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# JNMM

# Journal of Nuclear Materials Management

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JNMM

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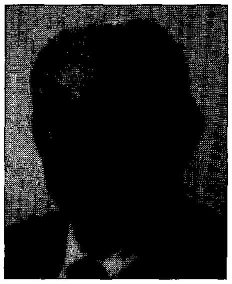
# Our Important Work Continues



In order to meet the *JNMM* publication deadline, I am preparing my message to the INMM membership on the day after the U.S. presidential election while attending the INMM Executive Committee Meeting in Tampa, Florida. As I write this, the winner of this election is still undecided in a very close race.

The recounts will be over by the time you read this and we will all know who the next president of the United States will be. Since many of our U.S. members work for the U.S. Department of Energy, there is a great deal of interest in how the outcome of this election will affect U.S. nuclear policy.

According to the candidates' campaign speeches, they have different opinions and approaches on issues such as Medicare, Social Security, and tax cuts, but nuclear policy—especially regarding weapons—was mostly absent from the campaign debate. However, we do have some idea where they stand on these important issues.

Both candidates favor further cuts in the size of the U.S. nuclear arsenal and both said they opposed the resumption of U.S. underground nuclear weapons tests. One of the major differences between the candidates was on the support of the Comprehensive Test Ban Treaty. Al Gore supports the CTBT and George W. Bush opposes it. I expect that within the INMM membership we have members who reflect this same difference of opinion. Even if the United States does not sign the CTBT, it is unlikely that the United States will resume underground testing.

Bush promised to launch a major review of the U.S. nuclear arsenal to determine how many weapons are really necessary and pledged "to pursue the lowest possible number consistent with U.S. national security." Both candidates support reducing the number of U.S. nuclear weapons, but in different ways. Gore said he would negotiate with Russia then pursue equal reductions while Bush said he'd be willing to make more reductions as a leadership or good faith step in hopes of encouraging Russia to make similar reductions.

The major emphasis of both candidates in terms of nuclear policy was on nonproliferation. The INMM also supports nonproliferation as one of our nuclear material management efforts.

Following the INMM Executive Committee meeting, I attended the INMM/ESARDA Third Workshop on Science and Modern Technology for Safeguards in Tokyo, Japan. There, many new and enhanced ways of improving nuclear materials management by the application of sciences technology and methodology were discussed to allow more efficient and effective safeguards.

I believe we all continue to have important work to do as we address these issues and that there is much to be done within INMM to make the world better and safer, regardless of which U.S. presidential candidate is the ultimate winner.

*James D. Williams*
*U.S. Department of Energy*
*Washington, D.C., U.S.A.*
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*Fax: 202/586-3617*
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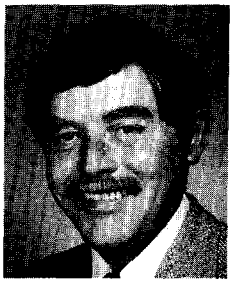
# Russian Nuclear Security Highlighted in This Issue



In this issue of the *Journal*, you will find four articles that I trust you will find interesting.

The first, Russian Nuclear Security—Perspectives and Analysis in 2000, by Ruth Kempf, Brookhaven National Laboratory, and Stephen Mladineo, Pacific Northwest National Laboratory, summarizes a seminar, Russian Nuclear Security—Programs and Prospects, held in Washington, D.C. last April. This seminar was co-sponsored by INMM and the Carnegie Endowment for International Peace. I found the authors' comments to be thought provoking. There are certainly lessons to be learned.

The second article, written by John Veilleux of Los Alamos National Laboratory, Non-Destructive Assay of Ce-144 in Presence of Transuranic Waste, is well-written and takes the reader through the issues associated with quantifying Cerium-144 in certain Los Alamos National Laboratory plutonium waste streams.

The third article, Statistical Analysis of the Results of Measurements of the Quantity of Nuclear Material during Physical Inventory, is authored by scientists from the Russian Research Center Kurchatov Institute, and by two members of Brookhaven National Laboratory. The paper focuses on how the Institute intends to implement statistical analysis for conducting physical inventories of the enriched uranium dioxide used in the Narciss critical assembly.

The fourth article, Deliberations on Safeguards Measurement Uncertainty, summarizes an all-day session held at the 41st INMM Annual Meeting. The session was organized by Margaret Tolbert of the New Brunswick Laboratory. Her co-authors are David Donohue of the International Atomic Energy Agency, and Paul De Bievre of the Belgium Institute for Reference Materials and Measurements.

Also in this issue of the *Journal* you will find reports from three INMM committees that were provided to the Executive Committee at its November meeting. The report on the study of the Institute's technical division structure by Fellows Committee is very interesting. You will also find five (out of six) reports from our Technical Divisions, and seven (out of twelve) chapter reports. We publish these reports in the issues of the *Journal* that immediately follow the Executive Committee meetings, which normally occur in March, at the Annual Meeting, and in November.

We attempted to capture the highlights of Roy Cardwell's life in our In Memoriam to him. We will miss Roy. He was truly a strong supporter of our Institute, as well as a dear friend to many. We wish Barbara, his wife, the best.

Finally, in this issue you will find a letter to the editor! Unfortunately, we do not get many of them. I would like to thank Roger Wellum for his letter.

I mentioned in my last note that this issue of the *Journal* would have an article on the newly instituted peer review process. (Alas, time seemed to fly by this fall.) I would like to say that the process is in full glory under the watchful eye of our Assistant Technical Editor Steve Dupree. We apply the peer review process only to technical papers. We do not use the peer review process obviously for policy-type papers or review papers. One should allow at least forty-five days for the process to be completed. As I mentioned in my last note here are the fundamentals of the process: a) When a technical paper is received, Steve and I determine the proper associate editor(s) to whom the review is assigned; b) the associate editor(s) identifies the reviewers; c) the reviewers, using an electronic form, provide comments back to Steve through the associate editor(s); and d) Steve then interfaces with the author to have changes incorporated as appropriate.

Depending upon the magnitude of the changes, the process could be iterative. When we formulated the process, we opted to have one whereby the identity of the reviewer is not revealed to the author(s). In some situations, it appears that the reviewers have decided on their own to contact the author(s) and discuss the article. Either way is acceptable.

Based on our publication schedule for 2001, please submit technical papers by March 26 for consideration in the Summer 2001 issue, by June 25 for the Fall 2001 issue, and by September 24 for the Winter 2001 issue. Articles received after those dates will be considered for the next issue of *JNMM.*

In closing, I would like to express my personal thanks to Cathy Key and Debbie Dickman for their support of the *Journal* over the past years. Cathy was our Communications chair, but with her election to the Executive Committee, she will be replaced by Jim Griggs. Debbie, of course, was our president, and in that role took a vested interest in the oversight function. She will be replaced by Ruth Kempf, our former chair of the Nonproliferation and Arms Control Technical Division, who likewise was just elected to the Executive Committee.

As always, I welcome your comments.

*Dennis L. Mangan*
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# Committee Reports

## Fellows Committee

One of the discussion topics at the Annual Fellows Luncheon held July 19, 2000, addressed the question of whether the technical divisions needed to be restructured to meet current conditions. The major element of the discussion dealt with the ability to focus or differentiate between nonproliferation, arms control, and arms reduction. To assist the Executive Committee, the Fellows Committee accepted the task of reviewing the current technical division structure and making recommendations or suggestions to the Executive Committee as appropriate.

A request for issue evaluation and input was sent to each Fellow. The request detailed the problem facing the Executive Committee and included an electronic version of each charter and a list of questions. Those questions included:

- Is the division structure sufficient to meet today's environment?
- Would simple title changes bring clarity and focus without recreating the division structure?
- Is more focus needed for the treaty verification and dismantlement areas or does the Nonproliferation and Arms Control charter address them adequately?

There was some discussion about the definition of terms used in the individual charters. There were several specific suggestions made regarding restructuring and renaming, but the most sensible common theme dealt with the addition of a disarmament division or the restructuring/renaming of the current Nonproliferation and Arms Control division to Nonproliferation and Arms Management to address the disarmament aspect. The following synopsis of these suggestions is provided as information and to facilitate the EC's thorough evaluation.

Those advocating a disarmament element articulated the uniqueness or difference between reducing/eliminating/dismantling and nonproliferation and control of current stocks. The *arms management* language was used specifically to address all of the things done to manage existing weapons including arms control, arms reduction, dismantling, treaty verification, and transparency. The suggested standing committees within a nonproliferation and arms management division included nonproliferation, arms reduction, and dismantling and treaty verification and transparency.

The Fellows concluded:

- Some divisions have committees designated for subtopical areas. Some of the committees exist formally while some are informal and not all are evident or fully functional.
- Not all of the divisions have designated positions such as vice chair and secretary that can provide continuity and speak for the division when the chair is otherwise unavailable. Often they do not have supporting members to provide direct assistance to the chair and distribute the workload, which is critical in a volunteer organization.
- At times it appears that the internal and external communication of selected divisions is lacking.

### *Conclusions*

The Technical Division structure was established to provide a focus on the Institute's technical strengths and to provide a focal point for information and activities related to individual members' specialties. The concept is sound and the implementation has been successful at achieving the desired goals.

The basis for the question related to divisional structure stems from issues related to the Nonproliferation and Arms Control Division. From the dialogue at the Fellows Luncheon and the input received, it is apparent that the issues relate to confusion or misunderstanding surrounding the components of the division and the perception of a less than fully functional organization. Both may be due to the sheer volume, scope, and intensity of the work related to the division or they may be due totally or in part to the previously mentioned items. In neither case should the issues surrounding the nonproliferation and arms control division be used as a basis for partitioning this division or any division.

If the volume, scope, and intensity of any division is too great for one division chair, vice chair, secretary, and supporting committees, then consideration should be give to altering that structure. However, until there has been a concerted effort to review and revise the division charters, strengthen the division organizational structures, and implement the changes, there should not be any serious consideration given to major organizational changes.

### *Recommendations*

The following recommendations are offered as potential courses of action to strengthen the implementation and operation of the technical divisions.

- Division charters should be reviewed from the perspective of organizational efficiency. Expansion/modification to formally include vice chair, secretary, and committee structure should be evaluated.
- Where committees within a division are formed, the descriptions of such committees and their chairs should be documented and provided to the membership in writing and listed on the INMM website.
- The Executive Committee should

- review the performance of division chairs annually and institute changes when necessary.
- As the technical division charters are being reviewed and revised, the Technical Program Committee chair should be consulted relative to specific verbiage associated with Annual Meeting coordination.

*Obie P. Amacker, Jr.*
*Chair, INMM Fellows Committee*
*Pacific Northwest National Laboratory*
*Richland, Washington, U.S.A.*

## Communications Committee

The Communications Committee has addressed two primary areas of communications in recent months—the INMM informational brochure and the INMM website.

During the Annual Meeting in New Orleans, communications met to discuss the INMM brochure. The INMM Membership Committee had looked at this brochure earlier in the year but determined it should be handed over to Communications.

At the Annual Meeting in New Orleans, it was determined that *JNMM* Managing Editor Patricia Sullivan would rewrite this document based on our discussions. She would also contact all of the six division chairs and request their input and confirmation of the wording concerning their division. This was done.

The rewritten text was sent out for approval and members of the Executive Committee requested work on the brochure be held up pending the results of the Fellows Committee's work on the possible restructuring of the technical division structure.

A few more changes have been made to the brochure based on an October 12 meeting with headquarters staff in Chicago. The headquarters staff has designed several possible covers for the brochure that were presented to the Executive Committee for approval.

The design and text of the brochure was approved at the November meeting and a new brochure will be produced in early 2001.

Redesigning the INMM website is a priority this year. The necessary funds for this endeavor were approved by the INMM Executive Committee and work will commence immediately. The website has been updated already. Cathy Key, with assistance from James R. Griggs, will work on this project in conjunction with headquarters staff.

*Cathy Key*
*Chair, Communications Committee*
*BWXT-Y12-LLC*
*Knoxville, Tennessee, U.S.A.*

## Membership Committee

We are in the midst of membership renewal.

The Membership Committee held a working lunch meeting on Tuesday, July 18, 2000, during the INNM Annual Meeting. Issues discussed of potential interest to the Executive Committee included the following:

- **Senior Membership Application.** The committee discussed the need to review the Senior Membership application in view of current experience with applicants and applications received to make the application more clear. The drafter of the original application, Bruce Moran, volunteered to review the current structure of the application and to propose revisions. His proposal has been reviewed by the current Membership Committee and was presented to the Executive Committee for its review.
- **Membership News for *JNMM*.** Nancy Jo Nicholas has had discussions with *JNMM* editors about including a member news section in addition to the new members page in the *Journal*. The new section appeared in the fall issue of *JNMM*. It will include articles by committee members on the careers of INMM members.
- **Student program.** Scott Vance is taking the lead on developing a fresh marketing approach to attract student members. He is drafting and making plans to distribute a new student-oriented brochure for prospective student members (enrolled full-time in a college or university and have no other full-time employment).
- **Membership Committee Meeting schedule.** Those present agreed that a working lunch meeting on Tuesday of the annual meeting is the preferred time for the Membership Committee to meet. Committee members, a representative from the local and regional chapters (if available), and a representative from headquarters should attend. The committee chair will work with staff to arrange next year's meeting.

*Nancy Jo Nicholas*
*Chair, INMM Membership Committee*
*Los Alamos National Laboratory*
*Los Alamos, New Mexico, U.S.A.*

## International Safeguards Division

The International Safeguards Division meeting was held July 16, 2000, at the 41st INMM Annual Meeting. Fifty-three members of the international safeguards community from the IAEA, Euratom, ABACC, EC JRC ISPRA, EC JRC IRMM, Australia, Belgium, Canada, Finland, France, Germany, Japan, Korea, Sweden, Switzerland, United Kingdom, and the United States participated in the meeting.

The principal topics discussed in this meeting were:

- INFCIRC/540 and the Agency's integrated safeguards development;
- Safeguards costs and the IAEA budget;
- Cooperation with regional and state SACs;
- Communication with governments, operators, and opinion makers; and
- Technical matters.

The IAEA presented a brief status report on the development and implementation of integrated safeguards. Cooperation with regional and state SACs was of particular interest at this juncture in the development of integrated safeguards. The International Safeguards Technical Division offers the potential to be a good forum to promote communication between all parties. It was recognized that the meshing of the new system with the old system and full implementation of the new system will be a challenge for all parties, requiring a very cooperative atmosphere as well as a new mentality in the safeguards community. As in past division meetings, the discussions were very frank and open.

Cecil Sonnier closed the meeting expressing sincere appreciation for all participants in this and past division meetings. Sonnier proposed that Jim Larrimore succeed him as chair of the division, subject to approval of the INMM Executive Committee. Larrimore, who recently retired from the IAEA, is known throughout the international safeguards community. Appreciation was also expressed to Vice Chair Roger Howsley of BNFL and Secretary Steve Dupree of Sandia for their outstanding support of the division. The new vice chair will be Gotthard Stein, who is also well known throughout the community. Dupree will remain as secretary.

The next division meeting will be held Monday, May 7, 2001, in Bruges (Brugge), Belgium, the site of the 23rd ESARDA Annual Meeting. Topics for discussion will be distributed in the near future.

The Third Joint INMM/ESARDA Workshop on Science and Modern Technology for Safeguards was held in Tokyo, Japan, November 13-16, 2000. A report on this workshop will be included in an upcoming issue of *JNMM.*

*Cecil Sonnier*
*Chair, International Safeguards Division*
*Jupiter Corp.*
*Albuquerque, New Mexico, U.S.A.*

## Nonproliferation and Arms Control Division

Ruth Kempf has stepped down as division chair after eight years. She had been the chair for the entire life of the division to this point, so I have big shoes to fill. As of August 15, 2000, I have assumed the role of chair, and Larry Satkowiak has agreed to serve as deputy chair. Together we have been developing a strategy for the future of the division. Our first goal is to reach out to the INMM membership and the larger nonproliferation and arms control community.

As part of the transition to a new team, we have an opportunity to reexamine the division's charter, organization, and direction, and to decide together what changes the division might make to better serve the membership and the community. For example, the charter calls for three standing committees. Whether these three committees are the right number, have the right focus, or are the best way to organize our efforts should be reviewed. Also, we believe an area of importance is the development of an outreach program to bring nonproliferation issues into the public focus.

