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Looking to the Future of *JNMM*

By Cathy D. Key
INMM President

This issue of the *Journal of Nuclear Materials Management* will be coming out as we are experiencing the Institute's 46th Annual Meeting, being held July 10-14, 2005, at the JW Marriott Desert Ridge Resort in Phoenix, Arizona, USA. I hope that you are reading this as you attend our continually successful meeting. If you are *not* reading this while you are attending the INMM Annual Meeting, we hope that you will be making plans to attend the 47th INMM Annual meeting in July 2006, which will be held in my home state of Tennessee. Specifically the meeting will be held in the city of Nashville, Tennessee.

The Institute of Nuclear Materials Management is moving toward some exciting and positives moves in relation to our *Journal.* The Executive Committee has been discussing its desire to place old editions of the *Journal* and place them on the INMM Web site (www.inmm.org) as reference documents. There has been an enormous number of technical papers published in the many years of quarterly journals. This is an obvious wealth of knowledge, experience, and proven functionalities that we should all be able to reference for the work that we do in our industry.

Hopefully this will be accomplished within the upcoming year. Also, we will be exploring the pros and cons of placing all new issues of the *Journal* on the INMM Web site as well. Now don't worry, we are not anticipating immediately topping the printing of the *Journal* and mailing it out, as is our standard practice, as there are issues with placing the *Journal* on the website. But we will be exploring that very end of having the *Journal* mainly online with a specified number of copies of each issue still printed to continue to mail out to libraries, universities, and other institutional subscribers. Those organizations that will have a need to have hard copies on their shelves for reference will continue to receive them. Once again, this will be out in the future, and we would appreciate your thoughts on this..

I believe this could be a very positive move for our professional organization. Everyone all over the world has the wonderful capability of computers and Internet. Within a short period, all of our members will have the "library" of the *Journal of Nuclear Materials Management* at the touch of their fingers. I think that we will all look at this as a positive move. As this project progresses, we will keep our members informed of its status.

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

Paradigm Shifts

By Dennis Mangan
Technical Editor

Two "paradigm shifts" entered *my mind* (may have been already there in your mind) recently that I would like to elicit your thoughts and comments. The first occurred when I attended the INMM Workshop in April 2005. The *INMM Safeguards and Security System Effectiveness Workshop,* sponsored by the Material Control and Accountancy (MC&A) Technical Division the Physical Protection (PP) Technical Division, and the Southeast Chapter, focused on addressing a methodology for evaluating effectiveness of material control and accountancy systems (MC&A) against the insider threat. The conversation was definitely interesting from various points-of-view. My background is in physical protection and containment and surveillance in international safeguards as practice by the IAEA, and monitoring systems for arms control treaties—my familiarity with MC&A is not too great. In fact, I honestly thought the MC&A focus was on material measurements and relevant accountancy techniques. I didn't pay much attention to the "C" in MC&A until my participation in this workshop.

My paradigm shift was, for effectiveness evaluations, to separate the evaluations of MC and the MA in MC&A. The MC part in protecting against the insider, fundamentally uses PP technology, which can, I believe, be evaluated for effectiveness using existing PP evaluation methodologies, perhaps with some modifications. The MA effectiveness, I believe, can be accomplished with existing accountancy-effective statistical-types of techniques. When one considers the effectiveness of such efforts as the U.S. Department of Energy's Materials Protection, Control and Accountancy (MPC&A) applied at various facilities in the Russian Federation, for example, separating the MP, MC, And MA individually to assess the effectiveness of each, and then combining the three to achieve an overall effectiveness of MPC&A is intriguing to me.

The second paradigm shift I had concerns the legacy of the weapons-useable materials in the nuclear weapons states and the legacy of the weapons-usable nuclear material from research reactors around the world. Without a doubt, these materials are of concern for the potential proliferation of nuclear materials by terrorist and non-state actors, and their protection needs to be paramount. However, these legacies permeate discussions on the future of civilian nuclear energy. It seems as though discussions on the proliferation aspects of the civilian nuclear fuel cycle unfortunately have to carry this legacy baggage at times. I can understand fully the proliferation concerns these legacies have, but I get the feeling now and then that many believe that the proliferation concerns of these legacies need to be solved before the civilian fuel cycle can go forth. To me, there are two different issues: the nuclear weapons industry needs to solve their proliferation problems and the civilian fuel cycle folks need to aggressively address the proliferation concerns from their perspective. The two should be separated. Again, comments are welcome.

