURE-1 Reference 5, 24	1975 Hanford	A can of less than 300 g of plutonium glovebox sweepings ruptured and ejected from storage position in vault. Container was a food-pack can sealed and placed in storage about four days before the event took place. Scrap powder from oxalate precipitation process oxide production line was involved. Some powder from the precipitator/calciner glovebox, reported to be dry and free-flowing, was sealed out and stored without thermal stabilization. Visible oxide contamination of storage vault floor resulted.	Gas was generated from unstabilized oxide constituents. Material spilled from oxalate precipitation process in a glovebox was added to can without calcination.	Yes. The 500-600°C calcination temperature of the subject process produced tons of well-behaved PuO_2 that had measured LOI of <0.5%. The 950°C calcinations requirement of the standard far exceeds the demonstrated stabilization temperature for this type of material. More than a thousand containers of product with LOI (done at 450°C) in the range 0.2-1.0% were produced. These items have not presented pressurization problems in over 15 years of subsequent storage. The 950°C calcination requirement of the standard far exceeds the demonstrated stabilization temperature for this type of material.
PRESSURE-2 Reference 5	1984 Hanford	This case is very similar to case PRESSURE-1, involving food-pack can of plutonium glovebox sweepings. In this instance, the can was being stored in a shipping container that was closed but not bolted closed for shipment as only temporary storage was intended. The shipping container was so badly contaminated that it had to be discarded.	Gas was generated from unstabilized oxide constituents. Material spilled from oxalate precipitation process in a glovebox was added to can without calcination.	Yes. The 500-600°C calcination temperature of the subject process at Hanford produced tons of well-behaved PuO_2 that had measured LOI of <0.5% during the mid-1980s.

TABLE 2. Failures From Gas Pressurization (continued)

Case Number (Reference)	Year/Facility	Case Details	Cause of Failure	Failure Avoided by STD-3013?
PRESSURE-3 Reference 5	1976 Hanford	A food-pack can of plutonium oxalate precipitate derived from analytical laboratory wastes was found to be slightly bulged and leaking an oily-appearing substance during storage. Slight contamination of the storage rack resulted.	Packaging of unstabilized material led to gas generation and corrosion of container. The food-pack containers were intended to hold dry, stabilized materials.	Yes. The 950°C of the standard is adequate to remove gas-generating constituents and corrosive materials are prohibited by the standards.
PRESSURE-4 Reference 55	1979 Hanford	A food-pack container of high decay heat plutonium oxide ruptured, releasing a plutonium oxide aerosol. The room, equipment, and three workers were contaminated. The can had been sealed and removed from the glovebox on the previous day and was in a shipping container for about 12 h just prior to the rupture. The material contained lumps up to 0.5-in. suspected of not being fully heated to the 450°C calciner temperature. The lumps may have been avoided during sampling, making the sample taken not representative. Analysis was specific for water and would not have indicated potential for nitrate decomposition.	Gas generation probably was caused by insufficient conversion of nitrate to oxide and was promoted by self-heating of the high-heat material.	Yes. The 950°C calcination temperature required by the standard is sufficient to decompose all nitrate constituents. Also, the container pressure rating prescribed by the standard is much higher than for food-pack cans.
PRESSURE-5 Reference 56	1980 Hanford	Enriched uranium/plutonium scrap oxycarbide material was contained in a 1-pound, slip-lid can and enclosed in two layers of plastic. The material had been stored for about 15 years in a brass vial thought to contain kerosene. As the item was taken from a glovebox after being packaged, the material spontaneously ignited causing the container to breach. The event took place within an hour of opening the brass vial. The materials spontaneously ignited, the can over-pressurized can and gross contamination of the room and personnel resulted.	Gas pressurization resulted from inadequately stabilized material, plus formation of pyrophoric products. Interaction with residual hydrocarbons was suspected.	Yes. The 950°C calcination temperature specified by the standard is sufficient to completely convert oxycarbides and organics to stable oxide products. Organics are forbidden in the STD-3013 package.
PRESSURE-6 Reference 25	1980 Savannah River Site	An oxide storage package ruptured due to over-pressurization, resulting in contamination of a large area of the storage vault. The stored material consisted of glovebox sweepings and reject pressed compacts containing plutonium oxide in contact with an aluminum stearate-dodecanol die lubricant. Inspection of similar packages indicated pressurization from build-up of hydrogen and methane due to radiolytic and/or thermal degradation of the organic material.	Radiolytic and/or thermal degradation of organic material present in the plutonium oxide resulted in pressurization and rupture of the storage can.	Yes. The 950°C calcination temperature specified by the standard is sufficient to eliminate organic constituents and produce stable oxides.
PRESSURE-7 Reference 57	1979 Savannah River Site	During removal of cans from a welded stainless steel capsule a shipping container, pressure and contamination were released into and out of a plastic containment hut. Pressurization of the capsule occurred during post loading leak testing of the shipping container with helium. Porosity in the capsule closure weld allowed injection of helium into capsule. The capsule end broke away from the body during opening with a pipe cutter. Release of helium pressure from welded capsule during opening of capsule released plutonium oxide into the room and contaminated personnel.	The incident was caused by inadequate leak testing procedures and weld quality assurance.	Yes. Helium leak testing of both inner and outer containers at time of packaging provides assurance that helium cannot leak into container in subsequent testing. Quality assurance requirements on welds should ensure detection of inadequate welds.

therein). None of the paneling cases listed in Table 3 led to release of contamination and no instances are known to the authors for weapons-grade metal or metal phases other than alpha. The experience strongly suggests the importance of elevated temperature and reactive metal (alpha phase) for the paneling process.

Generally Declining Failure Frequency

For the documented cases presented in tables 1 and 2, a general decline in the frequency and consequence of package failures in recent years is evident. The 1999 SRS incident (Case SEAL-9, Table 1), due to a quality assurance failure, as discussed above, is a notable exception to this rule. Table 3 indicates a greater recent frequency of unusual occurrences without failure, but this is most likely a result of more aggressive surveillance and reporting in recent years. The general decline in failure rate is attributable to the development and application of improved stabilization and packaging protocols from applying lessons learned from previous packaging failures and successes, in combination with improved surveillance. Forums such as the 1984 DOE training seminar, Prevention of Significant Nuclear Events, the March 1999 American Chemical Society symposium on fifty-year storage of nuclear materials, and active complex-wide working groups have provided valuable mechanisms for information exchange in this regard.[33]

It is noteworthy that Dodson's 1994 report[20] indicated that only three package failures had been documented or remembered by facility personnel between the start of plutonium operations at LLNL in 1961 and the publication of her report. Only one of these failures was discovered during processing of more than 606 packages containing plutonium during an inventory reduction campaign. No failures have been observed at LLNL since completion of this campaign.[34] Several unusual occurrences without contamination release (e.g., bulging cans containing impure oxides that had not been processed according to the standards) have been reported by LLNL, as indicated in Table 3.

In the mid-1990s, a visual inspection of LANL's entire vault inventory of nearly 8,000 plutonium items was conducted.[35] This exercise found that 361 containers had some visually observable abnormality. Of these, eighty-two containers had lost secondary (outer) containment as indicated by raised lids, corrosion or other factors. However, no containment losses occurred that dispersed material outside the packages. Indeed, during about twenty-five years of operation of LANL's plutonium facility, no containers of oxide or metal have failed in an uncontrolled environment.[36] The most commonly observed cause of package abnormalities has been mechanical, for example, a bagout bag pushing against a taped slip-lid. A few cases of primary container failure involved corrosive or inadequately dried materials. None of the containers that lost primary containment had been stabilized or packaged in a manner consistent with the requirements of STD-3013, and all of these cases have rational explanations well outside the requirements of the standard.

It is important to note, however, that the overall recent success in safely storing plutonium in vault environments have involved lower temperatures than for some postulated bounding storage scenarios after packaging according to the STD-3013 and did not universally involve welded closures.[37,38] Specifically, these hypothetical scenarios involve long-term storage in shipping containers in facilities that are not actively cooled. Some temporary off-normal scenarios assume extreme exposure of the shipping containers to direct solar radiation.

Figure 6. Photograph of a STD-3013-type package, showing a screw-cap inner convenience container and the weldable inner and outer stainless steel containers

Critical Storage Standard Considerations

In this section, four key considerations for safe storage of plutonium oxide and metal are discussed within the context of STD-3013 and the two dominant observed failure modes discussed previously. The four key considerations are:

TABLE 3. Examples of Unusual Occurrences Without Failure

Case Number (Reference)	Year/Facility	Case Details	Cause of Failure	Failure Avoided by STD-3013?
PANEL-1 Reference 5	1975 Hanford	Several cans received in a single shipment of fuels-grade plutonium metal were found to be punctured, paneled, charred, or deformed inward. One such deformed can contained about 350 grams of corrosion product. Contamination was observed on the inside of several shipping containers.	High decay heat caused abnormally high temperatures in shipping container causing discoloration of cans. The high temperature also enhanced reaction of plutonium with air in the cans, causing paneling. Similar later occurrences indicated formation of plutonium nitride at similar temperatures.	Yes. The STD-3013 containers will be strong enough to withstand total vacuum, elevated temperature and anticipated mechanical impacts.
PANEL-2 Reference 58	1983 Hanford	Two cans containing fuels grade metal buttons were found to be paneled. The buttons had been in storage in food pack cans for 4 and 14 years at the time of the discovery. No contamination was released. Reference 58 also mentions two previous similar occurrences. One was Case PANEL-1 and the other was a single Hanford can found in 1981 to be paneled.	Partial vacuum from metal reaction with air was sufficient to cause the can to panel.	Yes. The STD-3013 containers will be strong enough to withstand total vacuum.
PANEL-3 Reference 20	1986 Livermore	Approximately 186 g of Pu scrap metal was bagged out of a glovebox in a pint-sized can, placed in a gallon can and stored in a vault. After 15 months in storage, the gallon can was found to have collapsed under vacuum.	Partial vacuum from metal reaction with air was sufficient to cause the can to panel.	Yes. The STD-3013 containers will be strong enough to withstand total vacuum.
PANEL-4 Reference 59	1995 Savannah River Site	Two vault stored items containing fuels-grade plutonium metal exhibited inward can wall paneling on the outer cans. No contamination was released.	Partial vacuum from metal reaction with air was sufficient to cause paneling.	Yes. The STD-3013 ontainers will be strong enough to withstand total vacuum.
PANEL-5 Reference 60	1998 Hanford	One of the buttons discussed in Case PANEL-1 spontaneously ignited when the container was opened in an air glovebox in 1975. Oxidation was assumed to be complete when burning ceased. The resultant oxide then was placed in a food-pack assembly and stored. When examined thirteen years later, the outer can of one of the items was found to be paneled.	Partial vacuum from metal reaction with air was sufficient to panel food-pack can.	Yes. The STD-3013 containers will be strong enough to withstand total vacuum. The 950°C calcination temperature specified by the standard will be sufficient to convert all metal fines to stable oxide.
PANEL-6 Reference 30,61	1998 Savannah River Site	A can of scrap mixed oxide derived from Pu/U carbide from FFTF fabrication program was found to be paneled. The container had been stored for about 15 years and paneling had not been observed during previous routine surveillance. The material apparently contained residual Pu/U carbide.	Partial vacuum from carbide reaction with air was sufficient to panel the food-pack can.	Yes. The STD-3013 containers will be strong enough to withstand total vacuum. The 950°C calcination temperature specified by the standard will be sufficient to convert all carbide to stable oxide.
PANEL-7 Reference 60	1996 Hanford	Six paneled cans were observed in a population of 52 metal items examined by radiography. The cans contained metal ingots each with approximately 12 W decay heat. No container rupture was observed and no contamination was detected during handling to obtain radiographs.	Partial vacuum from metal reaction with air was sufficient to panel the food-pack can.	Yes. The STD-3013 containers will be strong enough to withstand total vacuum.

TABLE 3. Examples of Unusual Occurrences Without Failure (cont.)

Case Number (Reference)	Year/Facility	Case Details	Cause of Failure	Failure Avoided by STD-3013?
PANEL-8 Reference 30	1998 Savannah River Site	A food-pack container of oxide from LLNL was discovered to be paneled. The material was believed not to be fully oxidized and to contain small metal particles.	Partial vacuum from metal reaction with air was sufficient to panel the food-pack can.	Yes. The STD-3013 containers will be strong enough to withstand total vacuum. Also, the 950°C calcination temperature specified by the standard will be sufficient to convert all metal particles to stable oxide.
SEAL-9 Reference 62	1993 Savannah River Site	A can containing a Pu metal button was observed to steadily gain weight over a period of 4 years since original packaging. When opened, the inner can was found to have a defective seal. The oxide formed in the inner can filled the can but did not mechanically rupture the can. No contamination was released from the outer container.	A defective seal allowed entry of air into inner can with subsequent oxidation of metal.	Yes. The standard's container sealing requirements (leak tested welded closure) and redundant barriers will ensure that air in-leakage does not occur.
PRESSURE-8 Reference 63	1994 Livermore	During routine surveillance, two sealed packages, each consisting of concentric double food-pack cans containing calcined plutonium mixed oxide residues, were discovered to have bulging lids.	Gas was generated from inadequately stabilized materials.	Yes. The 950°C calcinations temperature specified by the standard is adequate to remove gas-generating constituents.
PRESSURE-9 Reference 64	1985 Hanford	A container of uncalcined mixed oxide gel sphere material was observed to be bulged.	Gas was generated from inadequately stabilized materials.	Yes. The 950°C calcination temperature specified by the standards is adequate to eliminate gas-generating constituents.
PRESSURE-10 Reference 66	1986 Hanford	A bulged can (most likely food-pack type) was observed. The nature of the contained material was not included in the event fact sheet.	Gas pressurization very likely resulted from inadequately stabilized materials.	Yes. The 950°C calcination temperature specified by the standard is adequate to eliminate gas-generating constituents.
PRESSURE-11 References 25-27	1994 Savannah River Site	Several food-pack containers were found to be slightly deformed, indicative of an internal pressure of about 10 psig.	Pressurization probably was caused by a combination of thermal and radiolytic degradation of PVC bags, with a possible small contribution from heating of the can atmosphere.	Yes. The standard does not allow organics in the storage package. Also, STD-3013 containers will be strong enough to withstand total vacuum.

- Adequacy of the calcination process
- Container resistance to pressure
- Container sealing requirements
- Container resistance to corrosion and radiation

Adequacy of the Calcination Process

For oxide materials, STD-3013 requires calcination at 950°C for two hours to ensure the elimination of gas-generating constituents such as organics, oxalates and nitrates as well as moisture. These requirements are intended to eliminate all significant sources of gas pressurization. Accordingly, failures and unusual occurrences of this type should be eliminated. The moisture content is required to be lower than 0.5 wt. percent at the time of packaging to limit the potential for pressurization from hydrogen and/or oxygen generation.

As indicated in Appendix A of STD-3013, this water limitation is considered effective in this regard. However, it should be noted that the extent and consequences of water equilibria involving oxides that are likely to occur at some temperatures and water contents of interest have not been evaluated exhaustively and the possibility of condensed water inside the containers as a result of some bounding transportation scenarios has not been precluded categorically.[39,40] Research activities at LANL are actively evaluating such possibilities.

Container Resistance to Pressure

The plutonium storage container must survive or prevent four types of pressure scenarios:

- Gas vacuum
- Gas pressurization
- Material volume expansion due to metal oxidation
- Metal volume expansion due to phase changes

Tables 1-3 show failures and unusual conditions corresponding to the first three pressure scenarios.

The first pressure scenario (gas vacuum) is addressed in STD-3013 by specification of a storage container with sufficient mechanical strength to withstand total internal vacuum (0 psia).

The second pressure scenario (gas pressurization) is addressed in several ways in STD-3013. First, a package design working pressure of 699 psia is specified. The measured burst pressure of the package is nearly two orders of magnitude greater than the burst pressure of food-pack cans commonly used in the past.[41-43] In addition, to minimize the potential for gas generation, the standard requires calcination at 950°C to eliminate potentially problematic constituents. The standard also requires testing to ensure that water content of the packaged materials is below 0.5 wt. percent. These conditions were not assured for any of the gas pressure-induced incidents listed in tables 2 and 3.