To this end, we have communicated to the interested membership and to others our interest in seeking their input and participation. We have asked their assistance in evaluating the division's charter. Additionally, I attended the annual meeting of the Central Chapter of the INMM and spoke to the membership, inviting their participation and input. As it's feasible, I will try to do this at other chapter meetings over the next few months.

As soon as possible we intend to complete our evaluation of the division charter, complete the assignment of division officers, and begin to work on programs. We would like to build upon the success the division has had in the past, and develop further through improved participation, communications, and programs.

*Steve Mladineo*
*Chair, Nonproliferation and Arms Control Division*
*Pacific Northwest National Laboratory*
*Falls Church, Virginia, U.S.A.*

## Packaging and Transportation Division

Planning for the Packaging and Transportation of Radioactive Materials Symposium (PATRAM 2001) in September 2001 continues. Since our last report, efforts and accomplishments were:

- Finalizing the technical program format, session identification, and soliciting session chairs and co-chairs;

- The hotel contract was approved by the INMM president;
- The PATRAM 2001 Call for Papers was finalized and mailed to 3,400 addressees; and
- The fiscal year 2001 INMM/PATRAM budget was developed.

*Billy M. Cole*
*Chair, Packaging and Transportation Division*
*JAI Corp.*
*Fairfax, Virginia, U.S.A.*

## Physical Protection Division

The Physical Protection Technical Division conducted its annual meeting at this year's INMM Annual Meeting. Most of the time was spent discussing what type of workshop the division should sponsor in 2001. Dave Lambert from the Oak Ridge Complex and John Davies from BNFL agreed to take the lead in setting up a workshop based on the discussions at this meeting.

Preliminary thoughts on the workshop are that it will be based on the concept that many aspects of nuclear material protection are often overlooked in current evaluation processes. Identifying and quantifying these unaccounted-for, operations-based elements of protection will result in increased confidence in your physical protection system without additional cost.

The workshop will identify elements of nuclear material protection currently employed through a variety of disciplines. Based on empirical data, methods will be demonstrated to quantify increased detection probabilities of these unaccounted-for elements.

The objectives of the workshop are to understand the integration of safeguards and security systems with other disciplines such as:

- Criticality safety;
- Radiation/contamination controls;
- Nuclear waste management;
- Integrated safety management;
- Quality assurance programs;
- Using an unclassified, analog site, identify empirical data that can be used to analyze protection probabilities of detection for operations-based elements; and
- Using performance testing methodologies to acquire empirical data for analysis purposes.

The target audience for this workshop will be specialists involved in vulnerability and risk assessments, nuclear material operations managers, physical protection consultants from government and private-sector nuclear power plants, and nuclear material custodians.

We intend to attract an international audience. Potential locations for the workshop are Boston, San Francisco, Atlanta, London, Vienna, and Prague. We would like the workshop to take place around September 2001, giving us ample time to plan and organize it.

*Steve Ortiz*
*Chair, Physical Protection Division*
*Sandia National Laboratories*
*Albuquerque, New Mexico, U.S.A.*

## Waste Management Division

The following summarizes the activities of the Waste Management Division for the period of June 2000 through October 2000:

The division has been working on the INMM Spent Fuel Management Seminar XVIII, to be held on January 10-12, 2001, at the Willard Inter-Continental Hotel in Washington, D.C. Five sessions are scheduled covering waste management programs and policies, spent fuel storage technologies, spent fuel storage projects and NRC regulation, spent fuel transportation, and the status of the proposed Yucca Mountain geologic repository. The specific program has been developed, potential speakers have been invited, and their confirmations of acceptance are being received. It is expected that we will have approximately thirty-five invited presentations.

The seminar registration brochure was revised and the mass mailing of the brochure should take place by mid-November. The registration fees were increased marginally this year—on average the seminar draws approximately one hundred twenty-five to one hundred seventy-five attendees—and the fee increase is not expected to impact attendance.

At the conclusion of this seminar, the division will make a decision on the site of future spent fuel management seminars. The possibility of moving the seminar to a November-December timeframe also will be considered.

Another spent fuel management meeting, the Global Spent Fuel Management Summit, took place December 3-6, 2000, in Washington, D.C. The summit was sponsored and supported by NAC International. While principally covering issues related to spent fuel management, the meeting only impinges upon part of the subject matter of the INMM annual seminar. However, because the new meeting comes only one month before the INMM seminar and covers some of the same subject matter, it can be expected to adversely impact attendance at the INMM seminar.

*E. R. Johnson*
*Chair, Waste Management Division*
*JAI Corp.*
*Fairfax, Virginia, U.S.A.*

## Central Chapter

The Central Chapter hosted a very well attended and successful annual meeting in Oak Ridge, Tennessee, October 16-17. The expected attendance for the meeting was estimated to be approximately forty people. The actual attendance for the two-day program was slightly more than fifty-five (some unregistered visitors also showed up). Three local vendors (Canberra, ORTEC, and Nuc-Safe) provided corporate sponsorship for the meeting. We think this speaks very well for local interest in the chapter. An electronic version of the proceedings will soon be distributed to INMM members.

The Central Chapter is entering the final phase of restructuring with the election of new chapter officers. The solicitation of candidates is nearly complete and we hope an election can be conducted before the end of 2000. The chapter sincerely appreciates the help from the central INMM office in our efforts to reestablish ourselves as an active chapter.

*Chris A. Pickett*
*Acting Chair, Central Chapter*
*Oak Ridge Laboratory*
*Oak Ridge, Tennessee, U.S.A.*

## Japan Chapter

The election for the year 2001-2002 Executive Committee members of the Japan Chapter was carried out in August 2000 in accordance with the chapter's bylaws. The following members were elected:

Chair: Shunji Shimoyama
Vice Chair: Hiroyoshi Kurihara
Secretary: Takeshi Osabe
Treasurer: Yoshinori Shinohara
Members-at-Large: Takeo Adachi
Mamoru Inoue
Nobuo Ishizuka
Masayuki Iwanaga
Naohiro Suyama
Hiromi Terada

The 96th executive committee meeting of the chapter was held on September 20, 2000, at the Nuclear Material Control Center in Tokyo. The fiscal year 2000 chapter business report and the year 2001 business plan were deliberated and approved.

In new business, the chapter is developing a promotional campaign to invite those entities that are the subjects of the new safeguards regime under additional protocol INFCIRC/540 to join the Japan Chapter.

*Shunji Shimoyama*
*Chair, Japan Chapter*
*Japan Atomic Power Co.*
*Tokyo, Japan*

## Korea Chapter

The INMM-KC 5th Executive Committee Meeting was held in Taejon on June 30, 2000. Candidates for the new officers and members-at-large for the next term were nominated.

In July 2000, representatives of the Korea Chapter participated in the 41st INMM Annual Meeting, New Orleans, Louisiana. Twelve papers were presented at the Annual Meeting by Korea Chapter members

The 4th Annual Meeting of INMM-KC and a workshop, the Current Issues on the Korea SSAC, were held August 8. Seven papers were presented and two foreign speakers—one from the IAEA and the other from the INMM Japan Chapter—were invited. About 50 Korea Chapter members participated in the meeting.

On September 1, ballots to elect four new officers and two members-at-large were mailed to members. Thirty-five members voted. The votes were tabulated on September 22. The following people were elected:

President: Hyun-Soo Park
Vice President: Jong-Sook Hong
Secretary: Jang Soo Shin
Treasurer: Ho-Dong Kim
Members-at-Large: Chung-Won Cho
Chang Kook Yang

Kun-Jai Lee and Young-Myung Choi will continue to serve as members-at-large until their terms expire on September 30, 2001. Past president Byung Koo Kim will also serve on the board as member-at-large until September 30.

*Jang Soo Shin*
Secretary, Korea Chapter
TCNC/KAERI
Taejon, Korea

## Northeast Chapter

The Northeast Chapter is preparing for the election of chapter officers. The Nominating Committee chair has submitted the slate of candidates and the chapter secretary is preparing distribution of the ballots for voting.

*Ken Sanders*
*Chair, Northeast Chapter*
*U.S. Dept. of Energy*
*Washington, D.C., U.S.A.*

## Southwest Chapter

The Southwest Chapter held its Annual Business Meeting on Wednesday, July 19, in New Orleans, Louisiana, in conjunction with the INMM Annual Meeting.

Chapter organizational issues were discussed. Scott Kraus, of Aquila Technologies Group, was appointed as the new communications coordinator for the chapter. This position was created in an effort to improve communication with the chapter membership.

The nomination and selection process for the chapter executive committee was also discussed, and the membership approved a delay in the election for the open executive committee positions in order to fully develop and engage the membership in the nominating process. Wendy Doyle, of Aquila Technologies Group, and Donnie Glidewell and Jack Jackson, of Sandia National Laboratories, agreed to coordinate the nominating process.

Voting for executive committee members closed on October 1. The following people were elected:

President: Chad Olinger
Vice President: Cary Crawford
Secretary/Treasurer: Larry Kwei
Members-at-Large: Steve Ortiz
Grace Thompson

The new members-at-large join Donnie Glidewell and Wendy Doyle, who are in the second year of their terms as members-at-large.

On Thursday, October 19, the Executive Committee held a meeting as required by the chapter constitution and bylaws. The goal was to develop ideas for an annual meeting, to develop a calendar of chapter activities, and to discuss chapter committee responsibilities and opportunities. The 2001 annual meeting is tentatively scheduled for the first Friday in May and will be held in or near Taos, New Mexico. The theme is Advances in Physical Security. The meeting will consist of formal presentations in the morning followed by topical breakout sessions in the afternoon. A few extracurricular activities are being planned as well.

The Executive Committee is planning a winter dinner in early January in Albuquerque, New Mexico, featuring a high-level guest speaker from one of the national laboratories. The Executive Committee also discussed the development of an education committee with the goal of engaging local college students studying in fields related to nuclear materials management in chapter activities. The executive committee also discussed issues related to attracting and retaining members, particularly in the outlying states of Arizona, Colorado, and Texas. The existing program of state coordinators was reviewed as well as the possibility of local or regional dinner meetings as chapter activities.

*Lawrence K. Kwei*
*Secretary/Treasurer, Southwest Chapter*
*U.S. Department of Energy*
*Golden, Colorado, U.S.A.*

## Vienna Chapter

The selection of Vienna Chapter officers was held during September 2000. The Chapter Executive Committee Members for 2000-2001 are:

President: Shirley Johnson
Vice President: Neil Tuley
Treasurer: Diane Fischer
Secretary: John Oakberg
Members-at-Large: Igor Tsvetkov (second year of a 2-year term)
Joe Carrelli (first year of a two-year term)
Past President: Jaime Vidaurre-Henry

Richard Hartzig coordinated the election committee and reported the results to all Vienna Chapter members.

Members of the Vienna Chapter participated actively at the recent INMM meeting in New Orleans, Louisiana. The winning paper at our local International Safeguards Symposium in Vienna, Implementation Trial of the Model Additional Protocol in Japan, was presented at the INMM 41st Annual Meeting by IAEA Senior Inspector T. Renis. Nine additional symposium papers, sponsored by the IAEA Department of Safeguards, were presented at the meeting.

In September 2000, the Vienna Chapter was visited by outgoing INMM President Debbie Dickman.

*John Oakberg*
*Secretary, Vienna Chapter*
*IAEA*
*Vienna, Austria*

## Ukraine Chapter

The Ukraine Chapter met in September to approve its chapter constitution. The chapter has sent this constitution to the INMM Executive Committee for its approval.

Also at the meeting, the membership elected the chapter executive committee. Victor Gavrilyuk was elected chair; Alexander Scherbachenko was elected vice chair; and Alexander Yuspin was elected secretary.

*Alexander Scherbachenko*
*Vice Chair, Ukraine Chapter*
*Kiev Institute for Nuclear Research*
*Kiev, Ukraine*

# Russian Nuclear Security—Perspectives and Analysis in 2000

■

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■

## Introduction and Purpose

The seminar titled "Russian Nuclear Security-Programs and Prospects" was sponsored by the INMM Nonproliferation and Arms Control Division and the Carnegie Endowment for International Peace and was held in Washington April 26, 2000. It provided a forum for the discussion of U.S.-Russian joint efforts to improve nuclear nonproliferation in Russia. In this paper we summarize the highlights of that seminar and provide our perspective and analysis of the themes that dominated the proceedings.

## Seminar Highlights and Themes

Presentations on existing programs in weapons and fissile materials security, and in stemming weapons knowledge proliferation were given in the morning, followed by a luncheon speech by Sen. Pete Domenici of New Mexico. In the afternoon, two panel sessions aimed at articulating visions of future efforts in nonproliferation cooperation with Russia were held. The first panel focused on programs to engage former weapons scientists and provide new opportunities for economic diversification for the closed nuclear cities of the Ministry of Atomic Energy of Russia. Rose Gottemoeller, deputy administrator of the National Nuclear Security Administration, summarized achievements of the Nuclear Cities Initiative (NCI) and the Initiatives for Proliferation Prevention (IPP) programs. Jim Noble, from the State Department's Office of Proliferation Threat Reduction, presented an overview of the operation of the International Science and Technology Center in Moscow and of the Science and Technology Center Ukraine in Kiev.

Ken Luongo, director of the Russian American Nuclear Security Advisory Council, a nongovernmental organization, argued that while stemming weapons knowledge ("brain drain") programs are important, DOE, the State Department, and other executive agencies have done a poor job explaining their importance to Congress. He pointed out the absence of a coherent, overall strategy guiding the programs and that they were being implemented in a piecemeal fashion. This ad hoc approach has led to congressional skepticism and a reluctance to appropriate funds. It also inhibits long-term commitment of governmental support. Sen. Domenici reinforced this point by calling for plans and measurable milestones for progress in NCI. He announced that he would later introduce legislation along these lines. Subsequent to the seminar, he introduced the Domenici Amendment to the National Defense Authorization bill, which has since been signed into law.

Speakers in the second session addressed security of Russian nuclear weapons and fissile materials. Ken Sheely, acting associate assistant deputy administrator for the Office of International Material Protection and Emergency Cooperation, stressed that nuclear security is a long-term commitment and that quick-fix solutions were not sustainable. He provided an overview of the Material Protection, Control and Accounting Program, during which he argued that inherently sustainable security upgrades in Russia were required. Susan Koch of the Cooperative Threat Reduction Program office at the Department of Defense described cooperative security programs with the Russian Ministry of Defense, focused mainly on safe, secure transport, storage, and dismantlement of nuclear weapons.

Joshua Handler, from Princeton University, commented on the relatively easier job of improving the security of nuclear weapons compared to weapons-usable fissile materials. He expressed concern about the condition of Russian nuclear submarines which are in excess of Russia's needs, but which Russia seems unable to adequately secure, maintain, or defuel.

The third panel focused on visions for the future of U.S.-Russian nuclear security cooperation. Matthew Bunn of Harvard University's Kennedy School of Government detailed points from his report, *The Next Wave: Urgently*

*Needed New Steps to Control Warheads and Fissile Material.* Igor Kripunov of the University of Georgia gave an overview of developments in Minatom, particularly related to its interest in supporting commercialization of nuclear technologies domestically and, especially, internationally. He speculated on a stronger future for Gosatomnadzor (the Russian equivalent of the U.S. Nuclear Regulatory Commission) and reported that Russian President Vladimir Putin has committed $50 million for restructuring the Russian nuclear weapons complex, but that there is as yet no practical implementation mechanism by which to expend these funds.

Zachary Davis, from the Congressional Research Service, presented an entertaining litany of the plethora of acronyms that make up the nonproliferation programs of the U.S. He argued that unless supporters can demonstrate tangible benefits, clearly articulate the relevance to U.S. national security, and provide solid metrics to measure progress, Congress will remain hesitant to fund nonproliferation programs. He also indicated that, given the overload (or retirement) of important proponents of nonproliferation and arms control in the Congress, he is skeptical about continued or sustained support of existing programs.

In the fourth and final panel, Ambassador Ron Lehman, from Lawrence Livermore National Laboratory, commented on the importance of clear communication both within the United States and between the United States and Russia. He noted that terms like brain drain are used casually by people who have quite different understandings of its meaning. This inevitably leads to complications and wasted time. Carol Vipperman, president of the Foundation for Russian-American Economic Cooperation, described a model of how economic diversification can be achieved through developing institutions that unify all the players in a community. She has led the creation of international development centers to accomplish this in two Russian closed cities as part of NCI. Janine Wedel, from the University of Pittsburgh, drew from her research on aid programs in Russia to provide cautions on the control and distribution of assistance funds. She argues that using contractors who form personal relationships with Russian officials to implement programs using foreign assistance can result not only in corruption, but also in unexpected foreign policy impacts.