In This Issue

This issue contains five varied articles and a book review, all of which are interesting. The first, *The Development of Low-Level Measurement Capabilities for Total and Isotropic Uranium in Environmental Samples at Brazilian and Argentine Laboratories by ABACC,* is by Olga Mafra of the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) and her colleagues Khris Olsen from Pacific Northwest Laboratory and Doyle Hembree, Jr., Joel Carter, Micahel Whitaker, and Susan Hayes, all of Oak Ridge National Laboratory.

The second paper is by Wesley Hines of the University of Tennessee in Knoxville. *An Expert System for Long-Term Monitoring of Special Nuclear Materials* addresses an approach for effectively handling false alarms experienced in the Continuous Automated Vault Inventory System (CAVIS) at the Oak Ridge Y-12 National Security Complex.

The third paper summarizes an INMM workshop held on March 15, 2005, to engage topical experts in a discussion of UN Security Council Resolution 1540. This workshop was organized by Steve Mladineo of Pacific Northwest National Laboratory, chair of the INMM Nonproliferation and Arms Control Technical Division and the INMM Northeast Chapter.

On April 4–6, 2005, Sandia National Laboratories held its 14th International Security Conference, "Strengthening the Nuclear Nonproliferation Regime: Focus on the Civilian Nuclear Fuel Cycle." Arian Pregenzer and Dave Saltiel provide us an excellent summary in the fourth paper.

The final paper, *Control of Proliferation and the Challenge of Sensitive Nuclear Technology,* is a spin-off of a paper that Larry Scheinman of the Monterey Institute for International Studies presented at the International Security Conference.

The book review by Book Editor Walter Kane of Brookhaven National Laboratory looks at U.S. Senator Pete Domenici's book, *A Brighter Tomorrow: Fulfilling the Promise of Nuclear Energy.* Kane does an excellent job, including some of his own personal reflections.

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

The Development of Low-Level Measurement Capabilities for Total and Isotopic Uranium in Environmental Samples at Brazilian and Argentine Laboratories by ABACC

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Abstract

In June 1998, the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), with assistance from the U.S. Department of Energy (DOE), began a program to assess environmental sampling and analysis capabilities at laboratories in Argentina and Brazil. The program began with staff training conducted in South America and the United States by Oak Ridge National Laboratory (ORNL) and Pacific Northwest National Laboratory (PNNL). Both laboratories are participating members of DOE's Network of Analytical Laboratories (NWAL) that support the International Atomic Energy Agency (IAEA) environmental sampling program. During the initial planning meeting, representatives from ABACC and all the participating analytical laboratories supporting ABACC were briefed on how the first exercise would be managed and on key aspects necessary to analyze low-level environmental samples for uranium. Subsequent to this training, a laboratory evaluation exercise (Exercise 1) was conducted using standard swipe samples prepared for this exercise by the IAEA. The results of Exercise 1 determined that sample contamination was a major factor in the analysis, and a thorough review of laboratory procedures was required to reduce the level of contamination to acceptable levels. Following modification of sample preparation procedures, the laboratories performed Exercise 2, an analysis of a National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) 1547, Peach Leaves. The results of Exercise 2 demonstrated that several laboratories were capable of accurately determining the total uranium and uranium isotopic distribution in the peach leaves. To build on these successes, Exercise 3 was performed using a series of standard swipe samples prepared by the IAEA and distributed to laboratories supporting ABACC and to PNNL and ORNL. The results of Exercise 3 demonstrate that ABACC now has support laboratories in both Argentina and Brazil that are capable of accurately measuring both the quantity and isotopic composition of uranium at the levels expected in typical environmental samples (i.e., nanogram quantities).

Introduction

After the failure by the International Atomic Energy Agency (IAEA) and the international community to detect covert enrichment operations in Iraq, a series of field trials (93+2) were conducted by the IAEA in the early 1990s to evaluate additional measures to strengthen their safeguards approach. Based on the positive results of these field trials, the IAEA Board of Governors approved environmental sampling as a new safeguards measure to be implemented in 1996. In May 1997, the IAEA Board of Governors approved a Model Protocol addition to its safeguards agreements, which greatly expanded its inspectors' access to declared and adjacent facilities for visual verification and environmental sampling. In the case of Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), the swipe sampling technique was included as part of the current safeguards approach in declared facilities within Brazil and Argentina. With this idea ABACC, using Brazilian and Argentine laboratories to analyze environmental swipe samples, is preparing its technical staff and inspectors to extend the use of environmental sampling on declared facilities within Brazil and Argentina.