The 1998 peer review report of the UK Aldermaston Weapons Establishment (AWE) interim storage criteria for plutonium-bearing materials contains sections written by representatives from most major DOE plutonium facilities.[44] The sections indicate that, in the experience of the reviewers, no containers of oxide produced and packaged in a well-controlled, reasonably dry atmosphere at a temperature of 400°C or above has exhibited significant container pressurization, even though a loss on ignition value below 0.5 wt. percent may not have been attained at this relatively low stabilization temperature.

STD-3013 addresses the third pressurization scenario (oxidation of metal) by requiring the use of nested, welded, and leak-tested containers to essentially eliminate the possibility of exposing contained metal to air. The greater mechanical strength of the packages compared to food-pack cans also greatly enhances resistance to mechanical failure even if air in-leakage were to occur.

The fourth potential pressurization scenario (metal phase change effects) stems from a concern that volume expansions that occur when plutonium metal phase transformations occur near 115°C (alpha/beta) and 185°C (beta/gamma) may exert sufficient mechanical pressure to cause the storage container to fail. Our information survey revealed no documented or anecdotal evidence for this failure mode in containers with far less mechanical strength than those required by standard STD-3013. The metal phase change concern has been eliminated by worst-case experiments and finite element modeling.[45-47]

Container Sealing Requirements

As discussed in the preceding section, STD-3013 requires that mechanically strong, nested, welded, and leak-tested stainless steel containers be used for packaging plutonium metal and oxides for extended storage. This requirement is intended to ensure that the containers will be adequately sealed to minimize or eliminate the possibility of air in-leakage. A robust quality assurance program for container sealing also is required by STD-3013.

Container Corrosion and Radiation Resistance

With one possible exception (Case PRESSURE-3, Table 2), none of the oxide and metal storage package failures and unusual occurrences summarized in tables 1-3 have been caused by corrosion. (Numerous corrosion-related failures of *unstabilized* residue and waste packages have occurred.) STD-3013 minimizes the possibility of corrosion-related failures by allowing only stabilized oxides and metal to be packaged. In addition, the standard specifies that corrosive constituents be excluded and that corrosion-resistant container materials (e.g., L-series stainless steel) be used.

The issue of chloride-induced corrosion of storage containers has been addressed by Kolman.[48] STD-3013 and its predecessors do not specifically exclude chlorides. Kolman's key conclusion is that neither general corrosion nor stress corrosion cracking should pose a threat to 3013 containers under anticipated storage conditions, provided condensed water is avoided. The calcination, moisture, and sealing specifications of the standard are intended to avoid any possibility of condensed water in the packages. However, as mentioned above, recent results indicate the need for additional evaluation of moisture equilibria at bounding temperatures and water contents of interest.[39,40]

Kolman also addresses radiation effects on the stainless steel container. His key conclusion in this regard is that radiation effects are unlikely to be a significant safety issue if good welding practices are followed.

A recent report on chloride salt radiolytic effects in plutonium storage environments surveys complex-wide experience in storing pyrochemical salts.[49] This survey indicates that significant corrosion problems have not been observed in storage of pyrochemical salts, provided reasonable precautions had been made to avoid excessive moisture. For example, Hanford has stored plutonium-bearing NaCl-KCl salts in rim-sealed containers for nearly twenty years without significant storage problems (corrosion or otherwise).[50] These observations are supported by recent observations on pyrochemical salts at RFS, LANL, LLNL and AWE.[29,36,50-52] Again, it should be noted that much or all of this favorable experience with storage of plutonium/salt mixtures has been at temperatures lower than some postulated bounding conditions for STD-3013 packages.[37,38]

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For several years, Los Alamos National Laboratory has led the research and development project to resolve technical issues in implementing STD-3010. A crucial element of this program is the MIS project, in which representative materials from the principal DNFSB 94-1 sites are subjected to detailed characterization. The MIS effort strives to anticipate undesirable conditions that might arise during stabilizing, packaging and storing plutonium materials at the respective sites.

An essential element in focusing the MIS effort and interpreting the resulting information is an active working group comprised of senior subject matter experts with significant management and technical responsibilities at the major DOE plutonium sites. Weekly teleconferences, quarterly multi-day workshops, frequent technical data and report reviews, and other frequent information exchanges form the core of this effort. The membership of the MIS Working Group as of March 2004 is as follows:

- Hanford Plutonium Finishing Plant, Richard W. Szempruch and Theodore J. Venetz
- Lawrence Livermore National Laboratory, Karen E. Dodson
- Los Alamos National Laboratory, Richard E. Mason
- Rocky Flats Environmental Technology Site, Jerry L. Stakebake
- Savannah River Site, James W. McClard and Jeffrey B. Schaade

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Estimation of Proliferation Risks for a Nuclear Export Control System

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Abstract

A technical review of exported commodities (both nuclear and dual use) plays an important role in the export control system of the Russian Federation, as well as in Minatom's system of internal compliance. The current methods of export control are based largely on the qualitative approaches and estimations. The development of quantitative approaches and methods for estimating proliferation (and diversion) risk, as well as for developing similar methods for revealing indicators of proliferation, made on the basis of engineering analyses, would become a new stage in the development of export control.

Currently, export controls offers control officers only lists of controlled commodities to use as the basic tool of export control and as an addition to their personal knowledge. The control lists contain descriptions of commodities that are sensitive in terms of proliferation and technical parameters on which the analysis is based. At the same time, by virtue of the variability of items in the nuclear sphere, the control lists cannot offer a complete set of analytical material, therefore some uncertainty regarding the sensitivity of commodities still exists. This uncertainty creates a "gray zone of knowledge" in which experts have to make a decision on the basis of their own qualitative estimation of proliferation risk, or on "common sense."

The present paper argues that qualitative estimation of proliferation risk can be improved and that quantitative estimation should be considered. This paper gives specific examples related to nuclear reactors.

Introduction

The estimation of proliferation risk, with reference to sensitive commodities, represents both a methodological and a practical problem. The practical work on identifying sensitive commodities applies to all stages of international trade: 1) first of all, by an exporter, 2) at the state licensing level, and 3) at the customs control level. A commodity, being identified as export controlled, becomes subject to the procedure of licensing and, hence, requires a state expert review. The level of care applied during consideration of an export application depends, in a definite measure, on the perceived proliferation risk for the given commodity. Unfortunately, now there are no strict numerical estimations of "risk of proliferation" or "degree of sensitivity" for nuclear or dual-use commodities, and ready methodological approaches for numerical analysis do not exist. Nevertheless, the problem of such proliferation risk estimations remains.

The descriptions of many commodities in control lists are formulated in a general manner and no consideration is given for equipment modifications. Nevertheless, *a priori* it is known that the different types of nuclear reactors, for example, have their own specific degrees of proliferation risk. This applies to many other controlled commodities as well. Export of some commodities is controlled not so much because of a threat of their proliferation, but because they are considered to be convenient indicators of proliferation. The role of commodities as indicators of proliferation has not been well studied.

The purpose of this paper is to report on the potential use of a qualitative estimation of proliferation risks, and to raise the question regarding essential practical needs in developing quantitative methods, which would be aimed at analyzing the proliferation risks.

Existing Approaches to Estimation of Proliferation Risks

Risk of diversion is a qualitative category. Generally one speaks about a high risk of diversion whenever there is a real physical and technological chance for the diversion of a commodity (material, equipment, or facility) to a weapons application. Basically, all nuclear fuel-cycle technologies can be categorized as having some diversion risk, as well as some proliferation risk. We can speak about a *risk of diversion* for this or that material or equipment and imply that a *peaceful* commodity, being imported, could be secretly integrated, directly or after modification, into an illicit weapons project.

The *risk of proliferation* can be low or be absent if a commodity exported or imported cannot be used in weapons of mass destruction (WMD). This is in contrast to those cases with high risk of proliferation, when the commodities can be used directly to create WMD. The risk of proliferation can be evaluated as high not only due to technical parameters of a commodity, but also due to the country-recipient or its end user. The export of sensitive commodities to so-called "threshold countries," in which a secret state nuclear weapons program is presumed to exist, has a high risk of proliferation. A high risk of proliferation will also occur in the case of export under a contract with an end user suspected of commercial contacts with terrorist organizations.

The primary information needed for identifying commodities for purposes of export control is their description in the control lists. Such descriptions cannot be absolutely detailed *a priori* because if they were they could reveal confidential information that could be useful to a potential proliferator. At the same time, for the purpose of export control, it is important that this description provides a means for clearly identifying the commodity. This identification should be useful not only to a technical expert but, whenever possible, to other participants in export control procedures. Many such participants have no special knowledge in the field of nuclear fuel cycles (e.g., customs officers and officials of trade organizations). Thus in practice export control is inconsistent in its description of commodities on the control lists, i.e., the control lists seek economy of words with maximal details, especially in defining the parameters of the commodities that are to be controlled. The control lists contain no information about estimations of proliferation risk for any specific commodity. In some entries the control lists emphasize an essential technological significance of this or that commodity for some sensitive applications.

The description of a commodity in a control list, in addition to identifying particular features, can emphasize those basic features that caused the commodity to be designated controllable. Commodities can be controlled due to any of the following reasons:

1. Its technical parameters lie in a certain sensitive range (e.g., sizes, capacity, speed, frequency, and temperature).
2. The commodity can incorporate specific, supersensitive technology irrespective of its parameters (for example, commodities related to reactor fuel reprocessing, or uranium enrichment).
3. The commodity can belong to a definite class/type/model that is known to be especially designed for a sensitive process.

These approaches are clearly applicable to the export control of lasers, in particular, due to the great variety of such equipment.

Thus, the identification of commodities as controllable occurs by comparing significant features, which the expert enters in the control list along with the actual technical parameters and other features of the commodity. The question about proliferation risk (about the *degree of sensitivity* for this commodity) remains unanswered or else the question is decided only qualitatively, based on whether or not the description of the commodity indicates that it belongs to any technology considered sensitive.

Therefore, the estimation proliferation risk of a specific commodity can have only a qualitative character. The result of such an estimation is usually based on the pertinent individual's knowledge of the nuclear fuel cycle, and is characterized by the following approaches:

1. The maximum threat corresponds to the access of a proliferator to nuclear material of weapons quality.
2. The gravity of other threats of proliferation are qualitatively evaluated on the basis of the number of technological steps between the given commodity and access to nuclear material of weapons quality.
3. The risk of proliferation is increased if a) there is a realistic possibility for a secret transfer of the commodity from legitimate to proliferant use (for example, due to its small size); b) there is no time available for the global community to react to the fact of proliferation; c) the commodity is ready for weapons use and does not require a high degree of technical training, complicated setup, etc., on the part of a proliferator.

An example of qualitative categorization of commodities such as equipment, facilities, and technologies into four groups based on their proliferation risks for use by a hypothetic terrorist group is presented in Figure 1.[1] This sorting into groups is made by allowing for the following factors: 1) how many technological steps lie between a commodity and the possession of nuclear material of weapons quality; 2) whether the commodity represents a specific interest for terrorists; 3) what time remains for reaction of the world community to the fact of proliferation; and 4) whether the probability of detecting the proliferation is high.

This example must be significantly modified to apply to the proliferation threat from a state-proliferator planning secret weaponization. The proliferation risks associated with state-proliferators and terrorist groups are sharply different, for any specific commodity, due to divergent interests of these two kinds of proliferators. A state-proliferator would have a keen interest in developing the weapons part of the fuel cycle, especially such technologically difficult problems as, for example, enrichment technologies and reprocessing. A terrorist group will be interested in receiving ready or nearly ready weapons materials or weapons components. Thus, no uniform (even qualitative) classification of various technologies related to the nuclear fuel cycle in terms of proliferation risk is possible. Such classification is meaningful only in the terms of a specific threat. There should be two versions of the categorization, similar to those given in Figure 1, at a minimum—one for each of the these threats.

Methodological Problems of Risk Estimation

As is seen from the previous section, even qualitative estimation of risk of proliferation for a specific commodity depends not only on the kind of commodity and its applicability to specific portions of the nuclear fuel cycle, but also on the kind of proliferation threat it poses, or the type of proliferator it attracts. This picture is also complicated by the fact that a controlled commodity can have many modifications. Let's consider the nuclear reactor example, and those qualitative approaches available for estimating the proliferation risk for related sensitive equipment.

When considering the question of proliferation danger coming from nuclear reactors, it is necessary to note that any reactor will produce plutonium-239. This isotope is ever present in the spent nuclear fuel and can be used in a nuclear charge.

For a long time, the question about the possibility of using *reactor-grade* plutonium (i.e., plutonium with rich isotope content) in a nuclear device was discussed. It was supposed that plutonium extracted from spent fuel after high burnup irradiation cannot be used in nuclear weapons production. However, recent research on estimation of the potential proliferation danger coming from spent fuel found that plutonium of almost any isotope content should be considered as usable in the production of nuclear charges with various degrees of efficiency.

In the national export control lists a complete nuclear reactor and various reactor equipment are not differentiated by considering the reactor's type, though it is known that different kinds of reactors have much different technical possibilities for building up plutonium-239.[2, 3] Let's consider the factors determining the degree of sensitivity of different reactors in terms of proliferation.

Assessing the importance of a reactor, its equipment, and its materials and technologies in terms of proliferation should be based on two basic items:

- Declared purpose for the reactor
- Technical characteristics of the reactor

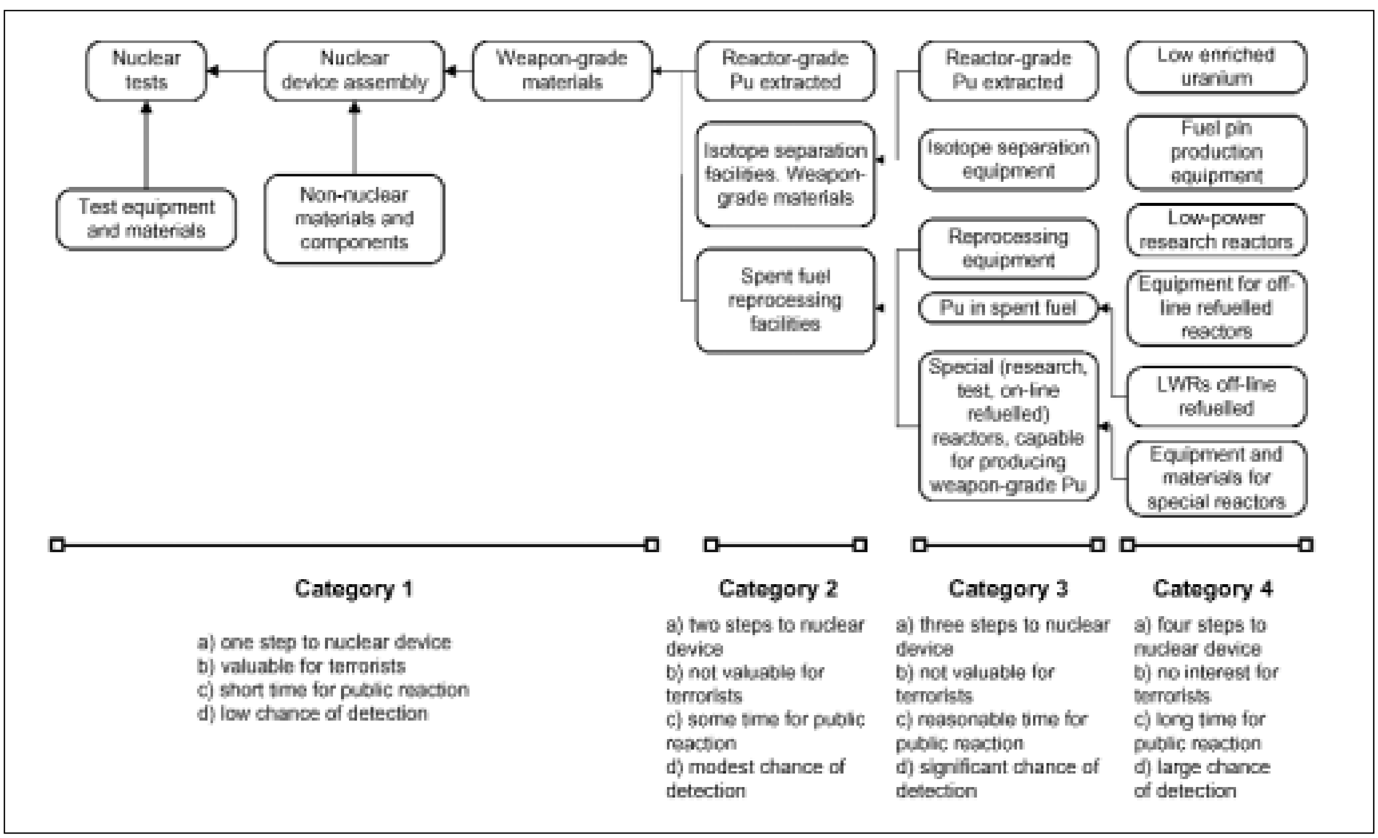
The type of fuel used is the best parameter representing the reactor in terms of its proliferation significance:

- Natural uranium—It has no direct use in nuclear charge applications, but at the present time the larger part of weapons-grade material in the world has been built up in heavy-water reactors with this fuel.
- Low-enriched uranium—It has the same proliferation danger as natural uranium, if a country has no enrichment facility. On the other hand, low-enriched uranium could be more effective feedstock for the enrichment industry than natural uranium.
- Highly enriched uranium or plutonium are weapons- or almost-weapons-usable materials (such fuel has a proliferation concern both before and after reactor irradiation).