We would note that since the seminar, Rose Gottemoeller, Jim Noble, and Zachary Davis have moved to new positions at the Carnegie Endowment, DOE, and Lawrence Livermore National Laboratory, respectively.

As is evident from this synopsis, the speakers presented a broad range of views on the subjects, but two dominant themes emerged from the presentations. First, the panoply of joint U.S.-Russian programs and initiatives in this area is confusing and difficult to keep track of, particularly for the Congress. It is likely even less understood by the American public. Second, the implementation of joint efforts in this area is subject to a large number of political, bureaucratic, social, cultural, and technical factors or influences. These can sometimes create barriers, conflicting expectations or differing expectations if not understood and dealt with appropriately. The succeeding sections elaborate and analyze these themes and their impact on the nonproliferation relationship between the United States and Russia.

## The "Proliferation of Initiatives"— from Parts to Whole?

Had a crystal ball been available, a comprehensive plan to address the vulnerabilities of former Soviet nuclear weapons, fissile materials, and scientific and technical expertise might have been developed in the early 1990s. Instead, information about and understanding of the situation came piecemeal. The United States and the international community reacted to perceptions of what assistance was needed. At the time of the disintegration of the Soviet Union, no one outside Russia had a full understanding of the security status of Soviet and, then Russian nuclear weapons and fissile materials. Very quickly, the United States became engaged with the Russians in attempting to make sure weapons were safely and securely transported, stored, and dismantled.

The dismantlement of weapons would lead to the addition of huge quantities of highly enriched uranium and plutonium into an apparently already overtaxed security structure. Russia desperately needed outside investment to help its embryonic free market economy. The United States and Russia negotiated the HEU purchase, which would, theoretically, over its lifetime, transform five hundred metric tons of HEU from weapons into thousands of tons of low-enriched uranium, while simultaneously pumping a total of $12 billion into Russia.

It was soon understood that there was no clear line of civilian and defense nuclear activity within Russia. This meant, for example, that some nuclear power plants produced electricity, district heating, and plutonium for weapons all at the same time. A given nuclear facility could perform research on nuclear weapons design and on nuclear medicine. Apparently, the Soviet method of maintaining *closed* nuclear cities with personnel under constant scrutiny, coupled with a *closed* economy worked effectively in keeping weapons and fissile materials within authorized hands. However, this traditional method of *safeguarding* fissile materials in the Soviet Union had to be revisited in light of the opening of the society and the economy. The appreciation of the new vulnerabilities of these materials was the genesis of the U.S.-supported MPC&A Program.

As the Russian economy continued to decline, it became clear that addressing the security of fissile materials was only part of the picture. Russian expertise in weapons design and fabrication could be a marketable commodity and some scientists might be desperate enough to resort to selling their weapons knowledge. In an attempt to address this very complex issue, the ISTC was created and initially subscribed to by the United States, Japan, and the European Union, who appreciated the need to give former-weapons scientists opportunity for gainful, constructive work outside of nuclear weapons. The complementary IPP program was developed at around the same time, adding the promise of industrial partnerships leading to commercialization of technology. That program also engaged scientists from chemical and biological weapons facilities.

While these programs were and continue to be valuable, they did not adequately address the creation of jobs to replace those lost through the process of weapons complex downsizing. So the NCI program was developed to share with Russia U.S. experience in economic diversification of its weapons complex.

In short, programs were developed to meet needs as they became known. Given the tremendous scope and unprecedented nature of the leap from Soviet policy, society, economy, and culture to an unknown future, it is not surprising that neither the United States nor the international community were waiting with a comprehensive strategy to fix all of Russia's problems. Unfortunately, the growth of joint nuclear security-related efforts appears to onlookers as proliferation of initiatives, each with its own agenda. The result is challenging for those coordinating and running these activities in the executive branch, difficult for Congress and staff, and confusing for Russian partners.

Ten years into this scenario, and hundreds of millions of dollars later, it certainly should be possible to formulate a comprehensive strategy with definable goals and an endpoint. Very probably, all of the efforts being made up to now will have their place in such a strategy. They will be seen, however, not as individual programs needing to maintain visibility and budget in competition with others, but rather as supporting members in a larger superstructure whose function is Russian nuclear security writ large. Presently, program acronyms float throughout Washington and Moscow without clear articulation of their place in the larger scheme. It might be considered analogous to different cells, organs, nerves, and blood vessels, each carrying out their function independently, without an understanding that each has a function but together they form a living body.

Fortunately, a comprehensive strategy need not be developed unilaterally. Rather, the last ten years have set the stage for the United States and international communities to work jointly with the Russians from the working level to the highest governmental authority. Certainly, serious high-level discussions are needed between the United States, other international parties, and the Russians looking to their nuclear future. It seems fair to say that whatever type of nuclear future Russia works toward, the United States and international community are concerned that it be a safeguarded one, not one vulnerable to chaotic or unauthorized manipulation. The agenda for such discussions needs to be one of seeking to understand the long-term needs and plans on the Russian side. Any hope of long-term commitment from cooperative partners is contingent on those partners, not only the United States, being able to articulate to their governmental budgetary authorities what they want to accomplish, how they plan to get there and how they will measure progress and completion. This means the Russians must share their plans with their counterparts; otherwise attempts to measure progress will be difficult at best or meaningless at worst, hurting efforts to maintain home support and putting further cooperation in jeopardy.

## Differing Perceptions, Differing Expectations, Differing Results

The second major theme of the seminar dealt with the economic, political, and cultural components of the cooperative nonproliferation programs between the United States and Russia. Although the Cold War is over, the uneasy relationship that has replaced the former hostility has not yet been fully developed. In addition to the obvious language and cultural differences, the two sides approach each aspect of their relationship with different assumptions and expectations. Bureaucratic politics within each country further complicate the relationship.

For example, in the MPC&A program, the United States is concerned about proliferation prevention, emphasizing the need to protect against insider theft of fissile materials. Except at a few facilities where actual insider thefts have taken place, most Russian facilities appear much less concerned about the insider threat than they are about the potential threat of attack from Chechen forces. As a consequence, the changes in perceived threat required to improve security against insider theft have proceeded more slowly than the upgrades in physical protection that both sides acknowledge are warranted.

Expectations differ in the area of stemming knowledge proliferation as well. Although Russia's Minatom came to DOE asking for help and the benefit of U.S. experience in defense conversion, their expectations are colored by their experience of the role of government. While government necessarily plays a large part in successful defense conversion, the U.S. experience has been that partnership among a larger community is necessary for success. And while infusions of government funding are essential, the real engine for economic diversification in the United States is an active partnership among national, regional, and local governments, industry, and the community.

There are certainly examples in Russia where this partnership has taken hold, but the more prevalent view stems from the continuation of an old central planning mindset that will likely take a generation or more to change. Russians tend to propose large, capital-intensive projects, dependent upon substantial government investment, and directed from above. U.S. advice continues to stress community involvement, entrepreneurship, and growth from below. Both sides are genuinely committed to the principle of cooperation, but their different perceptions of what needs to be done have interfered with progress.

Understanding of and agreement on the metrics for progress in cooperation is also challenging. Russia's Minatom sees the problem of downsizing their nuclear weapons complex as a jobs problem. Provide Minatom with enough money and they will be able to occupy those whose jobs were eliminated. The ISTC program and the early phases of the IPP program have followed this emphasis and have served as a necessary stopgap, while the process of real economic diversification can mature. The Nuclear Cities Initiative has the longer-term goal of helping Russia develop the conditions and infrastructure needed to create real economic diversification, resulting in real, constructive employment. Acknowledging that it takes a long time to create real jobs in the United States, where cultural expectations for successful entrepreneurship, legal, and other supporting infrastructure and community involvement already exist, the challenge in Russia is daunting.

Another related manifestation of different perceptions is the Russian emphasis on technology *push*, as opposed to market *pull*. Scientists and engineers who have successfully designed and fabricated sophisticated nuclear weapons tend to believe that their clever ideas for new commercial products will cause the world to beat a path to their door. The reality is that markets drive commercial success, and so market analysis and business plan development are necessary elements of the process for successful economic diversification. U.S. assistance emphasizes these requirements, and is helping to build in Russia the infrastructure necessary to support these processes.

Differing approaches to accounting for costs can also affect cooperation. Russian project proposals and business plans often tout their lower labor costs as conferring a compelling competitive advantage. But accounting for cost in a market economy is different from the Soviet practice. Such factors as the cost of electricity, for example, did not need to be accounted for in a Soviet economy, but must be in a market economy.

There are different views of the necessity for infrastructure changes needed to help the Russian economy grow. Changes in the legal code, the judiciary, property ownership rights, and tax policies will be necessary for Russia to achieve economic diversification. Access and openness is another area where changes are essential. Western investors need to be able to visit their investments. The system of closed cities, which may be desirable for security reasons, is not compatible with western business. U.S. experience in narrowing the extent of security areas during its own nuclear weapons complex downsizing is relevant, but so far has not been embraced by Russia.

Finally, infrastructure creation goes beyond issues of business planning, access, and market studies. The western emphasis on quality, exemplified in the ISO 9001 certification process for example, will be important for Russia, so that goods and services can be successfully marketed internationally.

## Summary

Western understanding of conditions within Russia has certainly improved since the early 1990s. We see that the main features of their new economy and improved nuclear security structure are in development. The sensitivity of Russian weapons-related nuclear activities and their mix with non-weapons activities affects U.S. efforts to assist in improving fissile materials security and economic diversification. Long-term cooperation will have to be built on lessons learned to date, with future efforts being planned with firm prior agreement on expected outcomes (effect and timing), metrics for progress, and respective contributions from each party, such as labor, funds, equipment, and intellectual property. The clear articulation of an overall strategy, which describes why it is in the interest of the United States as well as how all the pieces (initiatives) fit together, will be essential to achieving long-term congressional support for nonproliferation cooperation with Russia. Addressing the differing expectations in defining the threat, determining the role of government in weapons complex downsizing, developing infrastructure, standards and marketing approaches, etc. will be more difficult. Continued engagement, with frank and open discussion of interests, benefits, and concerns could go a long way towards better understanding and increased chances of long-term cooperation in improving Russian nuclear security.

# Non-Destructive Assay of Ce-144 in Presence of Transuranic Waste

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## Abstract

The Ce-144 isotope has been identified as a radionuclide produced in certain Los Alamos National Laboratory plutonium waste streams and thus may need to be quantified when present in reportable quantities for shipment to the Waste Isolation Pilot Plant. The most intense gamma ray from Ce-144 was found to be the 133.53 keV peak. At this energy, there were no interfering plutonium or plutonium daughter gamma rays. Furthermore, it was determined that there were no interferences produced by Ce-144 or its progenies that could degrade the plutonium isotopic analysis. At 5 percent of the total activity per gram of plutonium, the reportable limit, the Ce-144 peak at 133.53 keV will remain above the primary plutonium peak (129.3 keV) for approximately seven years and remain quantifiable for at least twelve to thirteen years from the time the isotope was chemically separated. It is therefore concluded that Ce-144 will be quantifiable whenever it exceeds 5 percent of the total activity per gram of plutonium, and will not interfere with the non-destructive assay of plutonium isotopic compositions.

## 1. Introduction

The waste acceptance criteria[1] for the Waste Isolation Pilot Plant require that certain radionuclides be quantified and at least 95 percent of the total activity in a container be reported. However, some radionuclides may cause interferences with the reportable isotopes or exceed 5 percent of the total activity but remain below the detectable threshold, resulting in erroneous quantification. Isotopes have been identified in waste streams based on process knowledge and these have been captured in process status (PS) codes. Non-plutonium isotopes that could be in these waste streams were identified from the PS codes and these are tabulated in Table 1. Many isotopes have already been incorporated in the Fixed-Energy Response Function Analysis with Multiple Efficiencies (FRAM) isotope analysis program[2], but not all. As a result, a study was initiated to complete the analysis of these isotopes. This report summarizes the findings for Ce-144.

## 2. Description and Properties of Ce-144

Cerium is a highly reactive rare earth metal in the lanthanide series of the periodic table. It is used in the nuclear industry and in analytic chemistry laboratories as an oxidizing agent. The Ce-144 isotope is a fission product lying near the high mass maxima of the fission curve[3]. Cerium has several radioactive isotopes ranging from Ce-134 to Ce-144 with decay modes including electron capture and $\beta^-$ emission. The isotope of importance in the LANL waste stream is Ce-144 with an atomic mass of 143.9 g/mole and a half-life of 284.1 days, decaying via $\beta^-$ and $\alpha$ particle to Ce-140.

**Table 1. Select Radionuclides Derived From Process Status Codes**

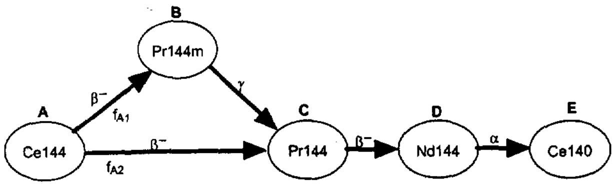
| Radionuclide | Assessed in PC/FRAM? |
|---|---|
| Am-241 | Yes |
| Am-243 | Yes |
| Ce-144 | Recently Added |
| Th-232 | Yes |
| U-233 | Yes |
| Np-237 | Yes |
| Cm-244 | No |
| Pa-231 | Yes |
| Depleted Uranium | Yes |
| Th-230 | Recently Added |

Ce-144 is important to the nondestructive analysis NDA measurements because the Ce-144 was originally thought to cause difficulties with the isotopic calculations performed by the FRAM assay system. Further, it had been uncertain if Ce-144 present at 5 percent of the total activity would be quantifiable.

## 3. Ce-144 Decay Properties

The Ce-144 decay scheme involves several steps as shown in Figure 1. Ce-144 undergoes radioactive decay with a half-life, T, of 284.1 days via $\beta^-$ emission to either Pr-144m or Pr-144. The branching ratio to the metastable state Pr-144m, $f_{A1}$, is 0.0143 and to Pr144, $f_{A2}$, is 0.9857. Pr-144m decays with a half-life of 7.2 minutes via $\gamma$ emission to the ground state, Pr-144, which subsequently decays via ß⁻ emission with a half-life of 17.3 minutes to Nd-144. The radioactive decay continues to Ce-140 by α emission with an extremely long half-life, 2.1 x $10^{15}$ years, stopping at Ce-140, which is stable. The properties[4] of interest for cerium and its progenies are summarized in Table 2.

**Figure 1. Ce-144 Decay Scheme**



### *3.1 Mathematical Description*

The number of atoms, N, of each isotope, A through E (Figure 1), is given by the following ordinary differential equations (ODE), where λ (=ln(2)/T) is the decay constant and t the elapsed time following chemical separation.

**Table 2. Properties of CE-144 and Decay Products**

| Isotope | Half-life, T | Molecular Weight, M (g/mol) |
|---|---|---|
| Ce-144 | 284.144 d | 143.914 |
| Pr-144m | 7.2 m | 143.913 |
| Pr-144 | 17.283 m | 143.913 |
| Nd-144 | 2.1 x $10^{15}$y | 143.010 |
| Ce-140 | NA (stable) | 139.905 |

$$\frac{dN_A}{dt} = -\lambda_A N_A \tag{1}$$

$$\frac{dN_B}{dt} = \lambda_A f_{A1} N_A - \lambda_B N_B \tag{2}$$

$$\frac{dN_C}{dt} = \lambda_B N_B + \lambda_A f_{A2} N_A - \lambda_C N_C \approx \lambda_A N_A - \lambda_C N_C \tag{3}$$

$$\frac{dN_D}{dt} = \lambda_C N_C - \lambda_D N_D \approx \lambda_A N_A - \lambda_D N_D \tag{4}$$

$$\frac{dN_E}{dt} = \lambda_D N_D \tag{5}$$

Two approximations were made for equations 3 and 4 to obtain a closed-form solution to the ODEs. In the first approximation, the half-life of Pr-144m is so small in comparison to the half-life of Ce-144 that the decay can be approximated as all coming from Ce-144 directly to Pr-144 and then to Nd-144. In the second approximation, the half-life of Nd-144 is so large in comparison to the half-lives of all the other precursors that the decay of Pr-144 can be approximated as coming directly from Ce-144. These approximations permitted the closed form solutions to the ODEs. The errors associated with the two approximations were assessed based on a mass balance between the initial mass and final mass. The largest error occurred at large elapsed times and was found to be less than 0.63 percent.