To achieve this goal, ABACC and U.S. Department of Energy (DOE) initiated an activity in November 1996 under its existing Safeguards Cooperation Agreement (Action Sheet 6: Environmental Sampling). The objectives of the action sheet are to assess the capabilities of analytical laboratories in Argentina and Brazil for analyzing environmental samples and to suggest improvements in sample preparation and measurement procedures that can meet IAEA's measurement criteria for total and isotopic uranium. Based on these objectives, ABACC and DOE designed an exercise program that first analyzed a series of swipe samples prepared by IAEA, analyzed a National Institute of

Standards and Technology (NIST) Standard Reference Manual (SRM) 1547 Peach Leaves standard for uranium, and analyzed a second series of IAEA-prepared swipe samples. Listed below are seven laboratories that participated in one, two, or all of the exercises:

- *Instituto de Radioproteção e Dosimetria* of the National Nuclear Energy Commission of Brazil in Rio de Janeiro, Brazil (IRD-CNEN);
- *Laboratorio de Mediciones Ambientales* of the Argentinean Nuclear Regulatory Authority in Buenos Aires, Argentina (ARN);
- *Laboratorio de Analises Quimicas* of the National Atomic Energy Commission of Argentina in Buenos Aires, Argentina (CNEA);
- *Laboratório de Caracterização de* UF_6 of the São Paulo Navy Technological Center in Sao Paulo, Brazil (CTM-SP);
- *Laboratório de Caracterização Quimica* of the Instituto de Pesquisas Energéticas e Nucleares in São Paulo, Brazil (IPEN/CNEN-Group 1)
- *Departamento de Radioproteção Ambiental* of the IPEN in São Paulo, SP, Brazil (IPEN/CNEN/Group 2)
- *Laboratorio de Analises Quimicas* of the Dioxitek, Planta Córdoba, Córdoba, Argentina.

Several Brazilian and Argentine laboratories did not have access to the required mass spectrometer systems needed to analyze these samples. Therefore, some laboratories teamed with other laboratories having the required analytical instruments. The ARN in Buenos Aires digested samples and Dioxitek analyzed those samples by inductively coupled plasma mass spectrometry (ICP-MS); the *Departamento de Radioproteção Ambiental* of the *Instituto de Pesquisas Energéticas e Nucleares* (IPEN) in São Paulo digested samples and the *Laboratório de Caracterização Quimica* of the *Instituto de Pesquisas Energéticas e Nucleares* in São Paulo analyzed the resulting samples by ICP-MS. The results of each laboratory's participation in the three exercises are discussed in the following sections.

Exercise 1: IAEA-Prepared Swipe Samples

Five analytical laboratories in Argentina and Brazil participated in the first exercise. A set of test materials, which had previously been analyzed for the IAEA by five DOE NWAL laboratories, was distributed to the participating laboratories. Arrangements were made with IAEA using its Safeguards Analytical Laboratory (SAL) to provide sets of cotton swipes (TexWipe™) spiked with the same standards used for quality assurance/quality control (QA/QC) in their environmental sampling program. The samples were distributed to laboratory representatives in June 1998. Each participating laboratory received three samples containing 300 ng of uranium, each of which had isotopic composition close to natural abundance. The isotopic compositions of the three samples along with that of natural uranium are given in Table 1. The $^{235}U/^{238}U$ ratio of Standard B is about 2 percent lower than Standard C, while Standard D is approximately 2 percent higher than Standard C. In addition, Standards B (lower) and C (higher) differ from natural by approximately 1 percent, while Standard D is approximately 3 percent higher than natural. The laboratories were also supplied with quantities of certified reference material (CRM) 111A (^{233}U spike) from New Brunswick Laboratory to use as a spiking solution for isotope dilution mass spectrometric analysis of the samples.