The type of moderator also plays a role as an indicator of proliferation significance:

- Light water is not sensitive material.
- Heavy water poses proliferation concerns for two reasons:
    - Tritium, a weapons-usable material, is formed during the irradiation of heavy water.
    - Any state-proliferator possessing a facility for spent fuel reprocessing could extract plutonium built up in a heavy-water reactor running with natural uranium fuel.

Figure 1. An example of proliferation risk categorization for nuclear commodities (materials, equipment, or technologies)



- Reactor-grade graphite is similar to heavy water with respect to plutonium production possibilities during irradiation of natural uranium.

The *conversion ratio* is defined as the part of the amount of fissile material produced in a reactor to the amount initially loaded in the reactor. In regard to this conversion ratio, reactors can be categorized as *burners, converters* (reprocessors), and *breeders.* Burners–e.g., light-water reactors—have a low conversion ratio and a correspondingly low proliferation concern. The conversion ratio of converters is close to one but still small. Breeders, with a conversion ratio greater than one, have the greatest potential proliferation concern since potential weapons material is present at the reactor site both before and after fuel irradiation.

During reactor refueling, fission materials become vulnerable to diversion. There are two types of refueling: offline (when the reactor is shut-down) or online (when the reactor is operating). The refueling types differ in their risks of diversion: offline refueling could be controlled more thoroughly compared to online refueling.

Reactors with high fuel burnup have less proliferation concern than reactors having a short period of fuel irradiation, since long irradiation partially burns out plutonium and contaminates it by producing nonfissile isotopes. Thus, reactors with low fuel burnup create more diversion concern. The *power reactors,* according to their commercial aims, have, as a rule, the longest inter-refueling periods. Short intervals between refueling are characteristic first of all for *production reactors* designed to produce plutonium, as well as for *research reactors,* which, for example, could be shut down according to specific experimental requirements.

Thus, summarizing the analysis of proliferation significance of different types of nuclear reactors:

- *Any given light-water reactor*, for which the fuel is under IAEA safeguards, does not represent any significant threat for nuclear nonproliferation.
- *A heavy-water reactor,* together with an available spent fuel reprocessing industry, becomes a dangerous risk in terms of nonproliferation (effective weapons-grade plutonium production by irradiation of natural uranium; higher risk of diversion in comparison with LWR, tritium production).
- *Gas-cooled reactors* with graphite moderators correspond to the heavy-water reactors in many parameters, and are also attractive for proliferation.
- *Breeder reactors* are dangerous from the point of view of proliferation, since plutonium and highly enriched uranium are present at all stages of its fuel handling.

The simplest approach to go from qualitative to quantitative analysis of proliferation risk may be in the assignment of a weight significance for each of the risk factors considered above, or in suggesting a simple scale such as from 0 to 2, as is done in Table 1. In this case, so-called *conventional significance* was taken into account by obeying common sense and using a trivial scale based on classifying a commodity as *dangerous-not dangerous.* But even such a simple approach allows one to execute a simple analysis and to compare the proliferation risks of reactors, for example in dependence of highly enriched uranium and plutonium availability. This is shown in Table 2.

Table 1. Significance of reactor parameters in terms of proliferation risks

Key parameter	Type	Conventional significance
Fuel	Natural uranium	0-1
	LEU	0-1
	HEU, plutonium	2
Moderator	Light water	0
	Heavy water	1
	Graphite	1
Conversion ratio	Burners (conversion ratio <1)	0
	Breeders (conversion ratio >1)	2
Refueling	Off-line	0
	On-line	1
Burnup	Low (short irradiation run)	2
	High (long irradiation run)	1

Table 2. Reactor proliferation risks

Reactor Type	Dangerous parameters, features
Light-water power reactor	Plutonium build up is ineffective
Heavy-water reactor	• Plutonium build up from natural uranium • Simple diversion • Tritium production
Gas-cooled graphite-moderated reactor	• Plutonium build up • Simple diversion
Breeder reactor	Plutonium and HEU are available at the site in all stages of a fuel cycle.

The content of the both Tables 1 and 2 adequately reflects the qualitative approaches existing now in export control to assess proliferation risks.

Proliferation Risk Assessment as an Export Control Instrument

The transition to a quantitative estimation of proliferation risk (if it is possible at all) would provide a new tool for use in the export control regimes. Initially it could apply to those members of the regime who are technical experts. The quantitative estimations would allow:

1. Classifying the controlled commodities on a basis consistent with the degree of their proliferation risk
2. Analyzing specific commodities on the lists of export controlled items to identify those having no proliferation risk
3. Analyzing new commodities (or technologies) in the nuclear sphere to determine whether or not they should be included in the control lists
4. Simplifying the procedure for application to commodities with low proliferation risk, and switch to more careful technical analysis in cases involving sensitive technology
5. Offering participants in export control that do not have special knowledge of the nuclear fuel cycle more objective data on sensitivity of commodities in terms of nuclear proliferation risks

The development of methods for quantitatively estimating the technological vulnerability of nuclear equipment is necessary both from the methodological and practical points of view. The commodity traffic in nuclear markets would become safer from the standpoint of proliferation if engineers could definitely determine, and convincingly show, that specific equipment is not dangerous in proliferation terms.

The question of obtaining analytical data on especially sensitive technologies is complicated both for maintaining confidentiality and protecting information from potential proliferators. The development of methods for estimating proliferation risks should proceed in the frame of international cooperation and with a harmonization of approaches and analytical results.

Conclusions

1. The concepts risk of diversion and risk of proliferation are now used in the practice of nuclear export control in a qualitative sense and have almost no quantitative meaning.
2. The qualitative approaches to determining proliferation risks consist in attempts to categorize all sensitive commodities as a function of the threat represented for possible proliferation.
3. The proliferation risk of a specific commodity is determined by not only the technical capabilities of the commodity but also by proliferation profile of the importer (a state-proliferator or a terrorist group).
4. The application of some conditional importance to various technical parameters of the commodities, in terms of nonproliferation, allows one to classify various kinds of commodities, or modifications to commodities, qualitatively.
5. The development of methods for quantitative estimation of proliferation risk of sensitive commodities, including modifications to the commodities, would give an effective analysis tool to export control.
6. The development of methods for the quantitative estimation of proliferation risks of sensitive commodities requires one to resolve methodological problems and problems connected to the special confidentiality of the given commodities.

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The Local Area Nuclear Material Accountability Software (LANMAS)

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Abstract

The U.S. Department of Energy's (DOE) Office of Materials Inventory and Technology Development (SO-20.3) continues to support the improvement and standardization of nuclear materials accounting through the funding and program management of the Local Area Nuclear Material Accountability Software (LANMAS). The Westinghouse Savannah River Company (WSRC) serves as the lead developer. LANMAS conforms to the application and technology layers identified by DOE's Enterprise Architecture via the use of commercial off-the-shelf computer systems and Microsoft computer operating systems. LANMAS is a network-based nuclear materials accounting software product. In addition to meeting routine site nuclear material accounting needs, over the past year, several of the LANMAS sites requested that LANMAS functionality be expanded to assist with ongoing site closure activities, including the processing, disposition, and long-term storage of nuclear material in waste. More recently, SO-20.3 and WSRC LANMAS representatives are exploring how LANMAS capabilities and available commercial tool sets can be utilized to develop and maintain an independent store of timely and detailed nuclear material inventory information. This paper discusses current LANMAS capabilities, proposed new functionality, and how LANMAS supports the DOE's e-Government initiative for nuclear materials accountability. These activities ensure that LANMAS continues to remain a robust and viable software product with enhanced capabilities to support the DOE's various program needs.

Introduction

LANMAS is a network-based nuclear material accountability software product developed to replace outdated and legacy accountability systems throughout the DOE. The project is funded and managed by the Office of Materials Inventory and Technology Development (SO-20.3). The core underlying purpose of LANMAS is to track nuclear materials inventory and report transactions (such as movement, mixing, splitting, and decay) to the Nuclear Materials Management and Safeguards System (NMMSS). While LANMAS performs those functions well, there are several additional functions provided by the software. The focus of this article will be on the functionality and technology of LANMAS and its growing accompany of companion products.

Brief History

The LANMAS development effort began in the early 1990s. The WSRC is the lead contractor for development and maintenance support activities. Today, the program is in the operation and maintenance phase of its life cycle. However, significant strides are taken by SO-20.3 and WSRC to ensure the software product remains an active tool for the enhancement and standardization of nuclear material accounting throughout the DOE complex. By the end of fiscal year 2005, it is anticipated that the LANMAS user base will increase to fifteen facilities.

Underlying Architecture and Technology

LANMAS, prior to version 2.7, has been a traditional two-tier client server system. In more common terms, LANMAS has a client program running on a Microsoft Windows desktop computer with a database running on a centralized server. This traditional model has served and still serves most systems well. One of the underlying difficulties of this model is the concept of business rules. For LANMAS, these rules (i.e., orders, manuals, etc.) are the requirements to which all DOE sites must comply with maintaining and reporting their inventories and transactions. The added complexity of enforcing the rules consistently across the client application and the database server can be daunting. Some of the business logic is applied/validated at the *user interface* while other parts of the logic are applied/validated at the database server. This break in *responsibility* of enforcing the business logic is where many computer applications fail. Changes applied to the client side of the application (and sometimes many places in one side of the application) are not applied to the server/database side. The solution is to use a three-tiered approach. The first tier is responsible for the user interface, the second tier is responsible for enforcing the business logic, and the third tier is responsible for saving the information. Through the use of the middle tier, a single and consistent set of business rules are applied. LANMAS has embraced this methodology and included it in its long term plans. The plan was started with LANMAS version 2.8 where some of the business logic was moved to a centralized middle tier.

The centralization of the business functions of LANMAS are placed in *objects.* Object is a computer science term for the generalization of logic and data into a single entity (or object). Through the centralization of the logic and data of different entities, the middle tier of LANMAS will be born. An additional major benefit of the *object-oriented* method of software development is the ability to reuse the software that enforces the business logic. This benefit will be discussed below when the LANMAS Automation Services and Safeguards Information Bridge are reviewed.

How does LANMAS successfully accomplish such a daunting task? LANMAS is built on core Microsoft technology (some readers may now be excited or disenchanted based on any fundamental computer science beliefs). The Microsoft Windows 2000 operating system (both for the client and server computers) are the foundation that LANMAS builds from. In addition, Microsoft SQL Server 2000 and Microsoft Visual Basic 6 are the tools that make up the building blocks of the application. As a side note, in pure computer science terms Visual Basic 6 is not an *object-oriented* computer language, but object-like. In other words, although Visual Basic 6 does not meet all academic requirements for an object-oriented language, it is adequate.

Fundamental Philosophies of LANMAS

Before delving into all that LANMAS and its companion software does, it is important to share with the reader some of the fundamental philosophies incorporated into LANMAS. These philosophies are flexibility, extensibility, scalability, and usability.

While all of DOE operates essentially under the same sets of orders, each site has chosen individualistic methods to accomplish the required results to comply. Thus in order for LANMAS to appeal to such a broad audience as the DOE complex, LANMAS has to be flexible. To accomplish the level of flexibility necessary, LANMAS has an extensive administrator program allowing for features not only to be turned on or off, but in many instances, several levels of customization can be applied. Because of this flexibility, sites that implement LANMAS do not have to make extensive changes to their business process.

In addition, if a DOE site has special individual needs, LANMAS can be extended through the creation of a *site specific* plug-in. The plug-in may be developed in Visual Basic and typically has the same look and feel as LANMAS. Within LANMAS there are several predefined buttons and events that can be enabled by the LANMAS Administrator Program. The button or event is then *referred* to the site specific plug-in for execution. Since the LANMAS application launches the plug-in, and the plug-in has a look and feel like LANMAS, it appears as a normal part of the application, and thus is transparent to the user.

In the endeavor to satisfy the needs of such a heterogeneous group as the DOE materials control and accountability (MC&A) community, the philosophy of creating a software package that is scaleable is significant to the success of LANMAS. Users of the software application can range from a single user to upwards of one hundred. The number of transactions an organization might generate per month could be as few as a dozen or up to a few thousand. Therefore, LANMAS's scalability relies on the infrastructure created by Microsoft. By following proper software development methodologies and proper configuration of the Microsoft infrastructure, scalability has been achieved. LANMAS can be operated on a standalone laptop or a fifty node computer network and give comparable performance.

Usability is another philosophy of LANMAS. Unfortunately, the term usability is subjective and, therefore, LANMAS relies upon its user community to help identify what is usable and what is not. The focus of usability is to allow for rapid data entry and provide graphical features when those features are practical to use.

LANMAS the System

Starting with software version 2.8, LANMAS has become a feature rich, mature application. Moving into version 2.9 and beyond LANMAS has evolved to allow for multiple reporting paths as well as multiple methods for inputting data. LANMAS has moved beyond inventory and transaction management and reporting to include many necessary supporting functions as well.

While many previous systems have chosen to build their internal data structures on NMMSS's concepts of *material types,* LANMAS has based its entire inventory structure on a Periodic Table view of inventoried materials. Also, LANMAS internally maintains full precision on all its numeric values. In order for LANMAS to report to NMMSS, the business logic of reporting to NMMSS is superimposed on LANMAS. Thus, while LANMAS has more details than required by NMMSS, LANMAS's reporting module makes it appear to NMMSS as being structured around material types and NMMSS reporting units.

To begin lets identify some of the current functions that a fully utilized LANMAS can perform: shipping and receiving, mix/split/transfer of materials, decay calculations, container management, tamper-indicating device management, integrated security, limit checking, peer/transaction review, receipt measurement, material edit, adjustments, unique name, container and material measurements, IAEA reporting, and all associated NMMSS reporting. Remember that all of these functions and features can be customized based on a sites implementation. While the above list of functions is intriguing, the exciting part is how many of these functions are accomplished.

LANMAS and XML

LANMAS has been an early advocate of the use of the eXtensible Markup Language (XML). The excitement in the use of XML comes from the variety of flexible options that arise from its use. XML can, and does, perform the same function as many of the eighty column card reports still in use today. However, XML allows additional fields to be added to the data thus adjusting the level of information that can be displayed to users of the same report. The beauty of XML is that the addition of new data fields has no impact on the original user and specifier of the XML. Secondly, instead of staring at eighty columns of numerous rows of data all jammed together, the XML can be combined with a *style sheet* and turned into a viewable report inside of a browser. In addition to a viewable report, the report could also be made dynamic. Style sheets allow for many different views without having to create new reports. Features of the style sheet include: the ability to view detail or summary information just by clicking a *twisty*, the ability to sort or filter the data being viewed, and the ability to hot link between sections of the report.

LANMAS Services Automation and LSWatch

This is where several of the LANMAS efforts come together:

- LANMAS version 2.7 begins to use XML as a means to transfer detailed information between LANMAS sites for shipments and receipts.
- The LANMAS development team undertakes the review of a three-tiered object-oriented structure for LANMAS.
- At the same time, Rocky Flats identifies a need to bring all their waste back onto the books for disposition and would like to automate the weight adjustments of the thousands of items that will be re-measured.

Since necessity is the mother of invention, the LANMAS team assisted Rocky Flats by creating a prototype software package. The package used XML to transfer the data from the measurement system into LANMAS. The business logic was extracted from the user interface and placed into a collection of objects. From this endeavor, LANMAS Services Automation (LSAuto) was created.

LSAuto is now a companion product that was released with version 2.8. The software allows a user to select an XML file that matches the format identified by the LANMAS team and will perform all the operations as if a user or team of users entered the data by hand. Most of the LANMAS user functions are included in this automated tool.