The solutions to the above ODEs are given by the following equations, which were implemented in a Microsoft Excel spreadsheet to develop the tables and graphics shown below. For each equation, the solution was verified by differentiation and solving the original ODE to prove the identity.

$$N_A = N_{A0} e^{-\lambda_A t} \tag{6}$$

$$N_B = \frac{\lambda_A f_{A1} N_{A0}}{\lambda_B - \lambda_A} (e^{-\lambda_A t} - e^{-\lambda_B t}) + N_{B0} e^{-\lambda_B t} \tag{7}$$

$$N_C = \frac{\lambda_A N_{A0}}{\lambda_C - \lambda_A} (e^{-\lambda_A t} - e^{-\lambda_C t}) + N_{C0} e^{-\lambda_C t} \tag{8}$$

$$N_D = \frac{\lambda_A N_{A0}}{\lambda_D - \lambda_A} (e^{-\lambda_A t} - e^{-\lambda_D t}) + N_{D0} e^{-\lambda_D t} \tag{9}$$

$$N_E = \frac{\lambda_A \lambda_D N_{A0}}{\lambda_D - \lambda_A}\left(\frac{e^{-\lambda_A t}}{\lambda_D} - \frac{e^{-\lambda_d}}{\lambda_A}\right) + N_{d0}(1 - e^{-\lambda_d}) -$$

$$\frac{\lambda_A \lambda_D N_{A0}}{\lambda_D - \lambda_A}\left(\frac{1}{\lambda_D} - \frac{1}{\lambda_A}\right) + N_{E0} \tag{10}$$

The remaining parameters of interest given by equations 11 through 13 are the activity, $A_j$, the mass, $m_j$, and the number of gamma photons per unit time, $\Gamma_{j,k}$, for each isotope, j (j = A, B,...E), and gamma ray peak, k. The gamma ray photon intensity, $I_{j,k}$ expressed as a percent, is the number of gamma photons emitted per 100 disintegrations of the parent nuclide and $N^A$ is Avogadro's number.

$$A_j = N_j \lambda_j = N_j \frac{\ln(2)}{T} \tag{11}$$

$$m_j = \frac{M_j}{N^A} N_j \tag{12}$$

$$\Gamma_{j,k} = A_j I_{j,k} \tag{13}$$

In a waste matrix containing both plutonium and cerium, the ratio of the activity due to Ce-144 plus its progenies, $A_{ce}$, to total activity, A, of plutonium and cerium combined is given by equation 14 where $A_{pu}$ is the sum of the activities from all the plutonium isotopes and the plutonium progenies (Am-241, U-237, Np-237, etc.). The equation assumes that there are no other impurities in the waste stream.

$$\frac{A_{ce}}{A} = 1 - \frac{A_{pu}}{A_{ce} + A_{pu}} \tag{14}$$

### *3.2 Activity in Presence of Plutonium*

One gram of typical weapons grade plutonium as exemplified by a performance demonstration program (PDP)[5] standard (Pu-238: 0.0145 percent; Pu-239: 93.7614 percent; Pu-240: 5.9445 percent; Pu-241: 0.2237 percent; Pu-242: 0.0559 percent; Am241: 0.00 percent) will produce 10847 MBq when the material is first chemically separated. The activity from plutonium and its decay products (including Am-241), $A_{pu}$, will slowly decay with time (Table 3).

If Ce-144 were present at 5 percent of the total activity from one gram of weapons grade plutonium, it would represent 570.9 MBq of activity, or 4.83 μg, at time zero. The total isotopic activity from Ce-144 and daughters ($A_{ce}$) will vary during the period following chemical separation (Table 3). The activity variation is evident from a plot of the data (Figure 2). The initial activity from Ce (570.9 MBq) will increase to over 1000 MBq very quickly (less than one day) as the Pr-144 builds up. The $A_{ce}$ activity will drop below the initial activity after nine months following chemical separation (Figure 2 and insert). The activity from Nd-144 is insignificant.

### *3.3 Gamma Spectrum*

The gamma rays[4] from the decay of Ce-144 and daughters are summarized in Table 4. The cerium gamma ray peaks are compared with plutonium (or Pu decay product) peaks for possible interference. The peak at 133.53 keV is interference free, with the closest Pu line at 129.3 keV. The next peak, 146.0 keV, has zero intensity, meaning that its presence is doubtful. The 696.5 keV peak is also interference free with the closest peaks at 662.46 keV and 721.99 keV (Am-241). All the other cerium peaks are at energies not used in quantifying the plutonium isotopics in the current FRAM software. The cerium and daughter peak energies were also compared to background and no interferences were found using a fifteen-hour background spectrum. Consequently, Ce-144 and its daughters will not cause any interference with the quantification of the plutonium isotopes.

The most intense gamma ray is at 133.53 keV as shown in Figure 3. The gamma rate from cerium is compared to that from 1g of weapons grade plutonium using the most intense line (Pu-239 at 129.3 keV) and a rather weak line (Pu-238 at 152.7 keV). The 133.5 keV peak intensity remains above the Pu-238 peak intensity for about twelve years. Beyond twelve years, the gamma rays from all Ce-144 will become extremely weak and the activity will be well below the initial activity and the reportable quantity. Consequently, the ability of the FRAM system to quantify plutonium in the presence of cerium or its progenies will not pose any significant assay problem. Quantities of Ce-144 at or above 5 percent of the total activity will be detectable using the 133.53 keV line without interference with Pu quantification.

**Table 3. Activity from Ce-144 and Progenies at 5% of Total Pu Activity at t=0**

| | **Activity (MBq)** | | | | | |
|---|---|---|---|---|---|---|
| Time(Yr) | $A_{ce}$ | Ce-144 | Pr-144m | Pr-144 | Nd-144 | Apu(1g) |
| 0 | 570.9 | 570.9 | 0.0 | 0.0 | 0.0 | 10847.1 |
| 0.00001 | 682.6 | 570.9 | 3.2 | 108.5 | 0.0 | 10847.1 |
| 0.00010 | 1080.5 | 570.8 | 8.1 | 501.5 | 0.0 | 10847.1 |
| 0.00100 | 1149.0 | 570.4 | 8.2 | 570.4 | 0.0 | 10846.8 |
| 0.01 | 1139.8 | 565.8 | 8.1 | 565.9 | 0.0 | 10843.6 |
| 0.1 | 1052.0 | 522.3 | 7.5 | 522.3 | 0.0 | 10811.5 |
| 0.2 | 962.4 | 477.8 | 6.8 | 477.8 | 0.0 | 10775.9 |
| 0.3 | 880.4 | 437.1 | 6.3 | 437.1 | 0.0 | 10740.5 |
| 0.4 | 805.4 | 399.8 | 5.7 | 399.9 | 0.0 | 10705.3 |
| 0.5 | 736.8 | 365.8 | 5.2 | 365.8 | 0.0 | 10670.1 |
| 0.6 | 674.0 | 334.6 | 4.8 | 334.6 | 0.0 | 10635.2 |
| 0.7 | 616.6 | 306.1 | 4.4 | 306.1 | 0.0 | 10600.4 |
| 0.8 | 564.1 | 280.0 | 4.0 | 280.0 | 0.0 | 10565.8 |
| 0.9 | 516.0 | 256.2 | 3.7 | 256.2 | 0.0 | 10531.3 |
| 1 | 472.1 | 234.4 | 3.4 | 234.4 | 0.0 | 10497.0 |
| 1.5 | 302.5 | 150.1 | 2.1 | 150.2 | 0.0 | 10327.7 |
| 2 | 193.8 | 96.2 | 1.4 | 96.2 | 0.0 | 10162.3 |
| 3 | 79.5 | 39.5 | 0.6 | 39.5 | 0.0 | 9842.5 |
| 4 | 32.7 | 16.2 | 0.2 | 16.2 | 0.0 | 9537.0 |
| 5 | 13.4 | 6.7 | 0.1 | 6.7 | 0.0 | 9245.0 |
| 6 | 5.5 | 2.7 | 0.0 | 2.7 | 0.0 | 8966.1 |
| 7 | 2.3 | 1.1 | 0.0 | 1.1 | 0.0 | 8699.6 |
| 8 | 0.9 | 0.5 | 0.0 | 0.5 | 0.0 | 8444.9 |
| 9 | 0.4 | 0.2 | 0.0 | 0.2 | 0.0 | 8201.6 |
| 10 | 0.2 | 0.1 | 0.0 | 0.1 | 0.0 | 7969.1 |
| 15 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6952.7 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6142.9 |
| 30 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4983.0 |
| 40 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4245.0 |

## 4. Conclusions

Early in the NDA program, the Ce-144 isotope had been identified as a radionuclide that could produce difficulties in the non-destructive assay of plutonium waste. This analysis has shown that Ce-144 will not interfere with Pu assay and that it will be easily detected in quantities exceeding 5 percent of the total activity.

The decay scheme for Ce-144 was determined and a set of ordinary differential equations derived and solved in order to generate the time-dependent activity and gamma ray emission properties. The most intense gamma ray was found to be the 133.53 keV peak and at this energy, there are no interfering plutonium or plutonium daughter peaks.

Furthermore, it was determined that there were no interferences produced by Ce-144 or its progenies that could degrade the plutonium isotopic analysis using current FRAM NDA software. At 5 percent of the total activity (the current reporting criteria for WIPP) per gram of plutonium, the Ce-144 peak at 133.53 keV will remain above the primary plutonium peak (129.3 keV) for approximately seven years and remain quantifiable for at least twelve to thirteen years from the time the isotope was chemically separated. After this time, the activity from Ce-144 and its progenies will fall well below the WIPP reporting criteria.

It is therefore concluded that Ce-144 will be quantifiable whenever it exceeds 5 percent of the total activity per gram of plutonium, and will not interfere with the non-destructive assay of plutonium isotopic composition.

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**Figure 3. Quantifiable Gamma Ray Lines from Ce-144 or Progenies at 5% Total Activity/g Pu**

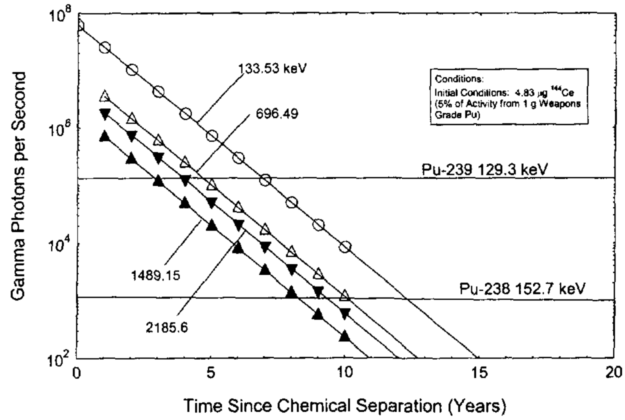

**Figure 2. Time to Reduce Ce-144 Activity to Below 5% Total Activity/g Pu**

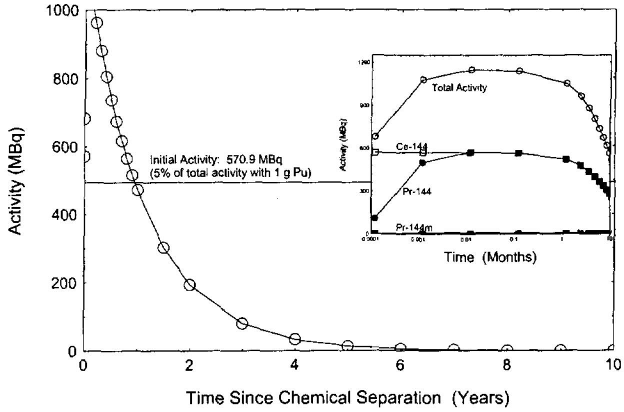

**Table 4. Ce-144 and Daughter Gamma Rays**

| # | Decay | Energy (keV) | Intensity (%) | Energy (keV) Overlaps Pu Line?[a] |
|---|---|---|---|---|
| 1 | Ce144 → Pr144 or Pr144m | 133.530 | 10.8000 | No |
| 2 | Ce144 → Pr144 or Pr144m | 146.000 | 0.0000 | 146.05 |
| 3 | Pr144m → Pr144 | 696.490 | 0.0600 | 696.6 |
| 4 | Pr144m → Pr144 | 814.150 | 0.0600 | 813.9 |
| 5 | Pr144 → Nd144 | 624.660 | 0.0010 | 624.8 |
| 6 | Pr144 → Nd144 | 675.020 | 0.0028 | 674.2 |
| 7 | Pr144 → Nd144 | 696.490 | 1.4900 | 696.6 |
| 8 | Pr144 → Nd144 | 814.150 | 0.0028 | 813.9 |
| 9 | Pr144 → Nd144 | 864.530 | 0.0027 | 863.6 |
| 10 | Pr144 → Nd144 | 1388.000 | 0.0065 | No |
| 11 | Pr144 → Nd144 | 1489.150 | 0.2960 | No |
| 12 | Pr144 → Nd144 | 1562.000 | 0.0003 | No |
| 13 | Pr144 → Nd144 | 2185.610 | 0.7700 | No |
| 14 | Pr144 →Nd144 | 2654.600 | 0.0002 | No |
| 15 | Nd144 → Ce140 | None | N/A | |
| 16 | Ce140 | None | N/A | |

[a] High purity Geraminum detector

# Statistical Analysis of the Results of Measurements of the Quantity of Nuclear Material during Physical Inventory

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■

## Abstract

This paper presents a view of how one Russian institute intends to implement statistical analysis for conducting and evaluating physical inventories of nuclear material items for the reweighing of a static inventory of items. Physical inventory measurement procedures and results for the Narciss critical assembly at Russian Research Center Kurchatov Institute are described in this paper. The Narciss critical assembly utilizes nuclear material in the form of uranium dioxide with a nominal enrichment of 96 percent. Details of results are presented for a subset of the inventory. Quality control charts were utilized to compare each mass measurement in the current inventory with the corresponding mass measurement in the previous inventory in order to determine whether any of the measured values fall outside the defined control limits of the mass measurement (weighing) process. Rank order statistical tests were employed to demonstrate that the cumulative distribution functions of the measured masses of the fuel elements are the same for the previous and current inventories. The nonnormality of the mass measurement data and the implications for the applicability of paired statistical tests are discussed. The contributions of errors to the measurement of mass, enrichment, and uranium content to the variance of the mass of fissile material were studied. The analysis demonstrated that the difference between the results of the current and preceding inventory is statistically insignificant. The observable deviation is well within the range of acceptable values providing assurance of nuclear materials security.

## 1. Introduction

The control and accounting of nuclear materials is one of the most important activities for the security of the modern state, especially nuclear materials that can be used for the manufacture of nuclear explosives components without further enrichment or transmutation. An effective system of control and accounting of nuclear materials based on statistical analysis expedites the timely detection of losses of nuclear materials and radioactive substances and may assist in determining the explanation for these losses.

In the majority of enterprises in the Russian Federation, the system of control and accounting of nuclear materials has relied on record keeping and has been based on the principle of a chain of responsibility. In this system, nuclear material becomes the responsibility of a specific individual at the enterprise from the moment of receipt. At the completion of the technological process specified in written instructions, the nuclear material then becomes the responsibility of another individual. For each technological process a norm is established for the nonrecoverable technological loss or percentage yield of finished product from raw material.

In the United States, Japan, the countries of the European Community, and other countries, the generally recognized method for nuclear material accounting is based on the physical determination of the quantitative and qualitative characteristics of fissile materials and analysis of the nuclear material balance. This method constitutes the basis of systems of international guarantees that are implemented by the International Atomic Energy Agency and EURATOM. The development and introduction of such a system at the Russian Research Center Kurchatov Institute is viewed as a most urgent task. The results of this task may contribute to the development of a State System of Accounting and Control of Nuclear Materials of the Russian Federation.[1]

Considering the above statements, the physical inventory taking or PIT measures conducted at the Narciss facility of the RRC KI had three objectives. The first was to conduct a fundamental test of nuclear material accounting directly at the Narciss facility. The second was to contribute to the development and implementation of methods, procedures and technologies for PIT activities at other facilities of the institute with nuclear materials. The third was to develop recommendations for procedures of possible use by the governmental regulatory oversight agency (GOSATOMNADZOR RF). An important part of this effort in preparing PIT at the Narciss facility was the development of the corresponding regulatory and organizational documentation, together with the necessary instructions.