The performance criteria established by the IAEA for bulk analysis of uranium in environmental samples by Network of Analytical Laboratories (NWAL) are:

Table 1. Composition of IAEA standards

Standard	$^{234}U/^{238}U$	$^{235}U/^{238}U$	$^{236}U/^{238}U$
B 1σ Std Dev	0.0000536 ± 0.0000003	0.007151 ± 0.000004	0.0000121 ± 0.0000003
C 1σ Std Dev	0.0000550 ± 0.0000003	0.007301 ± 0.000004	0.0000144 ± 0.0000002
D 1σ Std Dev	0.0000569 ± 0.0000004	0.007450 ± 0.000004	0.0000148 ± 0.0000002
Natural	0.0000554	0.00725	

	234/238	235/238	236/238	Concentration
Relative Standard Deviation (1 σ)	10 percent	1 percent	10 percent	10 percent

The test materials were developed by IAEA to determine the ability of NWAL to distinguish small differences among the three materials themselves and with natural uranium. The $^{235}U/^{238}U$ ratios are sufficiently close so that they present a reasonable challenge for laboratories starting new programs in environmental analysis for safeguards purposes. The challenge is even greater for distinguishing the minor isotopic ratios.

In general, laboratories supporting ABACC had some experience in analyzing environmental samples for total uranium, but little or no experience in analyzing swipe sampling for total and isotopic uranium. Therefore, an important goal was to identify problem areas, particularly with contamination control, sample preparation, and mass spectrometry.

Results

Table 2 contains four sets of results reported by the participating laboratories. Two laboratories in Argentina, ARN and CNEA, teamed to submit a single set of results. Results reported included the values for each uranium isotopic ratio by each laboratory, their standard deviations, and the ratio of the measured value to the certified value. The ratio values were certified by the Institute for Reference Materials and Measurements (IRMM) located in Belgium.

Table 2. ABACC results for IAEA prepared working standard samples

		Standard B			Standard C			Standard D		
	Isotopic Ratio→	234/238	235/238	236/238	234/238	235/238	236/238	234/238	235/238	236/238
Certified	Value	0.0000536	0.007151	0.0000121	0.0000554	0.007301	0.0000144	0.0000569	0.007450	0.0000148
	SD	0.0000003	0.000004	0.0000003	0.0000003	0.000004	0.0000002	0.0000004	0.000004	0.0000002
Lab 1	Measured	0.000030	0.0085	0.000010	0.00004	0.0137	0.00001	0.00003	0.0082	0.00001
	SD	0.0011	—	—	—	—	—	—	—	—
	Measured/ certified	0.56	1.2	0.83	0.72	1.9	0.69	0.53	1.1	0.68
Lab 2 (filament 1)	Measured	0.00012	0.00753	—	0.00017	0.00743	—	0.00018	0.00766	—
	SD	0.00005	0.00004	—	0.00001	0.00006	—	0.00001	0.00004	—
	Measured/ certified	2.2	1.05	—	3.1	1.02	—	3.2	1.03	—
Lab 2 (filament 2)	Measured	0.0002	0.0076	—	0.0004	0.0086	—	0.0002	0.0081	—
	SD	0.00003	0.0002	—	0.0003	0.0003	Not Reported	0.0003	0.0003	Not Reported
	Measured/ certified	3.7	1.06	—	7.2	1.2	—	3.51	1.09	—
Lab 3	Measured	—	—	—	0.000049	0.007302	—	0.000052	0.00741	—
	SD	—	—	—	0.000003	0.000028	—	0.000004	0.00003	—
	Measured/ certified	—	—	—	0.88	1.00	—	0.91	1.00	—
Lab 4	Measured	0.000096	0.0109	0.000044	0.000085	0.0105	0.000039	0.000060	0.00807	0.000023
	SD	0.00000002	0.0000008	0.00000005	0.00000008	0.00000001	0.00000004	0.00000005	0.00001049	0.00000002
	Measured/ certified	1.8	1.52	3.6	1.5	1.44	2.7	1.05	1.08	1.6

Comparing the data in Table 2 with the IAEA's performance criteria shows that in most cases significant improvement in precision is necessary to meet those requirements, although in some of the measurements the performance criteria were met; for example, results from Laboratory 3 for $^{235}U/^{238}U$ ratio for Standard C. The measured versus certified data given in Table 2 provide a measure of the accuracy of the data.

Another measure of the accuracy is shown graphically for both DOE and ABACC laboratories in Figures 1 and 2, respectively. Figure 1 demonstrates that laboratories, such as DOE laboratories with extensive experience in making low-level measurements, can attain the necessary precision and accuracy to distinguish between very similar isotope ratios.

Examination of Figure 2 shows that all the ABACC laboratories except Laboratory 3 encountered uranium levels higher than expected with the blank swipes, suggesting a laboratory contamination problem. Elevated levels of uranium measured in blank samples are to be expected for any new program where uranium isotope ratio measurements are attempted on sample quantities well below the natural uranium background. Contamination control is of paramount importance at every stage in the analysis process. Contamination can arise from many sources: water and reagents used for processing samples, glassware, or airborne particulates.