The next natural progression of LSAuto is to incorporate the same ideas of automated entry, but to eliminate the manual intervention of selecting a file to be loaded. Thus, LANMAS Services is being developed, as a suite of software programs. The suit of programs includes: LSAuto, LSWatch, LSWatch Manager, LSNotify, and LSSend.

LSWatch is a Windows NT/2000 Service that monitors a user-specified folder for the creation of files with an XML extension. When the XML file is placed into the watched folder, LSWatch will launch LSAuto to process the XML file. Once LSAuto has completed processing the XML file, LSWatch will move the file and the success/error report that was generated by LSAuto, to a user specified *Success or Error* folder. LSWatch can create an optional log file and supports the Windows NT/2000 Event Log. LSWatch contains internal file and mail queues that support *first-in-first-out* routing of files and messages (using LSSend). The service can be configured by the user through the use of the LSWatch Manager.

LSWatch Manager (Manager) allows a user (typically the system administrator or a designated power user) to specify *watch, success, error,* and *log* (optional) folders for the LSWatch Service. The Manager also allows the user to perform the following tasks: (1) *start, stop, or pause* the LSWatch Service, (2) set the LSWatch Service to automatically start when the operating system is started, (3) schedule the times that the LSWatch Service is allowed to run, (4) process the file queue manually, if the LSWatch Service is not scheduled to run, and (5) optionally, send network messages or electronic mail to specified distribution lists (created using LSSend) when an error file is created by LSAuto. The LSWatch Service operating/processing status is displayed in the Windows system tray.

LSNotify is a remote monitoring client for the LSWatch Service. With LSNotify, a user can monitor the LSWatch Service status and the contents of the watch, success, error, and log folders. The user can also *map, disconnect,* and *explore* network drives for ease of navigation. The LSWatch Service status is displayed in the Windows system tray.

LSSend is a messaging client that can be used as a standalone application or in conjunction with the LSWatch Service. LSSend supports network messaging and the Simple Mail Transport Protocol (SMTP). The user can create and manage *To, CC,* and *BCC* distribution lists for sending email or a computer list for network messaging. LSSend supports email attachments. If used in conjunction with the LSWatch Service, LSSend will automatically include the XML file, error report, and the necessary style sheet as attachments to the email message, when a file that was sent to LSAuto fails.

LANMAS and the International Atomic Energy Agency (IAEA)

In 2001 LANMAS began working with the Hanford site to develop an International Atomic Energy Agency (IAEA) reporting module for LANMAS. This endeavor required additional data associated with facility attachment (such as key measurement points or IAEA batch name) as well as necessary IAEA reports and was included in LANMAS version 2.8.

LANMAS and the Safeguards Information Bridge (SIB)

Shortly after September 11, 2001, SO-20.3 identified the need to have rapid, timely access to data. The SIB is being developed in a four-phase approach to meet this need. Leveraging the Microsoft tool set, WSRC developed a data store that uses data mining techniques for inventory assessment. Images and descriptions of sites and facilities, along with data tables (e.g., materials, forms, quantities) of the associated nuclear materials are contained in the SIB. This information is used to address ongoing questions concerning the DOE's nuclear material inventories and national security interests and supports the DOE's Continuity of Operations and Continuity of Government-related operations. In addition, successful implementation and operation of the SIB is an example of how detailed nuclear material inventory information from the LANMAS sites can be captured in a consistent, cost-effective, and timely manner.

LANMAS and the Weapons Information System (WIS) Upgrade Project

LANMAS offered to assist the DOE Kansas City Plant in developing an XML format that would consolidate several different, but overlapping reporting formats used by the existing Weapons Information System (WIS) into a single XML format. The resulting effort combined seventeen different reports into a single XML report. In the future, the WSRC LANMAS representatives will continue to assist the WIS Working Group in XML-related programming activities, as appropriate. In particular, activities that support future efforts within DOE to examine the feasibility and potential benefits to design a standard data format for the exchange of nuclear material-related information between the DOE, the DOE's National Nuclear Security Administration, the U.S. Nuclear Regulatory Commission, and contractor personnel.

Conclusion

In summary, significant enhancements and improved capabilities have been made to the LANMAS software product and program since the early 1990s. SO-20.3 and the WSRC LANMAS team will continue to meet the needs of the MC&A community and ensure successful interface with NMMSS. Development and operation of the SIB demonstrates the versatility of LANMAS and how the software product and the data it collects can be used to address the department's various needs. Ongoing participation in user group meetings, training, and various DOE/chief information officer-sponsored activities will ensure that LANMAS capabilities continue to improve and that the product remains an important software tool for complete nuclear materials accountability for use throughout the DOE complex.

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Proliferation Resistance Methodology: How to Take Benefit from Nuclear Safety Approach

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Abstract

Proliferation resistance (PR) has become one of the primary topics addressed in the framework of developing nuclear energy systems. While it has been implemented successfully for a long time, the need to structure the methodology has arisen. Nuclear safety (NS) has already developed a comprehensive methodological framework to address the risk of accidents and the related release of radioactivity. There is a parallel with PR, in addressing the risk of diversion of nuclear material or the misuse of a facility. The fundamental principle of *defense in depth* developed in NS can certainly be adapted to some extent to PR, in several ways: the concept of multiple barriers, the five levels of defense in depth, the implementation at all stages of development, and operation of the nuclear energy system. Other tools and approaches elaborated in NS can also be of relevance for PR, such as probabilistic risk assessment to assess the strength and robustness of a system and identify weak points, or the safety culture. This paper will elaborate on these topics. This paper aims at giving a firm basis of the concepts and their possible use. We recognize that this is only a first step that opens a wide field to implement them and derive effective results in concrete cases. This paper does not allow us to provide a detailed example, but we acknowledge current work in the United States and in Europe on some aspects (mainly probability safety assessment) and we encourage the practical use of the full methodology in proliferation resistance assessment.

The Framework of the Analysis

First, behind the general notion of proliferation, we must define precisely what threat we are dealing with. To this end, we may start from three basic definitions derived from the U.S. "NPAM" project[1] and the recent IAEA sponsored work[2]:

- **Proliferation:** Acquisition of one or more nuclear weapons by a nation that does not have them
- **Proliferation Resistance:** Those characteristics of a nuclear energy system that impede the diversion or undeclared production of nuclear material, or misuse of technology, by states in order to acquire nuclear weapons or other nuclear explosive devices. The word *characteristics* encompass technical (intrinsic) features as well as institutional (extrinsic) measures such as international treaties, safeguards, or export controls.
- **Proliferation Risk:** The likelihood of a nation acquiring one or more nuclear weapons within a given time period

Within the frame of this terminology, it appears that *proliferation risk* is a combination of two factors:

- Proliferation resistance as defined above
- Proliferator characteristics measure the willingness (that is motivation) and capacity of a given nation to acquire a nuclear weapon. These elements are related to political issues as well as to the economic and technical capabilities of the proliferator.

The analysis presented here is limited to PR only. More specifically, we address here only the so-called *horizontal proliferation,* i.e., the case of a state that does not possess nuclear weapons and is attempting to acquire one or more. Furthermore, other threats such as sabotage or fabrication of dirty bombs are not proliferation as defined above and are therefore are not addressed in this paper.

Global Approach on Nuclear Safety and Proliferation Resistance

The General Objective

NS and PR each have defined a fundamental, general objective. Let's consider the parallel that may be established between the NS and PR general objectives.

For NS, the general objective is to *"ensure appropriate confinement of radioactivity in all circumstances."* This general objective applies to any component of a nuclear energy system. This objective is sometimes adapted to some specific components such as a nuclear reactor: "to protect individuals, society, and the environment by establishing and maintaining in nuclear power plants an effective defense against radiological hazard."[3]

For PR, according to the definition given here above, it is to "prevent any acquisition of one or more nuclear weapons by a nation that currently does not have them." Here also, this general objective applies to any component of a nuclear energy system.

An extended formulation in the spirit of the above-mentioned safety objective can be derived from the result of the IAEA international meeting in Como[2] and recent GIF studies: "PR features and measures should be implemented in the design, construction and operation of future nuclear energy systems to help ensure that future nuclear energy systems will continue to be an unattractive means to acquire fissile material for a nuclear weapons program."

Thus, from the starting point, we see that in each case, we have one clear and *well-identified* objective and that we can draw a meaningful parallel. In both cases, the objective is avoiding the occurrence of a potentially damaging event. In both cases we wish to protect individuals and society. In both cases the achievement of the general objective requires proactive actions.

The Fundamental Principle of Defense in Depth

The next step is to establish how the general objective can be achieved. In the field of NS, we know that the basic principle on the general approach relies upon is the famous *defense in depth* principle. What does that means exactly?

Sometimes this notion is reduced to the simple concept of multiple physical barriers aimed at protecting any release of radioactivity to the environment, with the usual example of the three barriers of a nuclear reactor (fuel cladding, primary circuit, and containment building). These are important features of nuclear reactors but in fact, the defense in depth concept is much more than that. It states that all safety activities, whether organizational, behavioural, or equipment related, are subject to layers of overlapping provisions, so that should a failure occur it would be compensated for or corrected without causing harm to individuals or the public at large.[3] This idea of multiple levels of protection is the central feature of the defense in depth and it provides an overall strategy for implementing safety measures in nuclear facilities. When considering these measures, we find that they are generally of two types: *material* measures such as physical barriers and redundant circuits and *organizational* such as quality control, inspections, specific training, or procedures. It is also important to note that each of these measures can be implemented at the various stages of a process, that is design, fabrication and then operation of a nuclear system.

This notion of multiple barriers is important in PR. It is implicit in past studies and explicit in more recent work. For instance, the U.S.-led TOPS report[4] suggests a list of several features can act as barriers, with the assumption that they can be used together. The IAEA international meeting of Como[2] defined explicitly a specific principle as follows: "Proliferation resistance could be enhanced when complementary and redundant features and measures provide defense in depth." In the field of PR, it is also widely acknowledged[2, 4] that effectiveness will come from the combination of intrinsic (technical) features and extrinsic (institutional) measures. And it is also highly recommended that PR be implemented "from early design stage"[2] and then at each step to final decommissioning and ultimate waste management.

It is therefore clear that the global approach of defense in depth defined in NS is similar to the global approach sought in PR. We can expect that some of the more detailed recommendation translating defense in depth into concrete safety process can be adapted for use in PR.

All these measures are often called *the lines of defense* to reduce the occurrence of a given risk. The number of lines of defense may vary according to the importance of the risk but also according to the *strength* of each line of defense. For example, in the case of nuclear reactors, one of the defenses against the dispersion of radioactive product in the environment is the accumulation of three physical barriers mentioned above are the three lines of defense. Generally speaking, the success of such an approach strongly depends of its global coherence, which means that the whole set of lines of defense must be *comprehensive,* and that between them, they must be *homogeneous* and *independent* (to avoid common modes failures). This is a principle that is applicable also to PR.

The Five Levels of Defense in Depth

The strategy for defense in depth is twofold: first preventing severe accidents and second, if this prevention fails, limiting the potential consequences of these accidents and preventing their evolution to more serious conditions. Defense in depth is generally structured in five levels shown in Table 1, and described in several reference documents.[3] If one level fails, the subsequent level comes into play, and so on. Special attention must be paid to events that could potentially impair several levels of defense at the same time—called *common mode failures* (such as fires, floods, or earthquakes). This structure contributes to identifying the need and the strength of the several barriers.

The strategy applied in PR is also to discourage and prevent the misuse of a facility or the nuclear material (including the use of safeguards to verify that no diversion of nuclear material or undeclared activities are occurring), and to mitigate the consequences.

One of the current differences between safety and proliferation resistance is the level of definition and characterization of incidents and accidents. In the nuclear safety field, such incidents and accidents can relate to identifiable and measurable technical parameters or human behavior parameters, which can be quantified by various methods such as data collection from simulator. In the proliferation resistance field, there is still work to do to reach such a systematic characterization, and indeed everything will not be strictly speaking a *quantitative* parameter.

However, incidents or accidents can still be related to concrete and measurable facts. To give some examples, *incidents and anomalies* would include a failure of containment and surveillance system (e.g., a lapse of lighting in a spent fuel pond, rendering the camera monitoring ineffective for some hours), a seal found open, a higher than usual level of material unaccounted for (MUF), a procedure for physical inventory verification (PIV) and physical

Table 1. Levels of proliferation resistance

Level	Nuclear safety objectives	Proliferation resistance objectives
1	Prevention of abnormal operation and failure	Prevention of misuse of nuclear material and facilities
2	Control of abnormal operation and detection of failures	Transparency and implementation of verification regimes
3	Control of accidents within the design basis	Quick processing of detected anomalies and inconsistencies
4	Control of severe plant conditions including prevention of accident progression and mitigation of consequences of severe accidents	Management of significant anomalies, including the prevention of further diversion and undeclared production and difficulty of next steps toward weaponization
5	Mitigation of radiological consequences of significant releases	Management of breach of nonproliferation commitment, through UN resolutions and other political or diplomatic actions

inventory taking (PIT) may need improvement or, on a more qualitative basis, difficulties in assessing and evaluating the results of a verification. Moving to more severe incidents would be closer to *accidents*, examples would include the actual loss of nuclear material or a misinterpretation of the regulation leading to a lack of declaration for some nuclear material acquisition or movements, or the practical inability to establish an initial inventory.

For each of those levels, we can associate intrinsic and extrinsic barriers of special relevance. In Table 2 below, we have tried to illustrate this approach by suggesting for each level an example of PR combination of intrinsic features and extrinsic measures corresponding to NS objective assigned to each level.

The examples given here may be discussed or even disputed and this exercise shows that there is still some work to do to define levels of PR defense in depth. However, it is clear that the *basic principle of defense in depth can be applied to PR by considering at each step a set of lines of defense aimed at reducing the risk of proliferation.* In that sense, this principle provides an overall strategy for establishing efficient measures aimed at preventing proliferation.

Implementation of the Fundamental Principle

To be efficient, the defense in depth principle must be implemented with the same rigor at all steps of a project: design, construction, and operation phases of a process or a facility. For PR, the approach will also cover all steps of the fuel cycle holistically. Let us examine successively these three stages and examine how they can provide a complementary approach to design and review PR.

Table 2. Example of PR barriers corresponding to the NS levels of defense in depth

Level	Nuclear safety objective	Example of Proliferation resistance mean
1	Prevention of abnormal operation and failures	Intrinsic: Unattractivness of materials, barriers to facility access, time and cost required to modify a facility Extrinsic: State commitment (e.g., NPT, safeguards agreements), limitation of availability and access to sensitive technology and information.
2	Control of abnormal operation and detection of failures	Intrinsic: Nuclear material control and accountancy systems, built-in and specific safeguards instrumentation Extrinsic: verification measures (e.g., IAEA safeguards, regional safeguards, export control) to detect abnormal events (identification of anomalies and inconsistencies)
3	Control of accidents within the design basis	Intrinsic: Specific facility design or equipments to prevent or delay the diversion of significant amounts of nuclear materials. Extrinsic: Quick and effective processing of anomalies and inconsistencies by the verification institutions (IAEA, regional), possible precautionary strengthening of verification activities
4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	Intrinsic: Unattractiveness of material or facility: difficulty to use diverted material or technology for making a weapon Extrinsic: Rapid strengthening of verification activities and political or diplomatic actions
5	Mitigation of radiological consequences of significant releases of radioactive materials	Intrinsic: In some respect, same as level 4 Extrinsic: UN resolutions, other political or diplomatic actions

A Safe Design

Usually, at the design stage, NS considers the three first levels of defense, that is (see Table 1):

- Prevention of abnormal operation
- Detection and control of abnormal operation to come back to normal operation conditions
- Control of accidents during the design stage

Among the series of measures that are considered in the design to achieve these goals are design margins, monitoring and detection devices with appropriate alarms, and redundancies.

These safety provisions may be transposed to PR provisions, particularly in the domain of the monitoring and detection of any abnormal event related to material flows in the process or through the facility.