The intent of this paper is to describe how one Russian facility, RRC KI, intends to apply statistical methods in the relatively simple case of the reweighing of a static inventory of items at the Narciss critical assembly. This facility contains nuclear material consisting of pellets of highly-enriched uranium dioxide (~96 percent $^{235}$U) in the form of disassembled fuel elements. This work will present the results from PITs conducted in 1995 and 1996. The current inventory referred to in this paper was conducted approximately fifteen months after the previous inventory. Of primary importance in PIT of nuclear materials is the creation of an effective system of quality control of measurements developed on a foundation of mathematical statistics.[2] Special attention was given to the creation of special statistical quality control charts that permitted close control of the operation of the equipment and of the measurements. In estimating the confidence interval for the inventory difference obtained as a result of the PIT at the Narciss facility, an analysis of the nuclear material characteristics obtained from the nuclear fuel manufacturer as well as those measured at RRC KI was used. Statistical processing of the results on a personal computer was done using a special computer code, CONTROL.

Systems of nuclear material accounting and control typically assume that random errors for the components of the equation of material balance have an asymptotic normal distribution. However, knowledge of the distribution function is actually more limited. Therefore, it may be more appropriate to use the less rigid and more general hypothesis that the probability density of random variables belongs to the class of high-entropic symmetrical distributions (from uniform distribution to normal distribution). It should be noted, however, that the more familiar statistical tests such as the t-test, employing Student's t-distribution, may still be acceptable because of the robustness of these tests to non-normality. Therefore, for an analysis of possible deviations between the results of weighing in the current and previous inventories, the use of rank order tests is demonstrated in this paper, since such tests are independent of the type of probability distribution function of a random variable.[3]

In the body of this paper, Section 2 provides a brief description of the PIT procedures and measurements that essentially consist of the re-weighing of a static inventory of items. Section 3 describes the use of quality control charts to compare each mass measurement in the current inventory taking with the corresponding mass measurement in the previous inventory taking. The intent is to determine whether any of the measured values fall outside the defined control limits of the mass measurement (weighing) process. Section 4 outlines how three rank order tests may be employed to demonstrate that the cumulative distribution functions of the measured masses of the fuel elements are the same for the previous and current PITs. Section 4 also indicates how paired statistical tests may be employed and provides rationale for preferring a paired rank order test to the paired t-test in the present case. Section 5 presents the total mass data for the batch of fuel pellets under consideration as well as the uranium content and enrichment data. Section 6 considers the variance of the mass of fissile material and the relative contribution of the variances of the measurements of mass, enrichment, and uranium content to that variance. Section 7 indicates how the 90 percent confidence interval for the mass of fissile material was obtained. Section 8 gives the confidence interval for the differences in mass measurements between the two inventories for several different assumptions. Finally, Section 9 presents the conclusions.

This work was performed under the auspices of the U.S. Department of Energy's Material Protection, Control and Accounting Program, a joint Russian-American program for direct cooperation between Russian and U.S. institutes. The authors from Brookhaven National Laboratory participated in this work to the extent of assisting with the development of physical inventory procedures and providing critical commentary throughout. The authors from RRC Kurchatov Institute conducted the inventory and conducted the initial evaluation of the results. (Additional evaluation of the results by means of paired statistical tests was performed at the suggestion of the reviewer of this paper. The authors acknowledge the reviewer for many useful comments.) The authors acknowledge the U.S. DOE MPC&A Program for financial support and other DOE laboratories participating in the program for technical support.

## 2. A Brief Description of the Measurement Procedures of Physical Inventory Taking

The system of measurements of the quantity of nuclear materials in the material balance area of a given facility entails: (1) methods, instruments, and equipment used when determining the mass of the nuclear material; (2) procedures for taking samples and specimens for analysis; and (3) nondestructive analysis for obtaining the isotopic composition of the fuel pellets. The procedure for measuring the mass of nuclear material is unique to each facility and is determined by the type of nuclear material and by the equipment used.

During the PIT, each fuel element, which is comprised of a collection of fuel pellets and has a unique identifier (number), was measured. Fuel pellets from a specific fuel element are not combined with fuel pellets from other fuel elements. The fuel pellets are approximately 17.0 mm in diameter with a central hole 4.5 mm in diameter. A VLR-1 beam balance with assorted weights was used to determine the mass of uranium dioxide fuel pellets.

The additive model of errors was used in the subsequent analysis of the results of the weighing

$$W=W_m + b+ \varepsilon \qquad (1)$$

where

$W$ = measured value of mass
$W_m$ = true value (expectation)
$b$ = bias or systematic error
$\varepsilon$ = random error

so that the total weighing includes both random and systematic errors. The maximum estimate of a total error of measurement $\Delta = b + \varepsilon$ was obtained on the basis of the manufacturer's data for the weights and was $\Delta = \pm 25$mg. The calculation of total error considered the allowable error of weighing (±10mg)[random], error due to dissimilarity of the balance levers (±4mg) [systematic], error of inclusions of built-in weights (±3mg) [systematic], and error in the values of masses of weights used during weighing (±8mg) [systematic]. RRC KI has a set of weight standards that may be utilized for calibration of balances. For the balances employed in this study, reference 850g and 65g weights sets were periodically weighed during the working day. Statistical quality control charts (see below) were used to confirm the stability of the balances during the period of time that PIT measurements were conducted. Analogous considerations are being applied to the electronic scales that are now being used in current inventories.

The mass of fuel $Mu_i$ for each fuel element is defined as the difference of observations for two measurements in weights

$$Mu_i = W_i - W_0, \qquad (2)$$

where $W_i$ is the result of weighing of fuel pellets in the "i-th" fuel element with a tray on which they are placed during the weighing, and $W_0$ is the result of weighing of the tray.

This work presents the results of measurements of mass of fuel for a batch of fuel elements that were used during benchmark experiments on the Narciss facility.[4, 5] The current inventory is a remeasurement of a static inventory; in such cases, systematic errors of weighing have the potential to cancel. The inventory procedures and subsequent analysis of the results as described in this paper constitute an example of how the complete physical inventory of the nuclear materials in the material balance area was conducted. The measured mass of fuel of one fuel element was approximately 825 grams while the mass of the tray was 52.5 grams. There were thirty-seven fuel elements in the batch discussed in this paper. The fuel pellets of the batch under study contain more than 20 kg of the $^{235}$U isotope (with enrichment of 96 percent). The mass of each pellet is approximately 23g. According to the classification of nuclear materials in U.S. Department of Energy Order 5633.3B, the material balance area of Narciss is Category 1 and contains material of level of attractiveness C. (Note: DOE 5633.3B has been superceded by DOE 0474.1 and its associated manual DOE M474.1-1.)

Analysis of the isotopic content of available scrap from the fuel pellets of the fuel elements was conducted by mass spectrometry at RRC KI, so that the data could be compared with the values of enrichment available from the manufacturer. During PIT, sample measurements were taken of enrichment of individual fuel pellets from each fuel element on the portable $\gamma$-spectrometer (Canberra Industries InSpector®) in order to detect possible significant deviations in enrichment of nuclear material. Studies of changes in the phase and chemical composition of dioxide fuel were undertaken at the manufacturer and at RCC KI before the PIT. These changes can take place under long-term storage of uranium dioxide fuel pellets and when working with these pellets in the open air. The results have shown that these changes are insignificant and are within the range of acceptable measurement errors.

## 3. Quality Control Charts

Control charts are widely utilized in technical and industrial processes to detect departures from a state of statistical control, namely, that the measurements exhibit variability due only to chance variation. A control chart consists of a centerline (CL), which corresponds to the average quality of a process or series of measurements in a state of statistical control, and an upper and a lower control limit (UCL and LCL) determined by the nature of the process. In the event that a measured value falls outside these limits, the possible causes are investigated in order to identify and resolve any possible problems with the process. Using the computer code CONTROL, these quality control charts for measurements of mass of fuel of the fuel elements were constructed during the PIT process.[2]

The M- and R-charts described in this paper are based on the $\bar{X}$ and R-charts widely used in industry and research.[3] When constructing an M- chart, one plots the ratio of the values of masses of fuel for each fuel element, obtained in the current ($Mu_{EI}$) and previous ($Mu_{BI}$) inventory, along the axis of the ordinate. The expected value of this ratio of masses for a particular fuel element "i" is 1, which corresponds to the centerline on the M- chart. The values of the control limits are determined in the following manner:

$$UCL=1+\frac{A_2\bar{R}}{\overline{Mu}},\quad LCL=1-\frac{A_2\bar{R}}{\overline{Mu}}, \tag{3}$$

where $\overline{Mu}$ is the average value of the mass of the fuel element in each batch

$$\overline{Mu}=\frac{\sum_{i=1}^{N} Mu_i}{N} \tag{4}$$

and

$A_2$ = a coefficient which depends on the significance level $\alpha$

$\bar{R}$= the average range of the measured values

N = the quantity of fuel elements in the measured batch. Usually, when estimating control limits, it is assumed that the results of the measurements $x_i$ are independent random variables with a normal law of distribution N ($\mu_i$ $\sigma_i$ ). For a "three sigma" control chart,[3] $A_2\bar{R}$ is an estimate of $3\sigma_{\bar{X}}$, $\alpha$ = 0.003, and $A_2$ = 1.880 from tabulated factors for control limits. In the CONTROL code, $\overline{Mu}$ is computed from the results of measurements of mass of the fuel elements for the previous PIT and data obtained in the current PIT. The value of $\overline{Mu}$ is initially calculated in the CONTROL code from the results of measurements obtained in the preceding PIT and is successively recalculated with each new mass measurement during the current PIT.

When constructing the R- chart, the absolute value of difference $|Mu_{BI} - Mu_{EI}|$ is plotted along the ordinate axis. In a comparison of the results of measurements of the current and previous PIT, this difference in masses is expected to be zero. The centerline on the R- chart corresponds to the value of variation $\bar{R}$. The values of the upper and lower control limits are calculated from the following formulas:

$$LCL=D_3\bar{R},\ \text{and}\ UCL=D_4\bar{R} \tag{5}$$

where $D_3$ and $D_4$ are dependent on the significance level $\alpha$ and on the number of measurements per sample. For $\alpha$ = 0.003 and two measurements per sample (namely, $Mu_{EI}$, obtained in the current inventory, and $Mu_{BI}$, obtained in the previous inventory), $D_3$ = 0 and $D_4$ = 3.267.[3] The sample numbers of the fuel elements are plotted on the abscissa for the above-mentioned M- and R- charts.

Figures 1 and 2 give the M- and R- charts for the studied batch of fuel elements (N=37). Certain fuel elements (five pieces) lie outside the control limits. These fuel elements were repeatedly reassembled during neutron-physics experiments, leading to the destruction of pellets that were then replaced. The scrap mass (about 40g) from the destroyed pellets was measured separately and accounted for in the total balance. There were three cases, detected through the use of control charts, of operator error resulting from the incorrect calculation of total mass of the weights placed on the balance. These three cases of operator error are not shown in the control charts since they were detected and corrected immediately in the course of making the measurements.

**Figure 1. Control M-chart for Mass Measurement of Fuel of Fuel Elements (UCL=1.00011, LCL=0.99989)**

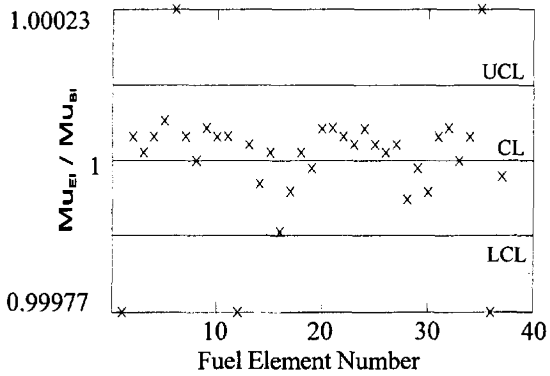
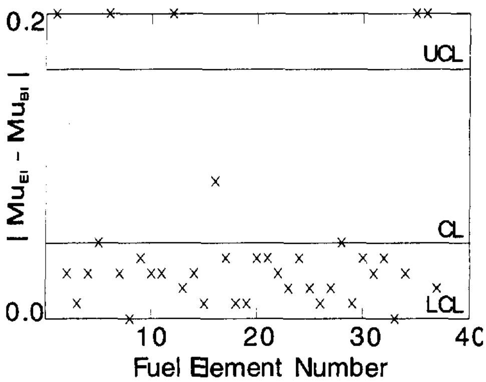


**Figure 2. Control R-chart for Mass Measurement of Fuel of Fuel Elements (UCL=0.163, CL= $\bar{R}$=0.05, LCL=0.0)**



Similar quality control charts were also constructed from measurements of the mass of the weighing tray and the reference masses in order to observe any drift in the measurement results. From the drift the stability of the measurement system and contamination of the tray may be assessed. As may be seen from Figure 1, only eight of the thirty-two ratios of the current and previous inventory masses are less than one (after removing the five outlier values from consideration) so that only these eight differences between the current and previous inventory measurements are negative. This result provides some indication of possible equipment drift, although the use of the same reference weight standards in each inventory would indicate otherwise.

The M- and R- quality control charts were also constructed for other batches of fuel elements located within the material balance area of the Narciss facility.

## 4. Analysis of Results of Weighing Using Rank Order Tests

Rank order statistical tests are termed "distribution-free" tests and are applicable in situations in which the probability distribution of the measurements is either unknown or is known not to be normal. (The term "distribution-free" is often used interchangably with "nonparametric" but the two terms are not the same. See, for example, Reference 3.) These tests are independent of the type of probability distribution of a random variable, and may be employed to verify what is commonly called the null hypothesis. Here, the null hypothesis is the assumption that the cumulative distribution functions of the measured masses of fuel elements are the same in the current and the previous PITs — in this case expressed as $H_0$: $F_{BI}=F_{EI}$ (see, for example, Reference 3). However, it would be acceptable in many cases to employ more familiar tests such as the t-test based on Student's *t*-distribution because of the robustness of these tests to non-normality. Robustness in this paper means distributional robustness, the insensitivity of the statistical test to small deviations from the normal distribution.

The distribution-free statistical tests are conducted by combining the measurements from the two populations (namely, by combining the N mass measurements from the previous inventory with the N mass measurements from the current inventory.) The measurement values (or samples) in the combined population are then ranked so that the smallest measured weight value has a rank order of 1 while the largest has a rank order of 2N. As a result, each member of the combined population of 2N measurements has a definite sequential number (rank n). For example, the fifth measured value of the weight in the current inventory ordered by weight may be the ninth value in the combined population ordered by weight, so that $r_5 = 9$. The hypothesis $H_0$ was checked by use of the following three rank order tests: Wilcoxon, Mann-Whitney, and van der Waerden.

In the case of the Wilcoxon rank order test, the sum of ranks n for measurements Mui is computed

$$W=\sum_{i=1}^{N} r_i = r_i + \dots r_N \qquad (6)$$

The statistic W is the sum of the rank order numbers of the measured weight values of the current inventory based on their rank in the combined population of measured weight values from both the previous and current inventories.[3]

In the Mann-Whitney tests, each measurement in the current inventory is compared with every measurement in the previous inventory. For N items, this results in $N^2$ comparisons. The statistic U is then the number of inversions — namely, the number of times that a measurement from the current inventory exceeds a measurement from the previous inventory.[3]

The calculation of the statistic $X_v$ utilizing the van der Waerden rank order test is more complex and consists of a summation involving the quantiles of the standard normal distribution function:

$$X_v = \psi\left(\frac{r_1}{2N+1}\right) + \dots + \psi\left(\frac{r_N}{2N+1}\right). \qquad (7)$$

Here $\psi$ is the inverse function of the standard normal distribution function and, once again, N is the number items measured in each inventory, and $r_i$ is the rank order of a current inventory measurement in the combined inventory. See the original work by van der Waerden[6] for a detailed explanation of this test.

Values for W, U and $X_v$ that were computed using the CONTROL code as well as their critical values are given in Table I. Based on these values, the null hypothesis $H_0$ is accepted and it is concluded that the deviations between the results of the weighing in the current and previous inventories are statistically insignificant. Analogous results of the analysis were obtained for other batches of fuel elements in the material balance area of the Narciss facility.