Some examples of these intrinsic features of the design itself are given in Table 2. Development of nuclear energy system integrates the needs of PR, and insofar as possible results in unattractive nuclear material, facilities difficult to misuse, tamper with, or duplicate, facilities, process, or material that are easy to verify, and safeguards. Specific safeguards instrumentation or methods can also be developed. It should be remembered that in PR extrinsic measures can play a role as early as the design stage: involvement of verification agencies to facilitate their work, define the safeguards approach (for new type of facilities), and integrate some of their specific requirements in the design when possible, policy on availability of information, choice in the concept between few fuel cycle facilities supporting a large number of reactors. A systematic approach should de encouraged to create an exhaustive list of such features and measures for a given type of plant or process, and for the whole nuclear energy system. It could then be used by the designers as well as for evaluation purposes.

High-Quality Design Activities, Fabrication, Testing, and Operation

This is, of course, of particular importance when dealing with safety in general. It includes classic quality assurance (QA) programs as well as quality control (QC) measures and audits.

Once again, the extended use of QA methods and procedures in NS may fully apply to PR. The scope is in fact wider in PR; of course, it can be used in order to ensure that equipment dedicated to it are designed and will function in a satisfactorily (reliability is a key requirement for safeguards equipment). But it also includes verification activities performed during the construction and commissioning of the facility, such as design information verification (DIV), and calibration of safeguards-relevant equipment such as an accounting tank in a bulk facility. During operation it also includes, for instance, QA/QC related to the destructive and nondestructive analysis (DA and NDA) prescribed in the safeguards approach or for the elaboration of nuclear material accountancy reports.

Stringent Operating Conditions

In NS, safe operating conditions are obtained with the help of several means that can be classified as follow:

- Human factors, includes training and man-machine interactions
- Operating procedures
- Organization
- Inspections

Past incidents and accidents have clearly shown that human factors are of particular importance for safety. This means that the possibility of a human error in operating a nuclear facility must be taken into account by facilitating correct decisions by operators and inhibiting incorrect decisions, and by providing means for detecting and correcting or compensating for errors. To this end, personnel engaged in activities bearing on nuclear plant safety must be trained and qualified to perform their duties. Designers must also take great care in the design of control and operation devices (man-machine interaction or ergonomy).

The human factor in PR is also important but quite different in its nature: on the operator side, human factors could be a willingness to circumvent the system and divert material or misuse the facility. It is in no way comparable to concerns about human factors in safety. Still on the operator side, and more in the spirit of safety concerns about human factors, could be a type of *negligence* resulting in poor nuclear material management, inaccurate accountancy, or inadvertent tampering with safeguards equipment (e.g., breaking a seal, lacking illumination at a location when a surveillance system is operating). Like in safety, it calls for training of staff directly involved in PR and safeguard related activities, and a sufficient information and awareness of staff whose activities may have an impact on PR or safeguards implementation.

The other major human factor consideration in PR is on the verification agencies and their inspectors. The role of safeguards is to ensure nondiversion and that there is no undeclared production of nuclear material. It will be of further importance for the implementation of the Additional Protocol with the goal of confirming the absence of undeclared activities. An inspection failure can have consequences in some ways similar to a safety failure. Here also professional training, regular complementary training, and maintaining the necessary inspection culture, and associated rigor and curiosity are strong requirements.

Adequate operating procedures are also needed to keep the plant within the boundaries of a domain of safe operation or to manage incidental or accidental conditions, even in severe conditions. Similarly procedures are established for specific PR actions in the facility from operators (accounting, PIT, PIV, escorting of inspectors, etc.) as well as from inspectors.

The same similarity applies with regard to the responsibility of the operating organization that must be in no way diluted by the separate activities of the designers, suppliers, constructors, and regulators. Organization is also important for PR. In large facilities, the team dedicated to nuclear material management shall be independent from operation teams to maintain its independence (it is the same requirement as, for instance, the requirement for QC).

Finally, it is clear that the principle of external and independent inspections that apply to NS are a fundamental principle for PR. While in safety no one is willing to act to create an accident, in the area of proliferation there may be no such restraint (despite commitments) from some states to acquire a nuclear weapon. Verification is therefore a prerequisite to harmoniously develop a peaceful nuclear program. In most countries, in addition to the operator's own control, independent control and inspection will be performed by national authorities, regional verification agencies (EURATOM, ABBAC), and the IAEA.

Complementary Provisions

Probabilistic Approach

In most nuclear countries and for many years, the deterministic approach briefly outlined above has been supplemented by the so-called probabilistic safety assessments, PSA (or probabilistic risk assessment, PRA) for nuclear reactors.

This method is based on a systematic in-depth analysis of all accident scenarios that can be postulated with the help of *event trees, fault trees, or graph of states.* The analysis takes into account material failures, common modes events and human errors. The quantification phase is based on data evaluated from feedback, experience, or expert judgment, or tests on simulators for human factor quantification.

PSA is recognized today as a very useful tool to estimate the safety level actually achieved and, more importantly, to identify weak points in the facilities or processes. In particular, this approach is often used to:

- Analyze the contribution of the different accident sequences to the risk, and thus, identify the importance of any possible weakness in the design or operation or during a potential accident sequence that contributes to the risk
- Homogenize safety provisions such as the number of redundancies or emergency circuits
- Help in the definition and hierarchy of actions and procedures related to safety
- Optimize periodic tests and maintenance programs
- Justify some operational technical specifications

It must be noted that in recent years, the U.S. Nuclear Regulatory Commission (NRC) has develop the risk-informed approach, which combines the advantages of deterministic and probabilistic approaches[5] and is a decision making tool to address safety related issues of operating nuclear rectors.

The system subject to proliferation resistance analysis can be defined along the pathway to obtain a nuclear weapon. It will therefore be based on a physical model and include the different facilities and material involved at each step of the fuel cycle, and the associated controls and verifications (safeguards, export controls, etc.). A more targeted analysis can be done on only one step or one facility, and then the system and its subsystem will be defined accordingly, still along the process lines. When testing proliferation resistance, the strength of a system may be assessed against a *proliferation scenario* or *diversion scenario*. While developed more for the assessment of integrated safeguards approaches, ISEM[6] gives an illustration of applied systems. The NPAM report provides also other examples of systems.

Now, the question is to know if such methods could be useful tools in the PR analysis of a nuclear system. The answer is most probably yes provided that these tools are implemented with enough caution and that the results are interpreted carefully.

As an example, it would be misleading to give a great deal of credit to an absolute value of probability of the failure of proliferation resistance of a given nuclear system; this is clearly not the main purpose of such methods. Furthermore, one can wonder about any conclusion that could be drawn from such figures. In particular it would be a mistake to use these kinds of figures to compare nuclear systems with regard to their respective PR merits—especially because of uncertainties that may affect the numerical data required for quantification and that may be much greater for PR evaluations than for NS (for example, evaluate the probability of an initiating event in NS may be easier than to evaluate a probability of non-detection of a clandestine laboratory in a facility). Besides, such comparisons between various kinds of reactors are not made in the field of nuclear safety.

Having said that, probabilistic approaches (or risk-informed approaches) may be useful to identify weak points in a given combination of intrinsic and extrinsic provisions implemented for PR. Here the system would most likely be a step in the fuel cycle or possibly a subsystem in a process or a facility. They may also bring valuable guides to assess the relevance or the effect of any modification in this set of provisions and help find a cost-effective optimum. These approaches may also help to optimize inspections and verification approaches.

In sum, it appears that the development of probabilistic methods in the field of PR should be worthwhile as it has been already demonstrated in the field of NS, but they should be applied with enough caution to avoid misinterpretation of the results.

Safety Culture

In recent years, the new concept of *safety culture* (SC) has been formalized in various national and international organizations such as IAEA.[7] This concept is in fact a set of principles and rules that govern the actions and interactions of all individuals and organizations engaged in activities related to nuclear power. Many of them are good practices already implemented for many years in the nuclear industry, but the purpose of SC concept is to enhance them or to introduce new ones in a more structured framework.

The SC refers to a very general matter, the personal dedication accountability of all individuals engaged in any activity that has a bearing on NS. This means that SC deals with organizational rules from the highest level (that is governments) as well as human behavior or management roles. Among topics addressed by SC are:

- Requirements at the policy level: the need for safety policy statements, coherent sets of legislative texts, etc.
- Requirements on managers: management practices molding the environment and fostering attitudes conducive to safety
- Response of individuals must be characterize a *questioning attitude,* a rigorous and prudent approach, and communication

One can wonder whether it would be interesting to introduce similar concepts in the field of PR. In fact, when we look more closely at the principles and rules or statements developed for SC, we see that some of them already are an integral part of

PR practices. One example among many is the following statement of SC (as formulated in Reference 3, p.14): "When problems are identified, the emphasis is placed upon understanding the root cause of the problems and finding the best solution without being diverted by who identified or contributed to the problem; the objective is to find 'what is right' and not 'who is right.'"

In summary, it would be certainly beneficial to carry out a systematic review of SC principals and practical rules in order to examine how they can be applied to PR. One of the key objectives could be to identify the organizations and identify within each organization the relevant staff whose function may in some ways impact on PR, and ensure that all of them are sufficiently aware of PR to take it into account in their *routine* practice.

Conclusion

From this analysis of key concepts, it appears that PR methodology and approaches can benefit from a number of nuclear safety principles, rules, and methods either by direct application of them or by their adaptation to the specific context of PR.

In fact, some PR principles and methods implemented today or under development are similar to those used in the NS domain. There already has been already some implementation of the defense in depth principle in PR, even if formalization and comprehensiveness still need to be developed. In another aspect, it is also the case for example of the risk-informed proliferation analysis (RIPA), which is a scenario analysis approach that uses influence diagrams.[1]

However, we believe that we are still at a very early stage in this domain and that there are still large untapped resources to further enhance PR by using NS approaches. We expect that the framework that we propose in this paper will enhance and focus a systematic review of potential applications of NS analysis tools to design and assess proliferation resistant nuclear energy systems.

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International Developments in Spent-Fuel Management

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Introduction

At the end of 2003, 440 nuclear reactors were operating in thirty-one countries worldwide,[1] providing 16 percent of the global electricity supply. More than 10,000 metric tons of heavy metal (tHM) are unloaded from these reactors each year, with annual discharges increasing to ~11,500 tHM by 2010. Since less than one-third is reprocessed, about 8,000 tHM/year on average will need to be placed into interim storage facilities.

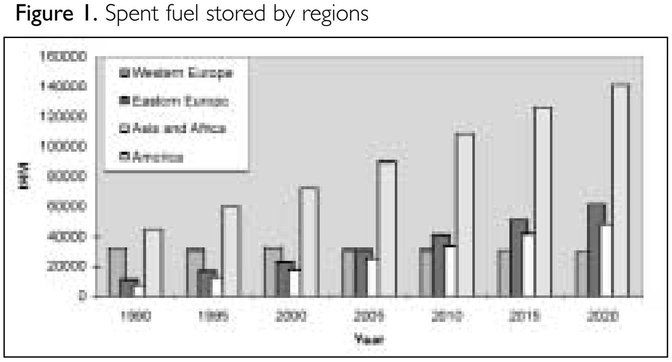
As reported by the International Atomic Energy Agency (IAEA) in 2003 and shown in Table 1, more than 170,000 tHM of spent fuel were in storage facilities, mostly under water but with an increasing amount in dry storage. The total amount of spent fuel cumulatively generated worldwide was close to 255,000 tHM.

Table 1. Status of spent fuel stored in world regions

Region	Amount
West Europe	36,100
East Europe	27,700
America	83,300
Asia and Africa	23,900
World	**171,000**

Projections indicate that the cumulative amount generated by the year 2020, the time when most of the presently operated nuclear power reactors will approach the end of their licensed operation lifetime, the total quantity of spent fuel generated will be approximately 445,000 tHM. Regional projections reported by the IAEA in 2003 are shown in Figure 1 below.

Figure 1. Spent fuel stored by regions



As delays are incurred in implementing reprocessing and in plans for geologic repositories, spent-fuel storage for extended durations is becoming a progressive reality.

Trends in Spent-Fuel Management

This trend of more storage capacity for longer durations is expected to continue. The situation is complicated by trends toward higher initial enrichment, higher fuel burnup, as well as other considerations including the use of evolving fuel designs and mixed oxide (MOX) fuel. Given the importance of effective spent-fuel management to sustainable utilization of nuclear energy, IAEA member states maintain an active interest in related work, as evidenced in part by participation in IAEA-sponsored meetings.

An international conference on storage of spent fuel from power reactors was held in Vienna in June 2003. The conference was organized by the IAEA in cooperation with the Organization for Economic Cooperation and Development's Nuclear Energy Agency. One hundred twenty-five participants, representing thirty-five countries and three international organizations, attended the conference. The participants represented utilities, industry, licensing authorities, national (management, and research) organizations and consultantsing engineers from most countries with nuclear energy programs (as well as some non-nuclear countries). The conference provided an opportunity to exchange information on the current status and prospects of spent-fuel storage, to discuss the major factors influencing the national policies in this field and to identify the most important directions for national efforts and international cooperation in this area. Conference participants identified the following conclusions:[2]

- At present, there is sufficient spent-fuel storage capacity on a worldwide basis. However, nationally or on a specific-site basis, the situation is different and may require urgent attention.
- Wet fuel storage is a mature technology with considerable experience and plays a major role in spent-fuel storage.
- Under present conditions, dry storage can also be regarded as an established industrial technology.
- The first geological repositories for the final disposal of spent fuel are not expected to be in operation before 2010. Many member states have not yet started specific site investigations. As a consequence, the use of interim storage will be the primary spent-fuel management solution for the next decades in many countries.

- Even more spent-fuel storage capacity is required if countries defer their decisions to open geological repositories.
- The storage duration becomes longer than previously anticipated, due to the *wait-and-see* policy chosen by many nuclear power countries. The use of fuel with higher initial enrichment and higher burnup results in higher decay heat and longer storage periods.
- With longer storage periods, dry storage becomes more and more important.
- Several papers described the importance of enhanced communication with a broad range of stakeholders, including the public.

Recent IAEA Activities in Spent-Fuel Management

For the last twenty-five years, the IAEA has been proactively involved in spent-fuel management activities. The Nuclear Fuel Cycle and Materials Section within the Department of Nuclear Energy organizes various meetings, often focused on producing technical documentation available to all member states on a topic of interest. While a list of technical documents (TECDOCs) on this topic published since 1998 follows this paper (see Appendix), most IAEA technical documents can be accessed free of charge at http://www-pub.iaea.org/MTCD/publications/tecdocs.asp. As a result of the trends noted above, IAEA activities on spent-fuel management have enhanced scrutiny of issues associated with long-term spent-fuel storage as described in the activities discussed below.

To address the challenges of extending storage in existing and new facilities for much longer durations, several meetings have been held in recent years, with the results published in a TECDOC titled *Long-Term Storage of Spent Nuclear Fuel.*[3] Resulting conclusions included noting that an extension of knowledge on the creep behavior of future cladding materials is needed for high burnup and MOX fuel. Additionally, a surveillance program could demonstrate long-term cask and fuel behavior. Further research activities were also identified for the development and confirmation of performance of advanced dry storage systems. While addressing long-term storage of spent fuel in dry systems, participants noted that storage must not be regarded as a final disposal option. As storage durations extend, more attention must be directed toward securing and maintaining related prerequisites including technical knowledge, records, and stability in funding and infrastructure.

Spent-fuel storage technology (particularly dry storage) is undergoing evolution, with modified/new fuel and material designs and increasing target burnup levels. Increased burnup infers higher strains and increased cladding hydriding and oxidation. The Coordinated Research Project on Spent-Fuel Performance Assessment and Research (SPAR) addressed research needed to justify spent-fuel storage for very long periods of time (more than fifty years). Building on the three earlier BEFAST projects (Behavior of Spent Fuel and Storage Components During Long-Term Storage), SPAR efforts began in 1997 with eleven participating countries, and resulted in a technical document published earlier this year.[4] While this report provided an overview of related technical issues, it specifically addressed materials issues in long-term storage facilities. As storage durations extend, obtaining and extrapolating information on materials behavior/performance is an important ingredient in continued confidence of implementers and regulators. While results to date anticipate safe dry storage for many decades, participants noted that source terms, including radioactive inventory, initial/final enrichment, must be well known.

As storage durations extend, attention to maintenance is crucial. The task on Operation and Maintenance of Spent-Fuel Storage and Transport Casks and Containers draws on the pool of knowledge that has been accumulated from industrial experience in the past several decades on the operation and maintenance of spent fuel casks. A technical meeting on this subject held in October 2003 benefited from perspectives provided by thirteen member states representing operators, regulators, and other stakeholders.

Cask designers face evolving challenges including long-term storage of higher burnup fuel with correspondingly higher initial enrichments, the use of mixed oxide (MOX) fuel, and obtaining regulatory approval for the use of burnup credit. Meetings were held in 2002 and 2003 to identify optimization issues and obtain views of both regulators and implementers, in preparation for a subsequent technical document, *Optimization of Cask/Container Loading for Long-Term Spent-Fuel Storage.* Participants noted that optimization can involve reducing design margin uncertainties by increased sophistication of both cask design and content definition (inventory list) in the areas of shielding, structural, thermal, and criticality design. Burnup credit is one of a number of significant considerations in this optimization process. In order to pursue the storage-related advantages of burnup credit, it is necessary to have good knowledge of spent nuclear fuel characteristics (e.g., from measurement and calculations). Both meetings endorsed the importance of considering burnup credit, with national representatives noting that related costs and benefits must be evaluated in specific national contexts.

An IAEA technical meeting/workshop on dry spent-fuel storage technology was held in 2002 to give guidance to experts from Central and Eastern European member states operating WWER and RBMK nuclear power plants and to exchange information. Fifty-six experts participated and concluded that the workshop was very helpful in communicating a wide range of related experience.

Meetings have also been held on the subject of emerging technologies for spent fuel treatment, leading to planned publication of a technical document.

Meetings held through 2002 on Technical and Institutional Aspects of Regional Spent-Fuel Storage determined that technical considerations and economic issues may be less significant than ethical and institutional issues for the development of a multinational projects. As described at the 2003 IAEA general conference and in subsequent publications, the IAEA director general has called for further consideration of the merits of multinational approaches to the management of spent fuel. A number of member states and international organizations have expressed support for the concept, albeit conditioned by some non-technical concerns. Accordingly, the agency's spent fuel program intends to develop updated documentation to further inform the dialogue on multinational approaches to spent-fuel management.

Based on meetings held over the past several years, a technical document is being prepared to provide guidance on methodology and selection criteria for away-from-reactor (AFR) facilities, together with updated information on related developments.

Economic considerations in spent-fuel storage projects grow in importance as spent-fuel storage quantities increase. Meetings held in 2002 and 2003 served as key steps toward ongoing development of a technical document, *Economics of Spent-Fuel Storage.*

Effective management and protection of storage-related data is a key condition for long-term spent-fuel management. As data storage technologies evolve and as personnel rotate, continuity of knowledge will require continuing attention. Consistent guidelines on information management are required for long-term management of spent fuel. A 2003 technical meeting involving participants from eleven member states established a basis for a subsequent technical document on *Data Requirements and Maintenance of Records for Spent-Fuel Management.*

Criticality safety analyses for spent-fuel systems traditionally assumed that the fuel was fresh, resulting in significant conservatism. Improved methods (calculations and measurements) for developing solid knowledge of spent nuclear fuel characteristics support efforts to take credit for the reactivity reduction associated with fuel burnup, by reducing this conservatism while maintaining appropriate criticality safety margins. The IAEA started its burnup credit (BUC) program with an advisory meeting in 1997 resulting in a 1998 proceedings[5] exploring worldwide interest in using BUC in spent-fuel management systems. Findings noted that economics was a prime motivator for pursing BUC; gathering needed data consumed time and funds; cooperative development and communication would mitigate these needs. A second major technical meeting was held in Vienna in July 2000 and attended by thirty-five participants from seventeen countries and two international organizations. As noted in the proceedings published in 2001,[6] it concluded that use of BUC, and understanding of related technical and regulatory issues, continued to progress. It also reiterated recommendations that BUC information and data be cooperatively developed and shared, including opportunities for international cooperation in organizing training courses on BUC applications. In October 2001, the agency contributed to a well-received two-week BUC training course held in the United States involving twenty-five participants from twelve countries. The IAEA organized a third major BUC meeting in April 2002 on Requirements, Practices, and Developments in BUC Applications. Fifty-four participants from eighteen countries participated in eight sessions held in Madrid, Spain, involving forty reports and discussions in working groups. These groups addressed validation of codes and methods, key issues, safety assessment and implementation, and future applications. This meeting encouraged the agency to continue its activities on burnup credit including dissemination of related information, given the number of member states having to deal with increased spent fuel quantities and extended durations. A technical document[7] produced in 2003 detailed these discussions on the progress and status of BUC applications for spent nuclear fuel. During the June 2003 international conference on spent-fuel storage, a panel of experts addressed the topic of "technical and regulatory challenges raised by long-term storage." During their discussions, they noted that wider adoption of burnup credit could reduce the total number of casks required for storage and transport applications, with attendant reductions in both expense and exposure.

Future IAEA Activities in Spent-Fuel Management

Participants in the June 2003 spent-fuel storage conference expressed particular interest in the following areas for possible future agency initiatives:

- Providing assistance in the evaluation and research of the long-term behavior of fuel and storage components in order to realize the anticipated long storage periods
- Continuing the exchange of information and data on spent-fuel storage technologies and public acceptance matters
- Broadening the scope of future conferences (e.g., to include safety requirements for storage facilities, criticality issues, burnup credit, decay heat calculations, transport of spent fuel, safeguards)
- Collaborating internationally on specific issues such as fuel integrity, application of burnup credit, code validation, cask component lifetime, long-term performance monitoring

In addition, representatives of member states with smaller nuclear programs informally expressed continued interest in regional storage initiatives, as well as topic-specific workshops and training courses.

The current spent fuel program for the IAEA includes the following efforts over the next few years:

Building on the results of the coordinated research project on Spent Fuel Performance Assessment and Research,[4] a subsequent coordinated research project (SPAR-II) is planned for 2004 through 2008 and will focus on continued data sharing as storage durations lengthen. Specific research objectives involve surveillance and monitoring programs for spent-fuel storage facilities, fuel materials performance evaluation for wet/dry storage, and collection and exchange of spent-fuel storage experience.

A new task is planned on advances in applications of burnup credit to reduce the number of transports and increase storage capacity with plans for a consultants meeting in 2004 in preparation for a major technical meeting in 2005.

An activity on issues around spent fuel treatment (reprocessing, conditioning, transportation) will focus on aspects of spent-fuel management other than spent-fuel storage. Meetings will be scheduled to gather information leading to updated technical documentation on this subject.

An activity on the influence of fuel design for high burnup and MOX fuel and advanced reactor operations on spent-fuel storage will involve meetings focused on trends in fuel design which are significant to spent-fuel management, leading to a technical document on this topic.

As noted above, a range of technical documents will be published on the topics including: data requirements and records maintenance, economics of spent-fuel storage, operations/maintenance of casks and containers, regional spent-fuel storage aspects, optimisation of cask/container loading. The IAEA will continue to seek opportunities using technical cooperation resources to assist member states in spent-fuel management activities. The IAEA will also continue plans for periodic large conferences on this topic to foster a wide exchange of current information and to stimulate creative dialogue on emerging trends.

Summary

Spent-fuel storage has been carried out safely and effectively for decades, and there is high confidence that this will continue to be the case. Yet as storage inventories and durations increase, issues associated with long-term storage compell more attention, as witnessed by participation of IAEA member states in the agency's 2003 international conference on storage of spent fuel from power reactors. Trends toward more storage capacity for longer durations are complicated by trends toward higher initial enrichment, higher fuel burnup, as well as evolving fuel designs. Motivated by these trends, the IAEA has enhanced scrutiny of issues associated with extended spent-fuel storage durations and quantities. Recent activities have examined issues associated with materials aging, performance monitoring, economics, maintenance, data requirements, cask loading, spent fuel treatment, regional facilities, and facility selection criteria. The IAEA also continues to prioritize activities associated with implementation of burnup credit, given the potential for increased storage capacity and resultant reduced costs and operational exposure.

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Appendix I

Agency Publications Related to Spent-Fuel Management –Last Five Years

IAEA-TECDOC-1012—*Durability of Spent Nuclear Fuels and Facility Components in Wet Storage* (1998)

IAEA-TECDOC-1013—*Implementation of Burnup Credit in Spent-Fuel Management Systems* (1998)

IAEA-TECDOC-1061— *Remote Technology in Spent-Fuel Management* (1999)

IAEA-TECDOC-1080—*Procedures and Techniques for the Management of Experimental Fuels from Research and Test Reactors* (1999)

IAEA-TECDOC-1081—*Spent-Fuel Storage and Transport Cask Decontamination and Modification* (1999)

IAEA-TECDOC-1089—*Storage of Spent Fuel from Power Reactors* (1999)

IAEA-TECDOC-1100—*Survey of Wet and Dry Spent-Fuel Storage* (1999)

IAEA-TECDOC-1103—*Status and Trends in Spent-Fuel Reprocessing* (1999)

IAEA-TECDOC-1192—*Multi-Purpose Container Technologies for Spent-Fuel Management* (2000)

IAEA-TECDOC-1241—*Implementation of Burnup Credit in Spent-Fuel Management System* (2001)

IAEA-TECDOC-1293—*Long-Term Storage of Spent Nuclear Fuel–Survey and Recommendations* (2002)
IAEA-TECDOC-1316—*Effects of Radiation and Environmental Factors on the Durability of Materials in Spent-Fuel Storage and Disposal* (2002)
IAEA-TECDOC-1343—*Spent Fuel Performance Assessment and Research* (2003)
IAEA-TECDOC-1378—*Requirements, Practices and Developments in Burnup Credit Applications* (2003)
IAEA-CSP-20—*Storage of Spent Fuel from Power Reactors, Proceedings of a conference held in Vienna June 2–6, 2003* (2003)

Active (Activation) Gamma-Spectrometric Methodology for Mass Determination of Nuclear Materials Samples

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Abstract

This paper describes experimental studies on neutron irradiation of nuclear material samples by Pu-Be sources with aim to initiate high-energy gamma radiation of short-lived fission products. The radiation intensity allows the determination of the mass of the nuclear material samples. Combination of these measurements with experimental determination of nuclear material isotopic composition on its own gamma emission is able to give complete information on the most significant nuclear material parameters with application to only one experimental methodology and only one the measuring system. Distinctive features of nuclear material assay procedures and some capabilities of the proposed methodology are considered in details.

Introduction

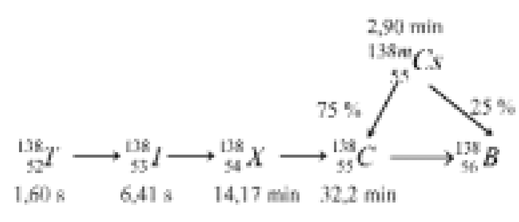
Traditionally, some combinations of two methodologies are applied to non-destructive assays of nuclear material mass and isotopic composition. These combinations include neutron-coincidence counting (passive or active options) plus gamma-spectrometry; calorimetry plus gammaspectrometry. The purpose of the present work is to continue an investigation of the possibility of obtaining data about nuclear material mass and isotopic composition using one gamma-spectrometric methodology.

Previously, in studies[1,2] the gammaradiation of individual fission products was detected in nuclear material samples containing spontaneously fissionable isotopes. As a result, it was concluded that it is possible to obtain full information about plutonium mass and isotopic composition using gammaspectrometric measurements in two energy ranges. Such an approach (let's call it a *passive* approach) could be applied in analyses of large enough (several hundreds of grams in mass) nuclear material samples, and the higher plutonium burnup (higher content of even-even spontaneously fissionable isotopes), the greater success in applications of this methodology.

In the present work, the authors attempt to extend the applicability for the complex gamma-spectrometric methodology by using an active (more exactly, activation) procedure of assays. The point of principal importance is the possibility of carrying out these assays with application of relatively low intense (α,n) neutron sources. Distinctive features of these neutron sources are simplicity and low cost. They do not require complicated maintenance efforts, and they do not generate significant dose loading for the personnel involved. However, short-term irradiation of nuclear material samples by these neutron sources can initiate rather intense gamma radiation of short-lived fission products, and this radiation is well-suitable for gamma-spectrometric measurements. The results of these measurements enable us to determine mass of nuclear material samples.

In the first experiments,[3] neutron source (intensity - 10^7 s^{-1}) was placed into a hydrogenous medium with the sample to be studied (plutonium or highly-enriched uranium). After thirty minutes of irradiation, the nuclear material samples are removed, and the gamma-radiation spectrum is measured with a Ge-detector. Peaks of short-lived fission products were observed in the measured gamma-spectra. The experimental results have demonstrated the activation assays could be carried out both with uranium and plutonium samples, and intensities of neutron sources at level of $10^7 \div 10^8$ s^{-1} appeared to be quite sufficient.

The previous conclusion confirmed[1,2] that the best experimental conditions (maximal count number in peak, maximal peak-to-background ratio, high penetrability of radiation) could be obtained in measurements of gamma-radiation emitted by ^{138}Cs (energy - 1436 keV, see Figure 1). It should be noted the radiation has a maximal penetrability because is energy belongs to the range where gamma-radiation absorption by uranium and plutonium is minimal. Half-life of ^{138}Cs is relatively short (32.2 minutes) that provides an acceptable time interval required for making an activation assay.



^{138}Cs activity depends on its decay rate as well as ^{138}Cs generation rate from its parent isotope ^{138}Xe. Therefore, in order to avoid introduction of various corrections, in the experiments described below the time regime was strictly maintained, i.e., the same irradiation time, the same pause time between the end of irradiation and the beginning of measurement, and the same measurement time were used for all the samples.

The possibility of shortening the time interval per an assay by measuring fission products-emitters of gamma-radiation with half-lives shorter than that of ^{138}Cs was investigated. Uranium samples were irradiated in five minutes, after 30 s-pause they were measured in five minutes.

In the spectra of the irradiated samples (Figure 2) several gamma-peaks were observed. Peak of ^{94}Sr (energy-1,428 keV, half-life-1.27 minute) stood out amongst another peaks. However, the count numbers in all these peaks were several decades smaller than the count number obtained for the peak of ^{138}Cs (1,436 keV) under standard experimental conditions (irradiation time and measurement time were equal to thirty minutes). Thus, ^{138}Cs measurements allow us to determine mass of nuclear material samples with a more precision.

In further experiments, the tool was used for irradiation of nuclear material samples that represented an organic glass cube (length of side-30 cm). Cylindrical cavity (diameter-100 mm, height-60 mm) was located in the cube center. Four Pu-Be neutron sources (total intensity - $2{\cdot}10^{7}\ s^{-1}$) were positioned in the center of the cavity, equal distance from all sides. Activation measurements of indium indicators have demonstrated that non-uniformity of the neutron field in the cavity did not exceed 4 percent.

To determine the range of nuclear material mass values that can be measured by means of the proposed methodology, three series of experiments were carried out with cylindrical samples: metal uranium samples (enrichment-2.0 percent ^{235}U, diameter-30 mm) and dioxide uranium samples (enrichment-1.8 percent ^{235}U, diameter-54 mm and 96 mm) of different heights. Uranium dioxide in powder form (density-7 g/cm^3) was manufactured by crashing the standard fuel pellets of RBMK-type reactor.

In each experimental series the samples of different mass were analyzed. Different samples were prepared by adding new layers of nuclear material to be assayed into container. In consecutive measurements, every new layer was placed at longer distance from detector. So, the radiation emitted by more distant layer was stronger attenuated because of the increased absorption on the pathway to the detector. Therefore, contributions from the last layers into the measured intensity of ^{138}Cs radiation gradually reduced. This factor limited the height (and mass) of the nuclear material sample that could be assayed.

Gamma-spectra of unirradiated samples contains peak of ^{234m}Pa (decay product of ^{238}U) with energy (1,434 keV) close to energy of ^{138}Cs peak (1,436 keV). On the one hand, in case of low intense neutron sources, this fact makes treatment of experimental results more complicated. However, on the other hand, this can be used to simulate conditions of ^{138}Cs radiation measurements without irradiation of the samples.

The data acquisition rate in ^{138}Cs peak (1,436 keV) and minimal measurable masses of nuclear material sample depend on efficiency of the applied detector. In the described experiments, two HPGe-detectors were applied: efficiencies—10 percent and 25 percent, energy resolutions (for gamma-radiation energy of 1,332 keV)–1.80 keV and 1.75 keV, respectively. The measuring system included the digital gamma-ray spectrometer DSPec. The dead-time corrections were determined using a reference source methodology (^{57}Co was used as a reference source).[4] The maximum values of dead time corrections reached 25-30 percent.