Since in the present case the primary interest is on inventory difference between of the measured masses in the previous and current inventories, a more limited null hypothesis that the mean value of the measured masses is the same in the current and previous PITs would be sufficient. It should be noted that the data are paired data; each data point in the current inventory $(Mu_{EI})$ has a corresponding data point $(Mu_{BI})_i$ in the previous inventory where $1 \le i \le n$ for the n fuel elements and n = 37. The test procedure then consists of analyzing for each pair of data points the difference $D_i = (Mu_{BI})_i - (Mu_{EI})_i$ between the measured value of the mass obtained in the current inventory and that obtained in the previous inventory.

If a normal distribution for the data is assumed, the paired *t*-test [6a] may be employed to test the hypothesis that the mean value of $D_i$ is zero. (This hypothesis is equivalent to the hypothesis that the total true mass of the previous inventory is equal to the total true mass of the current inventory.) The test statistic *t* is given by

$$t = \frac{\bar{D}}{S_D/\sqrt{n}} \qquad S_D^2 = \sum(D - \bar{D})^2/(n-1) \qquad \bar{D} = \sum D/n \qquad (7a)$$

where the summation subscripts have been eliminated for the sake of ease of presentation. The value of *t* is calculated to be -0.194, which is between the limits of 60.8 and -60.8 for accepting the hypothesis of D = 0 at the $\alpha = 0.1$ level of significance. If the five outliers are omitted from the analysis, the value of *t* for the remaining thirty-two weight differences is calculated to be -1.766.

Although the *t*-test is robust to most forms of non-normality, it is sensitive to outliers. Therefore, since five measurements lie outside the control limits, a distribution-free test may be more appropriate. In the present case, the Wilcoxon signed ranks test[6a], a paired version of the Wilcoxon test, may be employed as a distribution-free test that corresponds to the paired *t*-test. The i-th data point is again the difference between the mass measured for the i-th fuel element in the previous inventory and in the current inventory, namely, $D_i = (Mu_{BI})_i - (Mu_{EI})_i$ $(1 \le i \le n)$. The absolute values $|D_i|$ of the non-zero differences are then placed in rank order beginning with rank 1; an average rank is assigned if two or more $|D_i|$ are equal. The test statistic is again given by the sum of ranks in Equation 6, where $r_i$ = rank of $|D_i|$ if $D_i$ is positive and $r_i = 0$ if $D_i$ is negative. (The summation in Equation 6 for the Wilcoxon signed rank test is over the number of non-zero values of $D_i$). The value of W is calculated to be 235.5, which is between the limits of 214 and 416 for accepting the hypothesis that the median value of $D_i$ is zero at the $\alpha = 0.1$ level of significance. (For a symmetric distribution, the mean is the same as the median and this hypothesis is then equivalent to the hypothesis that the total true mass of the previous inventory is equal to the total true mass of the current inventory.)

**Table I. Test Statistics and Critical Values for Rank Order Tests[a]**

| Tests | Factor | Value |
|---|---|---|
| Wilcoxon[b] | $w_\alpha$ | 1,235 |
| | W | 1,382 |
| | $W_\alpha$ | 1,540 |
| Mann-Whitney[c] | $u_\alpha$ | 532 |
| | U | 674 |
| | $U_\alpha$ | 837 |
| Van der Waerden[d] | $\lvert X_v \rvert$ | 0.48 |
| | $X_\alpha$ | 8.07 |

[a] $(w_\alpha\ W_\alpha)$, $(u_\alpha\ U_\alpha)$ and $X_\alpha$ are critical values at significance level $\alpha$=0.1

[b] Hypothesis $H_0$ is accepted, if $w_\alpha < W < W_\alpha$

[c] Hypothesis $H_0$ is accepted, if $u_\alpha < U < U_\alpha$

[d] Hypothesis $H_0$ is accepted, if $|X_v| < X_\alpha$

## 5. Determining the Mass of Nuclear Material

For the batch of fuel elements described in this paper, Table II presents the values of the quantity of fissile material Mf ($^{235}$U) that were calculated from the measurements of the mass of highly enriched uranium dioxide fuel pellets. The values calculated from the measurements of the previous and current inventories are close to each other.

The mass of the $^{235}$U isotope in fuel pellets of the batch of fuel elements was found from

$$Mf = \varepsilon_u\, \varepsilon_5 \sum_{i=i}^{N} Mu_i = \varepsilon_u\, \varepsilon_5\, Mu \qquad (8)$$

where

$\varepsilon_u$ = content of uranium in fuel pellets (mass percentage)

$\varepsilon_5$ = content of $^{235}$U isotope in uranium (mass percentage)

Mu = mass of fuel pellets in the batch of fuel elements.

Mf was calculated utilizing manufacturer-supplied information for $\varepsilon_u$, namely

$$\varepsilon_u = 0.8794 \qquad (9)$$

and mass-spectrometric data for $\varepsilon_5$. Table III presents values of the isotope content $\varepsilon_5$ obtained from measurements at RRC KI and from the manufacturer. The value of $\varepsilon_5$ is obtained from the mean value of $\gamma$-spectrometer measurements of the enrichment for a pellet selected from each of the thirty-seven fuel elements.

**Table II. Data on the Mass of Fuel and the Quantity of Fissile Material for the Batch Under Survey**

| | Factor | Value |
|---|---|---|
| Mass of fuel (Mu)[a] | $Mu_{BI}$ (g) | 30,553.08 |
| | $Mu_{EI}$ (g) | 30,554.33 |
| $\Delta Mu = Mu_{BI} - Mu_{EI}$ | | 1.25 |
| Mass of isotope $^{235}$U (Mf) | $Mf_{BI}$ (g) | 25,749.06 |
| | $Mf_{EI}$ (g) | 25,750.12 |

[a] The available scraps of fuel pellets, stored separately for each batch of fuel elements, were considered for determination of the total mass Mu.

## 6. Variance of the Mass of Fissile Material

From preliminary estimates[2], the variance $\sigma_{yi}$ for the present case takes on small values ($\sigma_{yi} \approx \sigma_{xi} / x_i << 1$). From Equation 8, it may be shown that the variance of the mass of nuclear material consists of several component variances, given approximately, as follows:

$$\sigma^2_{Mf} = (\varepsilon_5 Mu)^2 \sigma^2_u + (\varepsilon_u Mu)^2\, \sigma^2_{\varepsilon_5} + (\varepsilon_u\, \varepsilon_5)^2\, \sigma^2_{Mu} \qquad (10)$$

where

$\sigma^2{}_u$ = variance of uranium content in fuel pellets

$\sigma^2{}_{\varepsilon_5}$ = variance of $^{235}$U isotope content in uranium

$\sigma^2{}_{Mu}$ = variance of mass Mu of fuel pellets in fuel elements.

In relation (10), the first, second, and third terms represent the errors in the determination of uranium content, the errors in the measurement of the $^{235}$U isotope, and the errors in the measurement of mass of the fuel pellets, respectively. The contributions of each to the total variance $\sigma^2_{Mf}$ are presented in Table IV. The primary contribution to the variance $\sigma^2_{Mf}$ results from errors associated with inaccuracy in determining the uranium content of the uranium dioxide fuel and the isotopic content (specifically, the $^{235}$U enrichment) of the uranium in the fuel. The total standard deviation, namely, the square root of $\sigma^2_{Mf}$, is 23.67 g.

**Table III. $^{235}$U Enrichment Values**

| Source of Value | $\varepsilon_5$ (mass fraction) |
|---|---|
| Factory-manufacturer | 0.9588 |
| Mass-spectrometry[a] | 0.9593 |
| γ-spectrometry[b] | 0.9531 |

[a] Uncertainty in measurement is ± 0.0005

[b] With enrichment greater than 90 percent, uncertainty in measurement by γ-spectrometer is about 4 percent.

## 7. The Confidence Interval of the Mass of Fissile Material

If the mass of fissile material, Mf, is a random variable, then the quantiles $Mf_{0.05}$ and $Mf_{0.95}$ represent the lower and upper bounds, respectively, of Mf with probabilities of Mf in the 5 percent to 95 percent confidence interval. The interval between $Mf_{0.05}$ and $Mf_{0.95}$ that contains 90 percent of all possible values of Mf is the confidence interval $d_{0.9}$. From tabulated values for the familiar cumulative normal distribution, it may be seen that $d_{0.9} = 3.29\ \sigma_{Mf}$. It may be shown[7] that this result may be generalized to the broad class of symmetric distributions discussed earlier in this paper. For such distributions, to a very good approximation, the confidence interval is given by

$$d_{0.9}=(3.2\pm0.10)\sigma_x \qquad (11)$$

From the results of this PIT, values were computed for the mass of fissile material Mf ($^{235}$U), quantiles $Mf_{0.05}$ and $Mf_{0.95}$, and also the value of confidence interval $d_{0.9}$,; these values are presented in Table V. The confidence interval $d_{0.9}$ is 0.3 percent of the mass of fissile material Mf ($^{235}$U), contained in the fuel pellets of a given batch of fuel elements. Similar results were obtained for other batches of fuel elements in the same Material Balance Area.

## 8. Analysis of Confidence Errors

If the PIT uncovers a discrepancy, $\Delta Mf$, between the results of the previous and current inventories, then it is important to ascertain the effect of errors of measurements on the error in $\Delta Mf$ in order to ascertain whether $\Delta Mf$ is significant. The error in $\Delta Mf$ depends on whether the beginning inventory BI and the ending inventory EI are independent random variables. (EI and BI are the actual quantity of nuclear material on hand, determined as a result of previous PIT and current PIT, respectively.) For a static inventory, these quantities determine the value of the inventory difference ID:

$$ID=BI-EI. \qquad (12)$$

The value of inventory difference obtained in this case, 1.05g, is significantly less than the maximum ID for this category of nuclear materials (300 g for $^{235}$U) permitted in the Russian Federation[8]. Therefore, there is no regulatory significance to the difference.

If BI and EI are independent random variables, the variance $\sigma^2_{ID}$ may be expressed as:

$$\sigma^2_{ID} = \sigma^2_{BI} + \sigma^2_{EI} \qquad (13)$$

Furthermore, it was assumed that between the inventories the composition of fuel and isotope content of $^{235}$U at the facility did not change and that the weighing of the fuel elements was performed on the same balance. The values of masses of fuel obtained during inventory were close to each

**Table IV. Contribution of Individual Factors to the Variance of the Mass of Fissile Material**

| Type of Error[a] | Contribution to $\sigma^2_{Mf}$ | | Contribution to $\sigma^2_{Mf}/Mf^2$ |
|---|---|---|---|
| | $g^2$ | % of relative units | |
| Uranium[b] content | 183.80 | 32.80 | 277 x $10^{-07}$ |
| $^{235}$U content[c] | 376.64 | 67.20 | 5.68 x $10^{-07}$ |
| Measurement of mass of pellets[d] | 0.01 | 0.002 | 1.78 x $10^{-11}$ |
| Total result | 560.45 | 100.0 | 8.45 x $10^{-07}$ |

[a] For the estimate of the variances $\sigma^2_u$, $\sigma^2_{\varepsilon 5}$, $\sigma^2_{Mu}$, a uniform distribution was assumed.

[b] For the estimate of $\sigma^2_u$, factory-manufacturer data was used ($\sigma_u = 4.63\times10^{-4}$g).

[c] For the estimate of $\sigma^2_{\varepsilon 5}$, the results of mass-spectrometry were used ($\sigma_{\varepsilon 5} = 7.23\times10^{-4}$g).

[d] In the computation of $\sigma^2_{Mu} = 2N\ \sigma^2_{meas}$, it was supposed that the results of weighing of the tray and fuel pellets did not depend on one another.

The errors for individual measurements is $\sigma_{meas} = 0.015$g.

other ($Mu_{BI} \approx Mu_{EI}$), so that $\sigma^2_{BI}$ and $\sigma^2_{EI}$ may be considered equal to each other. Therefore,

$$\sigma^2_{ID} = 2\sigma^2_{Mf} \qquad (14)$$

When the results of the previous PIT have been documented in accordance with the principles of nuclear materials accounting in force in the Russian Federation, the variance $\sigma^2_{BI}$ is assumed to be zero. In this case, the estimate for $\sigma^2_{ID}$ is

$$\sigma^2_{ID} = \sigma^2_{Mf} \qquad (15)$$

It should be noted that assuming that the variance $\sigma^2{}_{BI}$ is zero is not in accord with U.S. or Western European practice and experience.

However, only the measurements of the mass of the pellets were performed separately in the two inventories, since the values of $\sigma^2$ for uranium content and enrichment are taken from the same factory-manufacturer and mass spectrometric data. Then, by analogy with relation (8), we have

$$\Delta Mf = \varepsilon_u \varepsilon_5 \, \Delta Mu \qquad (16)$$

from which the following estimate of total variance $\sigma^2_{\Delta Mf}$ for $\Delta Mf$ may be obtained:

$$\sigma^2_{\Delta Mf} = (\varepsilon_5 \Delta Mu)^2 \, \sigma^2_u + (\varepsilon_5 \Delta Mu)^2 \, \sigma^2_{R_5} + (\varepsilon_u \varepsilon_5) \, \sigma^2_{\Delta Mu} \qquad (17)$$

where

$\Delta Mu$ = the difference between the results of measurements of the mass of fuel in previous and current PIT (Table II),

$\Delta Mf$= the quantity of fissile material, contained in $\Delta Mu$,

$\sigma^2_{\Delta Mu} = 2\sigma^2_{Mu}$ = variance of $\Delta Mu$.

In this case the contribution of the first two terms is 0.04 percent relative units; that is, the value of variance is determined for the most part by the error in measurements of mass of fuel ($\sigma^2_{\Delta Mu}$).

Table VI presents values of the confidence limits $\pm\Delta_{0.9}$ for the three different estimates of variance from equations 14, 15, and 17. The lowest value of $\Delta_{0.9}$ (and of the variance — which in this case is $\sigma^2_{\Delta Mf}$) is obtained from Equation (17), the case where only the mass measurements are considered to be independent in the two inventories, and depends almost exclusively on the accuracy of the weighing. The largest estimate of variance, $2\sigma^2_{\Delta Mf}$, derives from the Equation 12, the equation of material balance via Equation 14 for a case where the enrichment and uranium content measurements as well as the mass measurements are considered to be independent in the two inventories.

This last result for estimate of variance, $2\sigma^2_{Mf}$, indicates that the PIT described in this paper could be improved as a safeguards system by including measurements of the enrichment and of the uranium content as separate, independent measurements in both the previous and current inventories. Weighing with a random sampling for one or more other attribute measurements—for example, enrichment or uranium content or both—for periodic PITs would be an improvement over measurement of mass but reliance on manufacturer's data for the other attributes.

**Table V.**
**Mass of Fissile Material and the Values Associated wtih the 5 percent to 95 percent Confidence Interval**

| $^{235}U$ | Value |
|---|---|
| Mf (g) | 25750.12 |
| $Mf_{0.05}$(g) | 25712.24 |
| $Mf_{0.95}$ (g) | 25787.99 |
| $d_{0.9}$(g) | 75.76 |

**Table VI. Confidence Limits $\Delta_{0.9}$ for ID**

| variance, $\sigma^2_x$ | $\Delta_{0.9}=1.6\sqrt{\sigma^2_x}$ |
|---|---|
| $\sigma^2_x = 2\sigma^2_{Mf}$ | 53.55 |
| $\sigma^2_x = \sigma^2_{Mf}$ | 37.87 |
| $\sigma^2_x = \sigma^2_{\Delta Mf}$[a] | 0.245 |

[a] $\Delta Mf = 1.05g, \; \sigma^2_{\Delta Mf} = 2.35x10^{-2}g^2$

## 9. Conclusions

As a result of the study conducted, basic questions of control and accounting of nuclear material at the Narciss facility have been resolved, assistance has been provided in the implementation of the approach developed when conducting inventories at other facilities of the Institute, and the development of corresponding procedures has been implemented which may be used in the future activities of the oversight agency (GOSATOMNADZOR RF).

From the results of the inventory performed at the Narciss facility, it was shown that the actual quantity of highly-enriched uranium on hand (~96 percent on $^{235}U$) corresponds to the data registered for the MBA of the facility. According to U.S. DOE criteria for graded safeguards, this material is Category 1 of attractiveness level C. The observable deviation between recorded and actual quantities of nuclear material is well within the range of acceptable values.