The measurements were carried out with metal uranium samples of different masses that were irradiated in cadmium screen and without cadmium screen. The results of these measurements are presented in Figure 3. It can be seen that dependence of neutron-induced ^{138}Cs activity on mass of the samples irradiated without cadmium screen relaxes substantially earlier than that for the samples irradiated in cadmium screen. This effect can decrease the upper limit of the activation methodology applicability range. The observed difference of these dependences can be explained by enhancement of self-shielding effect of the samples in regard to thermal neutrons when ^{235}U content in the samples volume increases. This effect will be especially strong in limiting the measurable mass of highly-enriched uranium and plutonium.

The self-shielding effect in regard to epi-cadmium neutrons is absent. So, when the mass of nuclear material samples is determined with the application of the activation methodology, the samples should be surrounded with a cadmium screen (except low mass samples).

The effects of gamma-radiation self-absorption and geometry factors jointly affect the results obtained in gamma-spectrometric assays of nuclear material samples. A series of the dedicated experiments was carried out to separate and evaluate these effects. The geometry influence on results of the measurement was evaluated in the experiments with the sample that was positioned at a different height above detector surface. Metal uranium sample (5-mm thick) was used in the experiments. The required detector-to-sample distance was set by the distancing rings of different height. To evaluate the self-shielding effect in metal uranium samples of different height, we compared the counting rate S in peak of 1,434 keV, obtained in the measurements with real sample, with S^0—the expected counting rate with no radiation absorption that was calculated using the following formula:

$$S^0 = \sum_{i=1}^{n} S_i^0 \ ,$$

where S^0_i - counting rate in 1,434 keV peak obtained in the experiment with 5-mm sample placed at height i above detector; n-the number of uranium layers (5-mm thick each) corresponding with height of real sample.

Dividing S by S^0, we evaluated total absorption effect for the gamma-radiation emitted by individual sample layers in its pathway to detector, when the radiation goes through the underlying layers (the self-absorption effect $K_s = S/S^0$). The obtained results are presented in Figure 4. Under another conditions (for other nuclear material density, for example), another values of these effects could be obtained.

The next experiments were carried out with uranium dioxide samples irradiated in cadmium screen. Experimental results are presented in Figure 5 in form of two curves. As it was demonstrated above, the observed non-linear dependence of ^{138}Cs gamma-radiation intensity on the sample mass is formed under joint influence of two factors—self-absorption effect and geometry effect. The contribution of the second factor is larger in experiments with uranium dioxide samples because density of uranium dioxide is lower by a factor of 2.5 than density of metal uranium. As a consequence, height of uranium dioxide sample with equivalent ratio of the sample mass to cross-section area of the container base is larger by the same factor of 2.5. The more dense nuclear material to be assayed, the higher upper limit for measurable mass of the samples.

The curve 2 from Figure 5 that represents a dependence of the counting rate in 1,436 keV peak on mass of nuclear material S(M) was then used for evaluating errors in determination of nuclear material mass. For this purpose, experimental data on the counting rate S and associated experimental errors ΔS were applied. Then, using the curve S = f(M), the values M, $M + \Delta M$ and $M - \Delta M$ which correspond to the values S, $S + \Delta S$, $S - \Delta S$ were determined. The derived values of ΔM defined a dependence of experimental error in measurement of nuclear material mass on value of nuclear material mass (Figure 6).

If the sample mass increases, function S = f(M) becomes weaker due to enhancement of gamma-radiation self-absorption and geometrical effects. Let's accept that errors in determination of nuclear material mass must not be higher than 3 percent. Then, the limiting values for height and mass of the samples can be determined. Maximal measurable mass for uranium dioxide samples (diameter-96 mm) appeared to be about 2,000 g. Further increasing the height (and mass) of the samples results in so slight changes of gamma-radiation intensity for energy of 1,436 keV that their masses cannot be differed with the required accuracy.

Irradiation of the samples without cadmium screen allows the extension of the range of nuclear material masses measurable by activation experiments towards small masses. The experiments carried out with uranium dioxide samples (enrichment 1.8 percent ^{235}U) have demonstrated that combination of the measurements performed with and without cadmium screen opened an opportunity to cover the mass range including three orders of mass magnitude. When uranium enrichment increases, it becomes possible to measure the samples of even smaller mass. The graphs plotted on experimental results for uranium samples (enrichments 1.8 percent and 6.5 percent ^{235}U) without cadmium screen are presented in Figure 7. Minimal ^{235}U content in the samples was below 40 mg, error in determination of nuclear material mass was below 3 percent. The measurements of gamma-radiation emitted by nuclear material sample in area of 1,436-keV peak and in the energy range below 1,001 keV (applicability range of the FRAM code) can give an information about mass and isotopic composition of the sample.

The FRAM code[5] can be used to determine isotopic composition of unirradiated uranium and plutonium samples from experimental data on spectra of gamma-radiation emitted by the samples. The measurements of uranium samples with application of Ge-detectors are carried out within the energy range 100-1001 keV with ^{235}U peaks (143.8 keV, 163.4 keV, 185.7 keV, 194.9 keV, and 205.3 keV) in low-energy part of the range and ^{238}U peaks (742.8 keV, 766.4 keV, 945.9 keV, and 1,001.0 keV) in high-energy part of the range. Detection efficiencies for these radiations differ significantly. These differences can be taken into account, using the relative efficiency curve plotted with application of data on some additional peaks presenting in the spectra: E_γ = 258.3 keV (parameter set U125 Coax LowEnrch) or E_γ = 283.6 keV, 583.1 keV, 860.5 keV (parameter set U125 Coax HiEnrch).

To determine applicability limits of the FRAM code in the analysis of irradiated samples, the gamma-spectra of the samples were measured under conditions similar to those used for determining the sample mass from ^{138}Cs radiation parameters (irradiation time, 30 minutes, measurement time, 30 minutes). The uranium samples enriched up to 10 percent and 90 percent ^{235}U were used. Typical spectra are presented in Figure 8. Analysis of these spectra allowed us to make the following conclusions:

The gamma-peaks of fission products impede measurements of the gamma-peaks used by the FRAM code: it is observed either through direct overlapping or presence of these peaks in the channels applied for plotting the background line under ^{235}U and ^{238}U peaks. In the first turn, it concerns the gamma peaks of ^{235}U and the gamma peaks applied for plotting the relative efficiency curve. For example, ^{238}U peak (258.3 keV) coincides with ^{138}Xe peak (258.3 keV); ^{238}U peak (742.8 keV) overlaps with ^{134}Te peak (742.6 keV); ^{238}U peak (766.4 keV) overlaps with ^{134}Te peak (767.2 keV); ^{238}U peak (945.9 keV) overlaps with ^{131}Sb peak (943.4 keV) and ^{134}I peak (947.9 keV); ^{238}U peak (1,001.0 keV) overlaps with ^{142}Ba peak (1,001.2 keV).

Our attempts to determine isotopic composition of irradiated uranium samples with application of different FRAM code versions and with different parametric sets did not give positive results.

Evidently, in order to obtain full information about the uranium samples under investigation, it is necessary to take two measurements: the first experiment with unirradiated sample (to determine isotopic composition) and the second experiment with irradiated sample (to determine mass). Our recent studies have demonstrated that the FRAM code is applicable for analysis of the short-term neutron-irradiated plutonium samples, that allows us to obtain data about mass and isotopic composition from results of one measurement

Analysis of experimental results obtained in the performed studies allowed us to make the following conclusions.

- There is a real possibility determining the mass of uranium and plutonium samples by measuring intensity of ^{138}Cs gamma-radiation (energy – 1,436 keV) generated in process of the samples irradiation by neutrons from Pu-Be sources (intensity ~$10^7 \div 10^8$ s^{-1}). Under favorable geometry conditions (which depend on dimensions and form of the samples), the methodology applicability range can stretch from tens of grams of low-enriched uranium (decimal fractions of ^{235}U gram) to several kilograms of uranium with any enrichment.

- The main advantage of the proposed methodology consists in the fact that only one measuring device (gamma-spectrometer) is used instead of two devices (neutron-coincidence counter and gamma-spectrometer). It is a very significant advantage because of high cost of neutron-coincidence counters (hundreds of thousands U.S. dollars). Besides, neutron-coincidence counters are not manufactured in Russia at all.
- For determination of uranium mass in the samples, the calibration curve must be constructed and used. The experiments have demonstrated that accuracy in determination of uranium mass in the samples can reach 1–3 percent for irradiation time of 30 minutes and for the same time of measurement.
- Thickness of nuclear material container wall restricts a possibility to determine nuclear material isotopic composition, not nuclear material mass, because the high-energy gamma-radiation is used for determination of nuclear material mass.
- In our opinion, the activation gamma-spectrometric methodology can be applied for making assays of metal uranium samples, powder samples, micro fuel particles and uranium hexafluoride samples. Applicability of the proposed methodology for analysis of plutonium samples of different masses is under investigation now.

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2. Bushuev, A. V., A. L. Bosko, V. N. Zubarev, A. F. Kozhin, and I. M. Proshin. 2002. Development of the Method for Characterization of Samples Containing Spontaneously Fissioning Nuclides Using Fission Products Gamma Spectrometry. *Journal of Nuclear Materials Management,* Volume XXXI, Vol. 1, pp. 59-62.
3. Bushuev, A. V., V. N. Zubarev, and I. M. Proshin. 2002. Possibility of Active g-spectrometric Measurements for Determination of Nuclear Materials Mass in the Samples. *Atomnaya Energiya,* Vol. 93, No. 4, pp. 286-290.

Figure 1. Gamma-radiation spectrum of uranium dioxide sample (enrichment—6.5 percent). 1. Unirradiated sample. Peak of ^{234m}Pa at 1,434 keV can be observed. 2. The sample irradiated in cadmium screen. Peak of ^{138}Cs (1,436 keV) superimposed on peak of ^{234m}Pa (1434 keV). 3. The sample irradiated without cadmium screen. Intensity of ^{138}Cs peak is much higher than that of ^{234m}Pa peak. There is 1,001 keV peak that is used for the determination of uranium isotopic composition.

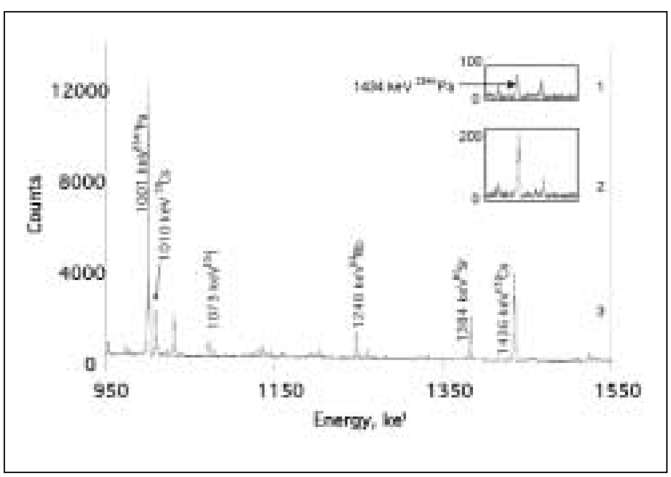


Figure 2. Layout of the irradiation facility. 1. Moderator. 2. Sample. 3. Pu-Be neutron source.

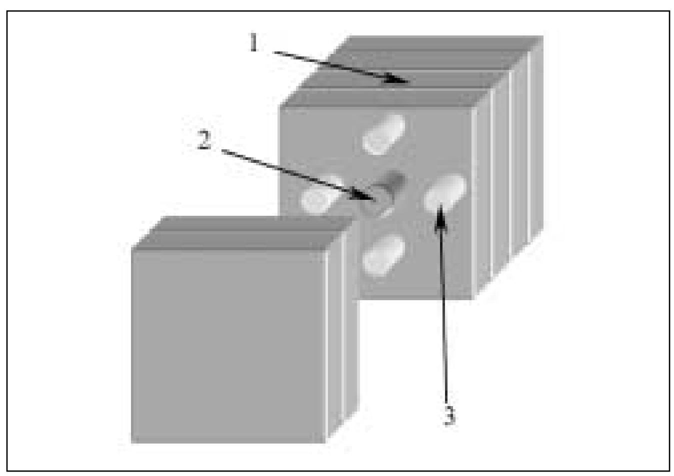


Figure 3. Layout of measurements with uranium dioxide samples. 1. Aluminum container (diameter - 96 mm, height - 60 mm). 2. Powder of uranium dioxide. 3 and 4. Lead and cadmium filters (respectively) to reduce loading of the measuring system by low- and middle-energy gamma-rays. 5. HPGe-detector.

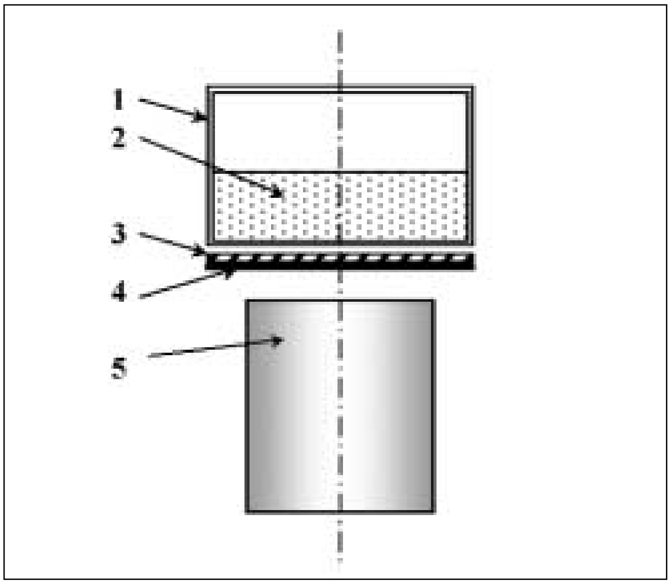


Figure 4. Dependence of the counting rate in [138]Cs peak (1,436 keV) on mass of metal uranium sample. 1. The samples were irradiated without cadmium screen. 2. The samples were irradiated in cadmium screen.

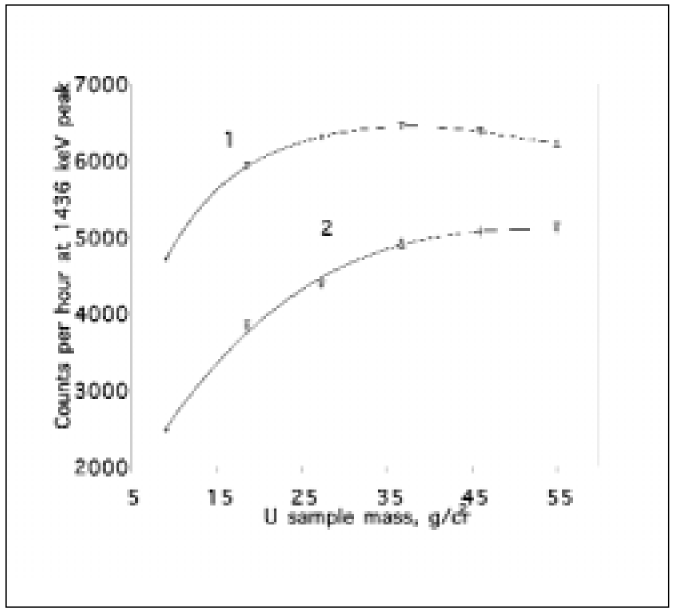


Figure 5. The factors affecting the results of gamma-radiation measurements (energy - 1,434 keV) from nuclear material samples. 1. Geometry effect, Kg. 2. Self-absorption effect, Ks. 3. Total effect, Kg * Ks.

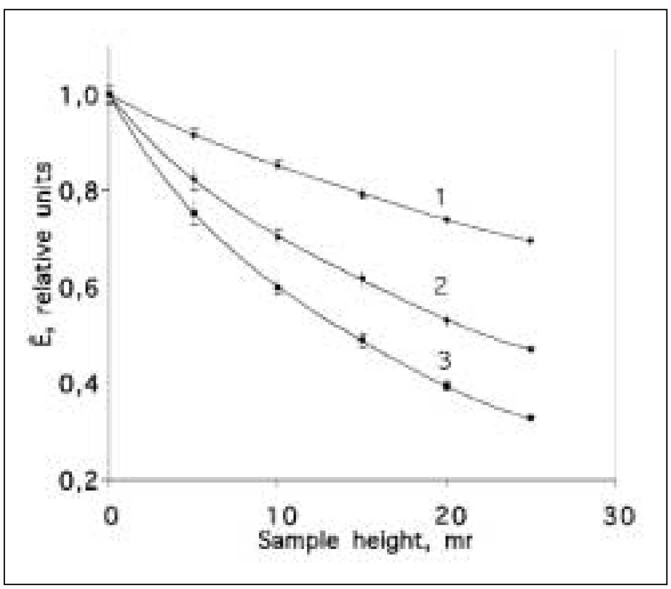


Figure 6. Dependence of the counting rate in [138]Cs peak (1,436 keV) on mass of dioxide uranium sample. Irradiation in cadmium screen. 1. The sample of 96 mm in diameter. 2. The sample of 54 mm in diameter.