During the survey, special attention was devoted to the development of an effective system of quality control of measurements, covering the various aspects of this complex and important task. In particular, the use of computerized statistical quality control charts made it possible to operationally implement control over the working of the measurement system and also to eliminate subjective operator errors when weighing. The use of rank order tests has made it possible to show that for each batch of fuel elements, the observed difference between the results of the weighing obtained for the current and for previous inventories is statistically insignificant. In accordance with the algorithm developed, a computer code CONTROL was written in Microsoft FORTRAN v. 5.10 language.

The method of quantile estimates makes it possible to determine the boundaries of confidence interval for a large class of high-entropic symmetric distributions from uniform to normal for a random variable, in the present case Mf, the mass of fissile material. Utilizing this methodology, the quantiles $Mf_{0.05}$ and $Mf_{0.95}$, the lower and upper bounds, respectively, of Mf in the 5 percent to 95 percent confidence interval, were determined without specific knowledge of the probability distribution function of Mf. Uncertainties in determining the composition of uranium dioxide and in measuring the isotope content of $^{235}U$ are the largest contributor to the uncertainty in the quantity of fissile material that is contained in the Narciss MBA. However, uncertainties in mass measurement are the largest contributor to errors in the inventory difference because values for the enrichment and composition were not re-measured. Weighing with a random sampling for one or more other attribute measurements — for example, enrichment or uranium content or both — for periodic PITs would be an improvement over the weighing and reliance on manufacturer's data for the other attributes.

The approach described in this paper can be used when performing physical inventory of nuclear materials at similar types of facilities.

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# Deliberations on Safeguards Measurement Uncertainty

■

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■

## Introduction

For the third consecutive year, an all-day session of the Institute of Nuclear Materials Management's Annual Meeting was devoted to discussions of a topic pertinent to safeguards measurements or safeguards reference material preparation and use. A different topic is addressed each year. In 1998, deliberations were captured in The Role of Analytical Laboratories in Safeguarding Nuclear Materials.[1] In 1999, a stimulating day-long session was held on Internationally Certified and SI Traceable: The Ultimate Aim for Reference Materials.[2]

By the end of the 40th Annual Meeting, a topic was chosen for the all-day session of the 41st Annual INMM Meeting. A revision of that topic is the focus of this paper. Upon later review, it was agreed that the topic selected during the 40th Annual Meeting should be revised and shortened to Application of Uncertainty Principles in the Field of Safeguards. This was further shortened to Safeguards Measurement Uncertainty after many discussions among representatives of several nuclear reference materials safeguards laboratories around the world. The shortening of the topic was followed by the development of subtopics. Potential speakers were matched with the subtopics, and the lead laboratory, the New Brunswick Laboratory, extended invitations. Positive responses poured in.

The session on Safeguards Measurement Uncertainty was held July 19 at the 41st INMM Annual Meeting in New Orleans, Louisiana, U.S.A. As in the previous years, Margaret E.M. Tolbert, director of NBL, in Argonne, Illinois, organized the session and served as chair. The morning session was highlighted with papers by representatives of NBL, the EC-Institute for Transuranium Elements, in Germany, the EC-Institute for Reference Materials and Measurements, in Belgium, the All-Russian Institute of Inorganic Materials of the Russian Federation, and COGEMA (La Hague) of France, as well as a paper by Paul De Bièvre of IRMM.

The afternoon session began with the presentation of two invited papers from the International Atomic Energy Agency. After the completion of the IAEA presentations, the roundtable discussion began with the objective of highlighting the close ties between traceability and uncertainty in nuclear material measurements. Meeting participants also discussed strategies for the application of uncertainty principles to safeguards measurements.

## Discussion

Moderators David Donohue of the IAEA and Paul De Bièvre of IRMM, set the tone for the deliberations on safeguards measurement uncertainty with their opening statements which stimulated a robust discussion. As in previous all-day sessions[3,4], salient points identified during the deliberations were captured for sharing with the global nuclear community. The essences of those deliberations are summarized here:

Participants discussed the importance of correlations between components of uncertainty (i.e., covariances). The paper by Helmut Aigner et al. raised the point that, in an isotope dilution mass spectrometric measurement, there are several components which are correlated. Isotope ratios are commonly used in the IDMS calculation to relate the amount of sample and spike isotopes to the total mass of the element (U or Pu) in the sample. De Bièvre pointed out that by using only ratios in the calculation it is possible to reduce the dependence on covariances. This was generally agreed in the case where the goal is to calculate amount ratios (in atoms or moles) but negligible covariances may still remain in the case where the total mass of an element is calculated. Sergio Guardini of JRC Ispra maintained that correlations are an important part of destructive analysis as well as nondestructive analysis measurement uncertainties. He suggested that a full uncertainty budget should be calculated in each case and a judgment made about the magnitude and importance of correlations.

Another point of discussion involved the content of certificates which accompany reference materials. A plea was made for the certificates to follow the ISO/BIPM guidelines for uncertainty evaluation and that there should be a complete uncertainty budget available for the certified value(s) of each reference material issued—most likely in a separate report available to the RM users rather than in the certificate itself. Roger Wellum of IRMM suggested that certificates of older reference materials, which do not follow these guidelines, can still be interpreted in a consistent way by, for instance, assuming that stated confidence intervals can be converted to standard uncertainty using a coverage factor of two.

Donohue[5] focused on the International Target Values paper[6] in one of his presentations given before the discussion period. As the discussion unfolded with Donohue as one of the moderators, several discussants chose to revisit that topic. Wellum and De Bièvre suggested that the year 2000 version of International Target Values as presented by the IAEA were not completely compatible with the ISO Guide to Estimation of Uncertainty of Measurements. It was suggested that the ITV paper[6] be rewritten to be fully GUM-compliant, but it was recognized that the present system of referring to random (within inspection) and systematic (between inspection) components was a holdover from previous ITV and ESARDA target value papers. De Bièvre estimated that it would take ten years for the measurement community to fully adopt the GUM model. Guardini pointed out that Type A and Type B are about the evaluation process of uncertainties whereas random and systematic are characteristics of errors. The former is how uncertainty is determined; the latter is what is the characteristics of the errors—random/systematic. All of this terminology is in the latest revision of the ISO guidelines.

The majority opinion of the meeting was that the old concepts of random and systematic errors were still valid and allowed under ISO guidelines. However, the modern trend is to speak of Type A and Type B uncertainty evaluation models, with Type A being those evaluation processes, which can be estimated by repeated observations (i.e., the repeatability of measurements) with the Type B evaluation processes covering everything else (requiring the judgment of the analyst in some cases). The benefit of changing to this terminology and the uncertainty budget approach is to increase transparency and to force analysts to confront all the possible sources of uncertainty, with the goal that total uncertainty statements will become more accurate. De Bièvre showed familiar data from inter-laboratory comparisons in which it is obvious that many laboratories seriously understate their total uncertainty.

A question arose concerning the proper way to incorporate the uncertainty of reference materials into a field laboratory's total uncertainty statement. Three possible models were presented—scalar addition, vector addition and use of a uniform distribution (top hat). It was generally agreed that the uniform distribution was not consistent with statistical considerations (central value theorem). The participants endorsed the vector addition model as being the most realistic and consistent with GUM.

De Bièvre stated that field laboratories could undertake to establish a full traceability chain connecting their measurement system with primary SI units. However, this would represent a significant amount of extra work and could be avoided by using an isotope-amount reference material (spike) provided by a reference material producer (IRMM or NBL, for instance) with its own traceability chain. The group discussed the danger of a circular argument as regards traceability, which can occur when both the reference material producer and the field laboratory use the same material (such as NBL CRM-U500) for calibrating their mass spectrometers. Michael Soriano of NBL referred to the use of a comparator, such as NBL CRM-U500, in the certification of new reference materials. Fortunately, there are several high-quality primary isotope ratio standards available for mass spectrometer calibration in addition to those produced by NBL. Steven Goldberg of NBL noted that NBL CRM-U500 was certified by comparison with primary (synthetic) calibration solutions. The uncertainties of this CRM and its traceability can be properly passed along to the quantitative statements that represent a calibration of a mass spectrometer. Further analyses or certification work using the instrument should incorporate these uncertainties. The issue may be one of confidence if only one CRM is used as a direct comparator.

The need for proper experimental design was identified both in the certification of reference materials and in the validation and quality control measurements performed by field laboratories. Soriano underscored the importance of this in the certification of reference materials. He stated that a statistician is always involved from the very beginning of the project planning process for the certification of all new reference materials at NBL. Quality control data from field laboratories can be used to revalidate a routine method and to revise the uncertainty statement of the method. It was, however, recognized that QC data might not be ideal for this purpose because of unbalanced data sets and the inability to separate out uncertainty components (i.e., the effect of different preparations of QC materials and changes over time of the operator, instrument). In this case, proper experimental design in the use of QC materials may solve some of the more obvious problems.

At the end of the session there was a discussion of possible topics for next year's meeting. The following topics were suggested:

1. Accurate estimation of uncertainty components related to bulk material measurements (i.e., tank volume/mass or mass of powders, pellets) as well as sampling uncertainty. Considering that the total uncertainty in closing a material balance involves a combination of bulk, sampling, and laboratory measurement uncertainties, it was considered important to examine these three sources to decide what the limitations are and to allocate resources to achieve the desired improvements.
2. Intercomparison of reference materials. This topic is related to the goal of providing RMs with internationally accepted reference values. Reference material producers might consider joint certification of new RMs for enhanced robustness and transparency, especially for use in international safeguards.
3. The role of internal and external quality control in safeguards measurements. This topic was suggested to show the relative importance of a laboratory's internal QC program compared to interlaboratory (external) QC programs such as REIMEP, EQRAIN, or SMEP.
4. The role of bulk, sampling, and laboratory measurement uncertainties in characterizing nuclear waste and waste disposal sites. This topic was seen as a subset of topic one, but with a clear emphasis on waste handling and nuclear material management issues related to waste.

The consensus opinion of roundtable discussants focused on topic three above, with the suggestion that topic one would probably be of interest to the INMM community as a whole. As is the tradition, representatives of the safeguards laboratories continued their discussions even after the meeting ended. This sometimes results in the selection of a topic that is related to one or more of those identified at the meeting. On other occasions, the final topic selection is totally different from those discussed at the meeting since deliberations continue throughout the year. Recently, the four topics identified at the meeting were discussed in more depth in preparation for the 42nd INMM Annual Meeting. Having led the organization and implementation of the all-day session for the past three years, NBL invited ITU to assume those responsibilities. ITU accepted the challenge and has moved ahead with meeting preparations. With ITU as the host laboratory, discussions on the topic for the 42nd Annual Meeting of INMM have continued. The overall topic is Facing Recent and Future Analytical Challenges and the tentative subtopics are Measuring Alternative Nuclear Materials, Measurements for Verification of a Fissile Material Cut-off Treaty, and Wide-Area Environmental Monitoring. If no additional changes are made, speakers will be invited by ITU to speak on these subtopics at the 42nd Annual Meeting.

## Closing Statements

Additional details on each paper presented during the all-day session on Safeguards Measurement Uncertainty are available in the form of abstracts in the final program[7,8] of the 41st INMM Annual Meeting, The papers are available in the Proceedings of the 41st Annual Meeting produced by the INMM on CD-ROM.

Activities such as the roundtable discussion and panel presentations described here facilitate continued interactions of scientists and foster collaborations and open dialogue on safeguards topics of mutual interest. Another potential major impact is the enabling of the early identification of solutions to material measurement problems in the nuclear community. Additionally, activities of this type could lead to the production of analytical data that is globally comparable and to the reduction of uncertainties in nuclear material measurements.

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*Margaret E.M. Tolbert is the director of the New Brunswick Laboratory/U.S. Department of Energy. She earned her Ph.D. in biochemistry from Brown University, her M.S. degree in analytical chemistry from Wayne State University, and her B.S. degree in chemistry from Tuskegee University. She has held R&D management and faculty positions in academia, the private sector, and the federal government. She is a member of the AAAS, ACS, Chicago Chemistry Club, INMM, Sigma Xi, and the New York Academy of Sciences. She has completed several tours of duty in foreign countries. Also, she has published articles in scientific journals and has served as an invited speaker for various organizations and institutions. Tolbert has served as a speaker, as well as lead organizer and implementer of the all-day sessions of the annual INMM meetings since 1998, bringing together scientists from several countries to discuss issues and concerns of interest to the nuclear community.*

*Paul De Bièvre is editor-in-chief of Accreditation and Quality Assurance (Springer)*—Journal for Quality, Comparability and Reliability in Chemical Measurement *and advisor on metrology in chemistry to the director of the EC-Institute for Reference Materials and Measurements in Geel, Belgium. He has served (and in some instances continues to serve) as a university lecturer and professor, group leader in mass spectrometry, IRMM division head, and advisor on reference materials. He is founder of EURACHEM and co-founder of the Co-operation on International Traceability in Analytical Chemistry. Additionally, he continues to hold leadership positions on a number of prestigious committees (e.g., president, Belgian National Committee on Pure and Applied Chemistry of the Belgian Academies; chairman, IUPAC Subcommittee on the Assessment of the Isotopic Composition of the Elements; member of IUPAC International Committee on Atomic Weights and Isotope Abundances; and member, Comité Consultatif pour la Quantité de Matière of the Comité International des Poids et Measures).*

# In Memoriam
# Roy Cardwell

The Institute of Nuclear Materials Management lost a valued member and leader with the death of Roy Cardwell September 7, 2000.

At the time of his death, Mr. Cardwell was serving as the chair of the Constitution and Bylaws Committee of the INMM. Mr. Cardwell joined the INMM in 1960 and served in a variety of roles. His contributions to the Institute and its work spanned four decades.

In 1952, Mr. Cardwell joined the Oak Ridge National Laboratory as a nuclear materials controller and systems analyst in the original pilot plant that both developed and manufactured dispersion-type uranium-aluminum fuel elements for the Materials Testing Reactor in Idaho.

Throughout his years with the Institute, Mr. Cardwell served as chairman in 1977-78; chairman of the first exhibits program in 1969; program chair in 1972-74; vice chair and chair of annual meetings in 1975 and 1976; and chair of the Constitution and Bylaws Committee until his death in 2000.

In 1965, Mr. Cardwell was a member of the U.S. delegation to the First International Symposium on Nuclear Materials Management in Vienna, Austria, where he presented a paper. This noted group consisted of sixteen invited technical and scientific personnel selected by the U.S. Atomic Energy Commission from several universities and nuclear facilities. This symposium was instrumental in the development of the IAEA safeguards program.

Mr. Cardwell authored a paper, Control of Nuclear Materials in Research—A Special Management Problem, that appeared in the first issue of the *Journal of Nuclear Materials Management* in 1971.

As chairman of the INMM, Mr. Cardwell presented the charter to the first overseas chapter of the INMM, the Japan Chapter, in 1978. He later visited the chapter on its tenth and twentieth anniversaries.

In 1980, Mr. Cardwell transferred to the Martin Marietta Energy System's Division of Operations Analysis and Planning. He was a project engineer and manager for safeguards research there.

In 1987, Mr. Cardwell became a Fellow of the Institute and in 1989, he received the INMM's Meritorious Service Award.

Mr. Cardwell was working as a consultant at the time of his death.

## Author Submission Guidelines

The *Journal of Nuclear Materials Management* is the official journal of the Institute of Nuclear Materials Management. It is a peer-reviewed, multidisciplinary journal that publishes articles on new developments, innovations, and trends in safeguards and management of nuclear materials. Specific areas of interest include physical protection, material control and accounting, waste management, transportation, nuclear nonproliferation/
international safeguards, and arms control and verification.
*JNMM* also publishes book reviews, letters to the editor, and editorials.

**Submission of Manuscripts:** *JNMM* reviews papers for publication with the understanding that the work was not previously published and is not being reviewed for publication elsewhere. Papers may be of any length.

Papers should be submitted in *triplicate*, **including a copy on computer diskette**. Files should be sent as Word or ASCII text files only. Graphic elements must be sent in TIFF format in separate electronic files. Submissions should be directed to:

Dennis Mangan
Technical Editor
*Journal of Nuclear Materials Management*
60 Revere Drive, Suite 500
Northbrook, IL 60062 USA

Papers are acknowledged upon receipt and are submitted promptly for review and evaluation. Generally, the author(s) is notified within 60 days of submission of the original paper whether the paper is accepted, rejected, or subject to revision.

**Format:** All papers must include:

- Author(s)' complete name, telephone and fax numbers and E-mail address
- Name and address of the organization where the work was performed
- Abstract
- Camera-ready tables, figures, and photographs in TIFF format only
- Numbered references in the following format:
  1. F.T. Jones and L.K. Chang. "Article Title," *Journal* 47(No. 2):112–118 (1980).
  2. F.T. Jones, *Title of Book*, New York: McMillan Publishing, 1976, pp. 112–118.
- Author(s) biography

**Peer Review:** Each paper is reviewed by two or more associate editors. Papers are evaluated according to their relevance and significance to nuclear materials safeguards, degree to which they advance knowledge, quality of presentation, soundness of methodology, and appropriateness of conclusions.

**Author Review:** Accepted manuscripts become the permanent property of INMM and may not be published elsewhere without permission from the managing editor. Authors are responsible for all statements made in their work.

**Reprints:** Reprints may be ordered at the request and expense of the author. Order forms are available from the Institute's office, 847/480-9573.

## PerkinElmer Awarded Japan Contract

PerkinElmer Instruments, with their joint partner in Japan, SEGG, has been awarded a contract to supply the K-edge densitometer measuring instrument for the pilot phase of the nuclear fuel recycling project at Japanese Nuclear Fuels Ltd. in Tokai, Japan.

This unit, to be supplied to the prime contractor, Mitsubishi Heavy Industries, will be built and tested by PerkinElmer Instruments in conjunction with the staff of the Los Alamos National Laboratory in New Mexico.

The unit uses technology developed at LANL and licensed exclusively to PerkinElmer.

The K-edge densitometer is an instrument that enables precise measurements of nuclides of plutonium and uranium to be made on the dissolver solution at the input to a nuclear fuel reprocessing facility. Such measurements are necessary to support the nuclear safeguards program operated in Japan.

PerkinElmer Instruments supplies solutions to support safeguards and nuclear fuel processing programs, and is a licensee of several technologies and products developed by leading national laboratories in the United States.

## DOE Releases Strategy for Nuclear Materials Management

In July, the U.S. Department of Energy released a comprehensive study that examined opportunities for greater integration in the management of nuclear materials across various department programs. The report also provides the first consolidated account to Congress and the public of the DOE's unclassified inventory of nuclear materials and offers a description of how and where these materials are managed.

DOE manages its nuclear materials under eight programs that have offices in thirty-six locations. This legacy follows, in large part, from the Cold War era, during which the department and its predecessor agencies operated facilities to conduct research on, design, test, and manufacture nuclear weapons; conduct basic science, nuclear engineering research and development, and special isotope programs; and support naval nuclear propulsion. Following the Cold War, new missions and programs were developed to support nonproliferation agreements and research other uses for our nuclear materials leaving behind the current challenge of integrating and managing large amounts of nuclear materials in various forms.

Some of the plan's action items include:

- Revising the department's strategic plan to ensure nuclear materials stewardship is integrated into the department's major missions.
- Performing a qualitative and quantitative projection of the long-term capabilities needed to accomplish the department's nuclear materials management missions.
- Establishing appropriate mechanisms and opportunities for involving the public on issues that could affect them.
- Making decisions regarding excess legacy nuclear materials and whether they should be disposed of or stored for other uses. A copy of the report is available on at http://www.energy.gov, the DOE website.

## Bicron Renamed Saint-Gobain

Bicron, a division of Saint-Gobain Ceramics and Plastics, Inc., is now called Saint-Gobain Crystals and Detectors. For more than thirty years, Bicron has been involved in the design, development, and manufacture of nuclear radiation detectors for use in medical imaging, geophysical exploration, physics, industrial, and safety monitoring applications.

## Demonstration Plant to be Built in Ohio

The U.S. Department of Energy in October 2000 announced plans to build an advanced technology demonstration plant for uranium enrichment in Piketon, Ohio. In addition, the existing Portsmouth Gaseous Diffusion Plant—one of only two uranium enrichment plants in the country—will be placed in cold standby for five years for possible restart in the event of a significant disruption in the nation's supply of enriched uranium.

The initiative follows an announcement in July by USEC, the private operator of the plant, to end enrichment operations at Piketon by June 2001. That decision would have resulted in the layoff of 1,200 workers over the next several years. Most of those workers will now be employed to support the DOE's standby and centrifuge operations, as well as in environmental cleanup activities at the Piketon Site.

The department's plan calls for placing and maintaining a portion of the Piketon plant in a cold standby condition for five years for possible restart. Under the plan, many of the operations, maintenance, utilities, and support personnel would be retained to maintain the facility in standby. This status is maintained until an advanced enrichment technology is successfully demonstrated, projected to be completed in five years.

## DOE Issues RFP to Build DUF6 Conversion Plants

The U.S. Department of Energy issued a request for proposals for the design, construction, and operation of new facilities at uranium enrichment plant sites in Ohio and Kentucky. Once built, these facilities will convert the federal government's large inventory of depleted uranium hexafluoride (DUF6) to a more stable form and prepare the material for disposal or potential reuse.

The DOE manages approximately 700,000 metric tons of DUF6 in about 57,000 cylinders stored at its Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee, sites. This material is a byproduct from more than forty years of uranium-enrichment operations in support of both national security and commercial customers. Depleted uranium hexafluoride is a granular solid at normal temperatures which can release hazardous chemicals under certain conditions. The inventory is maintained in large ten- and fourteen-ton steel cylinders that must be regularly inspected and protected from corrosion.

## Domenici Calls for Balanced Discussion on Nuclear Technologies

In accepting the prestigious Henry DeWolf Smyth Statesman Award for his work in Congress on nuclear issues, U.S. Senator Pete Domenici of New Mexico renewed his call for a balanced national discussion on the risks and benefits posed by nuclear technologies for the future of the United States and global security.

The award was presented Wednesday, November 15, 2000, during the 2000 International Meeting of the American Nuclear Society/European •Nuclear Society in cooperation with the Nuclear Energy Institute. Domenici is the twenty-fourth recipient of the award, which is bestowed to a single individual each year to recognize outstanding statesmanlike contributions to the many aspects of nuclear energy activities. In acceptance remarks, Domenici cited achievements since his October 1997 speech to the inaugural symposium of Harvard University's new Belfer Center for Science and International Affairs, in which he called for a national dialogue on nuclear issues, and aired concerns about the United States' nuclear policies in relation to domestic energy requirements, and national and global security.

"We've made progress since the Harvard speech, but we remain a long way from realizing the full benefits of harnessing the nucleus. If Dr. Smyth were with us today, he would appreciate the efforts that all of you have made to realize his visions for using nuclear energy to improve our lives. But he also would encourage all of us to continue our efforts," Domenici said.

"So much more attention will be required if we are to have a well-rounded, long-term American policy that incorporates nuclear technologies. Related to this is our participation in credible non-proliferation programs with the nations of the former Soviet Union," he said.

## DOE Announces Alternative for Nuclear Infrastructure

The U.S. Department of Energy announced its preferred alternative for the Final Nuclear Infrastructure Programmatic Environmental Impact Statement which was to be issued to the public in mid-December 2000. The NI-PEIS was developed to help the department prepare for future missions, including nuclear technology research and development, medical isotope production, and production of Pu-238 to support future U.S. space exploration. A record of the decision will be issued in January 2001.

The department's preferred alternative has three major components:

- The DOE will use its existing facilities to the extent possible and consider opportunities to enhance its current infrastructure to maximize the agency's ability to address future mission needs.
- The DOE will develop a conceptual design and a research program for an advanced accelerator applications facility to perform future research and testing, for which Congress has provided funding in fiscal year 2001.
- The preferred alternative anticipates permanent deactivation of the Fast Flux Test Facility at the Hanford Site near Richland, Washington. Commitments from the private and public sectors were not sufficient to justify restarting FFTF or building new facilities at this time.

The preferred alternative anticipates resumption of domestic production of Pu-238 using the Advanced Test Reactor in Idaho and the High Flux Isotope Reactor in Tennessee. The preferred alternative includes processing of the Pu-238 targets at Oak Ridge National Laboratory, in Oak Ridge, Tennessee.

# Letter to the Editor

In the Winter 2000 edition of your journal, it is mentioned in the article titled An Update of IAEA Analytical Capabilities for Safeguards Goals, Results, and Challenges, by S. Deron, D. Donahue, E. Kuhn, K. Sirisena, and A. Tsarenko, that:

> *"Discrepancies however were found with the IRMM 290 and IRNM 047a isotopic standards of plutonium. These are being discussed with IRMM." (pp. 31-32).*

A reference materials laboratory such as the Institute for Reference Materials and Measurements is dependent on its reputation and the remark in the above-quoted article leaves a distinct impression that certain of our reference materials are not of a satisfactory quality. For this reason, I would like to respond to the quoted statement.

IRMM 047a is not in the IRMM catalog; it was made in a small batch (ten in total) and was never put through the rigorous certification procedure used for cataloged materials. We have already informed our colleagues at SAL, IAEA that we do not support the value associated with this material and that they should not include it in comparisons with other well established reference materials. Perhaps I can take the opportunity to reiterate this here and request that any other laboratories using the material not put a high credence on the values. We have every intention of replacing this IRM with alternatives, but sources of the necessary 244-Pu are scarce at present.

IRMM 290 is a completely different case. Three series of a mixture of 239-Pu and 242-Pu enriched plutonium oxides were made by a painstaking process of identically purifying and calcining the material before mixing as oxides and dissolved together in nitric acid. The result was these series with ratios of 239/242 of 0.1, 0.23, 0.47, 1.0, 2.3, 4.65, 10.0. The extreme care taken and the ability to refer to the ratios directly to the weights of the oxides allowed a standard uncertainty of 0.01 percent (k=2) to be given to the certified ratio values.

IRMM 290 is regarded here as an excellent isotopic reference material and not without good grounds. For this reason we are sensitive to implications that place the certified values in doubt. Regarding the procedure carried out at SAL comparing a complete palette of PU isotopic reference materials we have some problems. Specifically,

1. The published data shown to us do not show a discrepancy outside the uncertainty limits. Interpretations of differences within uncertainty limits are, strictly speaking, not differences at all!
2. We have not seen a full uncertainty budget for these measurements. In particular, we doubt whether an uncertainty contribution for the mass-fractionation factor in their method (multi-collected/total evaporation) has been estimated or indeed included in their results.
3. We use the 290 series in routine work at IRMM to determine the mass-fractionation of the measurements. Over recent years we have collected a large number of measurements from almost all members of at least two IRMM 290 series (a much larger number than was measured at SAL). We have not found any indication of a difference between the various members reflected in the calculated mass-fractionation factor, arguably the most senstive method of detecting this.
4. The whole argument applied by the IAEA in their work in comparison of IRMs lies on a shaky basis in our opinion—basically, a machine calibrated by measuring IRMs. To use these results to judge other IRMs contains a certain circularity of argument which should be treated at most only as an indication.

To conclude, we believe that the IRMM 290 isotopic reference material is an excellent certified reference material. It has a certification with a very low expanded uncertainty and can be used to yield results traceable to SI if applied correctly.

We are strongly of the opinion that isotopic reference materials such as IRMM 290 are needed more than ever in the field of nuclear materials accountancy and safeguards. We hope that this letter can help the application of such materials in routine laboratory measurements.

*Roger Wellum*
*IRMM Safeguards Coordinator*
*Institute for Reference Materials*
*Geel, Belgium*

# Calendar

*January 10-12*
**Spent Fuel Management Seminar XVIII,** Willard Inter-Continental Hotel, Washington, D.C. U.S.A. Sponsor: Institute of Nuclear Materials Management. Contact: INMM; phone, 847/480-9573; Website, http://www.inmm.org.

*March 28*
**Seismic Probabilistic Safety Assessment Seminar,** Risley, Warrington U.K. Sponsored by BNES/SECED. Contact: Andrew Tillbrook, 1 Great George St., London, SW1P 3AA; phone, 44 (0) 20 7665 2241; fax, 44 (0) 20 7799 1325; E-mail, andrew.tillbrook@ice.org.uk.

*May 14-16*
**Radiation Dose Rate Management in the Nuclear Industry International Conference,** Windermere, Cumbria, U.K. Organized by British Nuclear Energy Society. Contact: Sue Frye, Conferences Services, British Nuclear Energy Society, 1 Great George St., London SW1P 3AA; phone, 44 (0) 20 7665 2315; fax, 44 (0) 20 7233 1473; E-mail, sue.frye@ice.org.uk.

*May 15-17*
**Annual Meeting on Nuclear Technology 2001,** Kulturpalast, Dresden, Germany. Sponsors: German Nuclear Society and German Atomic Forum. Contact: Congress Office, INFORUM GmbH, Tulpenfeld 19, D53113 Bonn, Germany; phone, 49 (0)228-507 223; fax, 49 (0) 228-507 262; E-mail, tagungen @inforum-GmbH.de.

*May 29-31*
**2001 Power-Gen Europe,** Brussels Exhibition Centre, Brussels, Belgium. Contact: Power-Gen Europe Pennwell, Penwell House, Horseshoe Hill, Upshire, Essex EN9 3SR, UK; phone, 44 (0)1992-656 631; fax, 44 (0) 1992-656 704; E-mail, attendingpge@pennwell.com.

*June 10-14*
**ASTM 13th International Symposium on Zirconium in the Nuclear Industry,** Annecy, France. Sponsor: ASTM Committee B-10 on Reactive and Refractory Metals and Alloys. Contact: Gerry Moan, AECL, 2251 Speakman Drive, Mississauga, Ontario, Canada L5K 1B2; 905/823-9060, Ext. 3232; E-mail, moang@aecl.ca.

*June 25-28*
**National Space & Missile Materials Symposium,** Monterey, California. Sponsor: Air Force Research Laboratory. Contact: Pat Sisson; phone, 973/254-7950; E-mail, psisson@anteon.com; Website, http://www.usasymposium.com.

*July 15-19*
**42nd INMM Annual Meeting,** Renaissance Esmeralda Resort, Indian Wells, California. Sponsor: Institute of Nuclear Materials Management. Contact: INMM; phone, 847/480-9573; fax, 847/480-9282; E-mail, inmm@inmm.org; Website, http://www.inmm.org.

*September 3-7*
**PATRAM 2001,** Chicago, Ill., U.S.A. Sponsors: U.S. Department of Energy, in cooperation with the International Atomic Energy Agency. Hosted by the Institute for Nuclear Materials Management. Chicago Hilton and Towers. Contact: INMM, 847/480-6342; Website, http://www.patram.org.

*September 9-13*
**International Meeting on the Back End of the Fuel Cycle: From Research to Solutions (GLOBAL 2001),** Paris, France. Sponsor: American Nuclear Society. Contact: American Nuclear Society Meetings Department, 555 North Kensington Avenue, LaGrange Park, IL 60526, U.S.A.; 708/352-6611; fax, 708/352-6464; E-mail, meetings@ans.org; Website, http://www.ans.org/meetings.

*September 17-21*
**45th General Conference of the International Atomic Energy Agency,** Vienna, Austria. Sponsor: International Atomic Energy Agency. Contact: Conference Service Section, IAEA, P. O. Box 100, A-1400 Vienna, Austria; 43 1 2600 21310; fax, 43 1 26007; E-mail, Official.Mail@iaea.org; Website, http://www.iaea.org/worldatom/.

*October 17-18*
**Nuclear Decommissioning (DECOM 2001) International Conference,** London, England. Organized by British Nuclear Energy Society/ImechE. Contact: Maureen Carter, conference office, Institution of Mechanical Engineers, 1 Birdcage Walk, London, SW1P 3JJ; phone, 44 (0) 20 7222 7899; fax, 44 (0) 20 7222 4557; E-mail, m_carter@imeche.org.uk; Website, http://www.imeche.org.uk.

*December 5-6*
**6th BNES/BNIF Nuclear Congress Conference and Exhibition,** London, England. Organized by British Nuclear Energy Society/BNIF. Contact: Andrew Tillbrook, BNES, 1 Great George St., London, SW1P 3AA; phone, 44 (0) 20 7665 2241; fax, 44 (0) 20 7799 1325; E-mail, andrew.tillbrook@ice.org.uk.

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