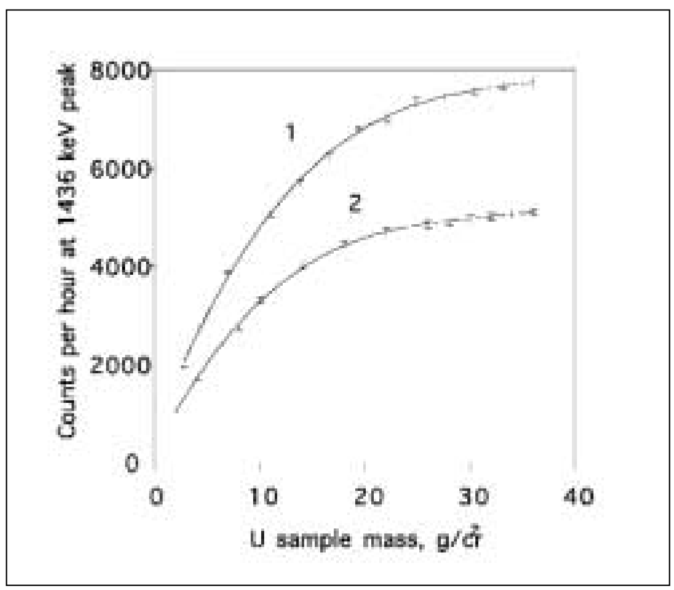


Figure 7. Dependence of a single measurement error on mass of uranium sample

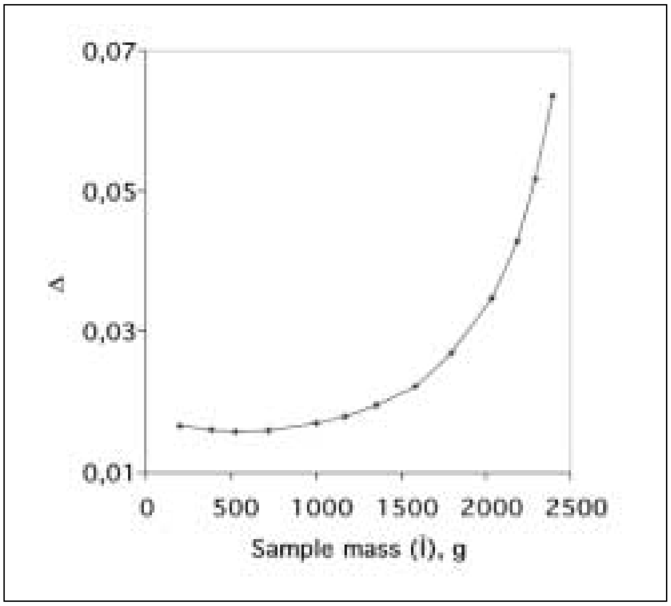
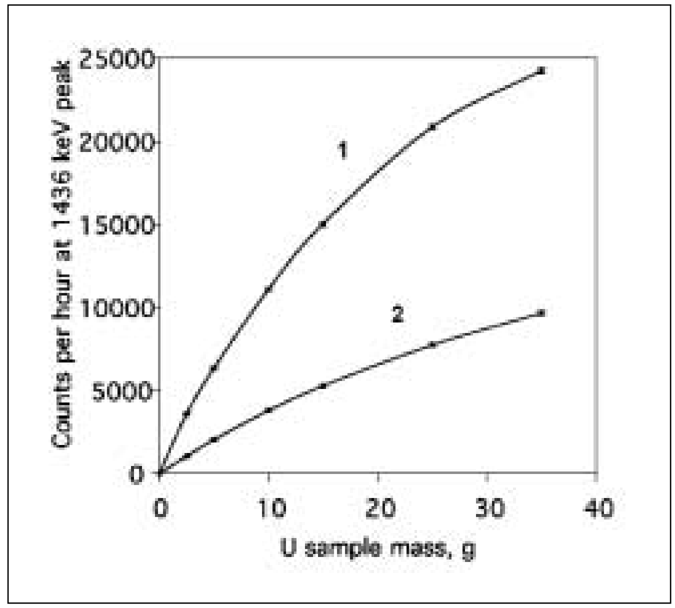


Figure 8. Dependence of the counting rate in ^{138}Cs peak (1,436 keV) on mass of dioxide uranium sample. 1. enrichment – 6.5 percent. 2. enrichment -1.8 percent



Agreement Allows U.S. Access to French R&D Facilities

In August, the United States signed an agreement with France's Atomic Energy Commission (CEA) that will allow cooperation between the U.S. Department of Energy's (DOE) Office of Nuclear Energy, Science, and Technology and the French CEA. The agreement specifically provides DOE access to the PHENIX fast spectrum test reactor, which has a capability that no longer exists in the United States.

The pact builds on a September 2000 agreement covering R&D cooperation in such areas as the Advanced Fuel Cell Initiative, Generation IV Nuclear Energy Systems Initiative and the Nuclear Hydrogen Initiative. The cooperation has provided access to French R&D that has saved the U.S. tens of millions of dollars.

Under the proposed implementing arrangement, DOE's Office of Nuclear Energy, Science, and Technology and the French CEA will perform an experimental irradiation project in the French PHENIX experimental fast reactor. They will test various types of fuel loaded with minor actinides under constant conditions and acquire data to permit selection of the best-performing fuel for future use in high-level waste transmuting systems.

Energy, Labor Departments Open California Benefits Assistance Center for Nuclear Weapons Workers

The U.S. Departments of Energy (DOE) and Labor (DOL) opened the new Energy Employees Occupational Illness Compensation Program Act (EEOICPA) Resource Center in Livermore, California, on August 31, 2004.

The resource center assists current and former DOE employees, contractors, subcontractors, employees of atomic weapons companies, and employees of designated beryllium vendors, as well as eligible survivors of employees filing for benefits under the EEOICPA.

The EEOICPA provides two different types of assistance. Part D is administered by the DOE and helps DOE contractor employees or their survivors apply for state worker compensation benefits for job-related illnesses. Under this program, an independent physician's panel determines if a worker's illness arose out of exposure to a toxic substance during the course of employment at a DOE facility. Beryllium vendor employees, atomic weapons employees, and DOE federal employees are not covered under Part D.

Part B is administered by DOL and provides a lump sum payment of up to $150,000 and medical benefits to current and former DOE employees, DOE contractors, and subcontractors, atomic weapons employees, and employees of designated beryllium vendors. Qualified survivors of covered employees may be eligible for the lump sum compensation. Specific illnesses covered by Part B of the EEOICPA are radiogenic cancers, beryllium diseases, and chronic silicosis.

For more information or assistance in applying for benefits call 866/606-6302, or visit the new center. More information is available at www.eh.doe.gov/advocacy.

Other EEOICPA resource center locations include: Anchorage, Alaska, Espanola, New Mexico, Hanford, Washington, Idaho Falls, Idaho, Las Vegas, Nevada, Oak Ridge, Tennessee, Paducah, Kentucky, Portsmouth, Ohio, Rocky Flats, Colorado, and Savannah River, South Carolina.

Secret Mission to Recover HEU in Uzbekistan Successful

Eleven kilograms of enriched uranium fuel, including highly enriched uranium (HEU) that could be used for nuclear weapons, were safely returned to Russia from Uzbekistan in a secret mission conducted by the United States, Uzbekistan, and Russia in September 2004.

The HEU was airlifted under guard from an airport near Tashkent, Uzbekistan, to a secured facility in Dmitrovgrad, Russia. There the uranium will be down-blended to low-enriched uranium.

The nuclear fuel assemblies were originally supplied to Uzbekistan for use in the Russian-designed ten megawatt VVR-SM multi-purpose research reactor, near the Uzbekistan capital, Tashkent.

During the one-day mission, approximately 11 kilograms of enriched uranium nuclear fuel, including HEU, were loaded into two specialized transportation containers provided by the Russian Federation. International Atomic Energy Agency safeguards inspectors and U.S. Department of Energy (DOE) technical experts were present in Uzbekistan to monitor the process of loading the fuel into the canisters.

The facility in Russia that received the material has worked with the United States to implement security upgrades under the U.S.-Russian Material, Protection, Control, and Accounting Program. The mission was conducted under the Global Threat Reduction Initiative (GTRI), whose mission is to remove and/or secure high-risk nuclear and radiological materials and equipment around the world that pose threats to the United States and to the international community.

This is the fifth successful shipment of uranium returned to Russia. In the past year, DOE has repatriated a total of 48 kg of HEU fuel to Russia from Romania, Bulgaria, and Libya. In August 2002, 48 kg of Russian-origin HEU were repatriated from a research reactor near Belgrade, Serbia.

DOE Demolishes "Most Dangerous Building in America"

In July 2004, the U.S. Department of Energy (DOE) began demolishing Building 771 at DOE's Rocky Flats Environmental Technology Site, a former nuclear weapons production plant near Denver, Colorado, termed "the most dangerous building in America."

The plutonium process building has a fifty-year legacy of plutonium leaks and spills. In 1994, the DOE concluded that Building 771 was its greatest vulnerability because of the hazardous and radioactive materials it once housed. It was dubbed by the national media as "the most dangerous building in America." Building 771 is the first plutonium process building of its size and complexity to be demolished in the United States.

The safe cleanup and closure of an entire former nuclear weapons production site has been a task of such magnitude and complexity that it has never before been attempted, or accomplished, anywhere in the world.

The demolition of Building 771 is the culmination of a comprehensive nine-year cleanup process that included safely draining and stabilizing 15,000 liters of plutonium solutions; and removing 240 contaminated gloveboxes, 251 tanks, more than eleven miles of aging piping, and 40,000 liters of contaminated sludges.

Rocky Flats is officially no longer a nuclear weapons site. Cleanup of Rocky Flats was expected to take sixty-five years and cost in excess of $36 billion. Through project reforms, Rocky Flats is expected to be cleaned up and closed in 2006.

The dismantlement of Building 771 was expected to take six to eight weeks and be completed in September 2004.

Rocky Flats is a DOE-owned cleanup and closure site operated by Kaiser-Hill Company under an accelerated closure contract.

DOE Cites Fluor Hanford for Extensive Violations

The U.S. Department of Energy (DOE) has issued a Preliminary Notice of Violation to Fluor Hanford, Inc. (FHI), one of the principal contractors at the Hanford site, for multiple and extensive violations of DOE's nuclear safety rules.

The violations stem from multiple deficiencies in FHI's design, construction, and testing of the K reactor basins' sludge and water system (SWS) intended to remove sludge that had accumulated from the storage of spent nuclear fuel. The violations are the result of numerous and long-term failures to comply with regulatory requirements for quality improvement processes, project oversight by FHI management, training of essential personnel, conduct of work processes, document and record keeping, facility and equipment design, inspection and acceptance testing, assessments of previously unreviewed safety issues, and information accuracy. An FHI preliminary readiness review of the SWS initiated in April 2003 was terminated after four days because DOE site personnel discovered that installed safety equipment was inadequate.

DOE is issuing a proposed civil penalty to FHI in the amount of $935,000. No mitigation of the civil penalty was warranted due to the numerous, extensive, and protracted nature of the deficiencies. Two of the violations were regarded as particularly serious. These involved the significant breakdown in management controls related to oversight of the project by all levels of FHI management, and FHI's failure to implement effective processes for correcting past nuclear safety violations, a problem for which FHI's predecessor company was previously cited in a 1999 enforcement action.

Additional details on this and other enforcement actions are available at http://www.eh.doe.gov/enforce.

DOE Cites Washington TRU Solutions for Violations

The U.S. Department of Energy (DOE) has issued a Preliminary Notice of Violation to Washington TRU Solutions (WTS), the management and operating contractor for the DOE's Waste Isolation Pilot Plant in Carlsbad, New Mexico, for violations of nuclear safety rules and procedures. The violations involve the procurement and associated deficiencies with the fabrication of four stainless steel structures known as "transportainers" designed to serve as secondary containment structures for TRU waste characterization activities.

The violations did not result in harm to workers or the public. DOE took this action because, if not corrected, the violations could have resulted in radiological harm to workers and or the public.

DOE also took this action because WTS failed to adequately correct known deficiencies of a similar nature associated with prior procurement of equipment relied upon for radiological protection of workers and the public.

DOE is assessing WTS a civil penalty in the amount of $82,500. Some mitigation of the maximum civil penalty was granted to WTS for recently implemented corrective actions.

Additional details on this and other enforcement actions are available at http://www.eh.doe.gov/enforce.

Implementing Agreement Signed With Romania Under GTRI

The United States and Romania signed an implementing agreement today to accelerate the groundwork for future work on nuclear nonproliferation activities, in September 2004.

The Implementing Agreement provides the framework for DOE to perform joint work supporting nuclear nonproliferation activities. As a result of the agreement, the United States will begin work under GTRI's Russian Research Reactor Fuel Return program to repatriate to Russia irradiated Soviet and Russian-origin fuel containing highly enriched uranium (HEU) from a research reactor in Romania. The Romanian government decided in 2002 to permanently shut down the Magurele reactor and prepare it for decommissioning. The DOE's National Nuclear Security Administration will assist with the removal of the irradiated nuclear fuel.

GRTI's goal is to identify, secure, remove, or facilitate the disposal of vulnerable nuclear and radioactive materials and equipment around the world that pose a threat to the international community as quickly and expeditiously as possible. International partners, such as the government of Romania, are key participants in this new initiative.

In Memoriam

The Institute of Nuclear Materials Management is saddened by the passing of three members who have contributed a great deal to its success over the years. All three, Cecil Sonnier, Hiroyoshi Kurihara, and Dale Moul, were honored at the 44th Annual INMM Meeting in Orlando, Florida, in July with resolutions of respect from the INMM.

Cecil Sonnier

June 19, 2004

Cecil Sonnier, who chaired the INMM International Safeguards Technical Division for more than twenty years, died Saturday, June 19, 2004.

A native of Lafayette, Louisiana, Cecil graduated from the University of Louisiana at Lafayette in engineering. He worked at Sandia National Laboratories for forty-two years. He joined INMM in 1975.

In 1993, he received a Distinguished Service Award for sustained performance in containment and surveillance, development, testing and implementation, and unselfish dedication to the advancement of international safeguards.

He spent three years in Vienna, Austria, first with the U.S. Mission and then with the International Atomic Energy Agency.

He had a lifelong love of traveling and experiencing new places and cultures, traveling throughout Europe, Russia, Australia, and more than fifty times to Japan.

Hiroyoshi Kurihara

June 15, 2004

Hiroyoshi Kurihara died Tuesday, June 15, 2004, after a career of more than thirty years of dedicated work in the areas of nuclear nonproliferation, national and international safeguards, physical protection, and nuclear materials management. He joined INMM in 1989.

He served as a division director at the International Atomic Energy Agency. He was a member of INMM Executive Committee as was a founding member of the INMM Japan Chapter and served as its vice chair for many years.

His valuable service to the nuclear materials management community was recognized by his progression to INMM Fellow and receiving the 2003 INMM Distinguished Service Award.

Dale A. Moul

April 24, 2004

Dale A. Moul died Thursday, April 29, 2004, after a long career in nuclear safety, physical security, information security, emergency preparedness and safeguards analysis at Battelle. He also worked in support of the U.S. Department of Energy in Washington, D.C. He joined the INMM in 1978.

During his career, he served the INMM as statutory agent and through innumerable other activities have been exceedingly beneficial to the nuclear materials management community.

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Web site: http://www.ornl.gov/inmm

December 1–17, 2004
International Symposium on Disposal of Low Activity Radioactive Waste
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Organizer:
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Sponsors:
Agence nationale pour la gestion des déchets radioactifs (ANDRA) France, in cooperation with the OECD Nuclear Energy Agency (NEA)
Web site: http://www-pub.iaea.org/MTCD/Meetings/Announcements.asp?ConfID=124

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