The results suggest the main problem laboratories encountered was sample contamination. The most important outcome of this exercise was to demonstrate to the laboratories the potential sources of contamination and what would be required to decrease the levels of contamination to acceptable levels. Specific recommendations included measuring reagent blanks (e.g., water, reagents), analyzing blank TexWipe™ swipes, and using test samples such as NIST SRM 1547, Peach Leaves.

Figure 1. Comparison of $^{235}U/^{238}U$ ratios for five DOE NWAL laboratories with their certified values

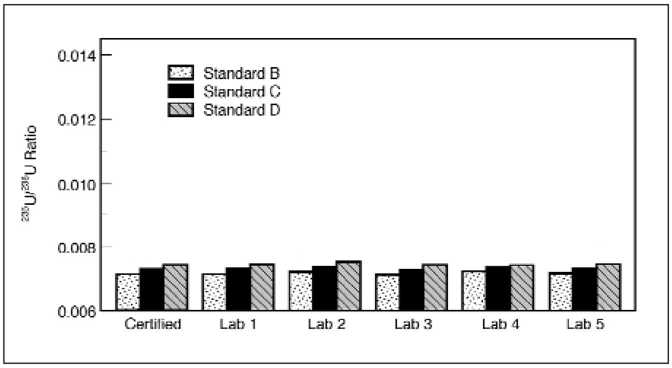
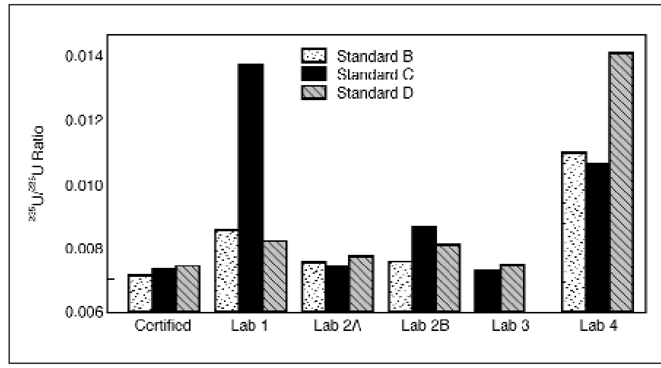


Figure 2. Comparison of 235U/238U ratios for four ABACC laboratories with their certified values



Many improvements were made at the various laboratories based on the results of the swipe exercise, such as relocating or using a laboratory in a separate building away from contaminated areas and using dedicated Teflon flasks and platinum crucibles for swipe samples. One laboratory procured a small muffle furnace, microwave digester, and laminar flow fume hood with the intention of decreasing uranium contamination during sample digestion. In addition to these improvements, some laboratories have adopted procedures for cleaning, minimizing, or limiting the use of glassware during sample processing. Only laboratories 1 and 2 reported blank results as given in Table 3.

In summary, laboratory activities began with an initial exercise analyzing IAEA-prepared test material. Evaluation of data from the exercise showed that ABACC laboratories made progress in developing the capability to determine both the quantitative value and isotopic composition of uranium at levels expected in typical environmental samples. However, in most cases it was evident that sample contamination was seriously affecting laboratory results. The results highlighted the importance of contamination control in environmental analyses, where the uranium concentration in the sample is often many times less than that found in the ambient environment (i.e., the sample preparation and analysis laboratories). As a follow-on to the first exercise, it was decided that CRM 111A (^{233}U spike) should be employed by each of the laboratories to quantitatively measure total uranium, including the uranium background (i.e., the blank).

Table 3. Blank results reported by laboratories 1 and 2

Laboratory 1			
	Uranium content	Standard deviation	Relative standard deviation (%)
Reagent blank	0.020 ng	0.001 ng	5.0
Swipe blank 1	0.570 ng	0.050 ng	8.8
Swipe blank 2	2.430 ng	0.020 ng	0.8
Laboratory 2			
	Uranium content	Standard deviation	Relative standard deviation (%)
Swipe blank A	2.0 ng	-	5.0
Swipe blank B	6.0 ng	-	5.0
Swipe blank C	3.0 ng	-	5.0
Swipe blank D	2.0 ng	-	5.0

Exercise 2: Analysis of NIST SRM 1547

Seven laboratories in Brazil and Argentina and one DOE laboratory (PNNL) analyzed the NIST SRM 1547, Peach Leaves standard. The SRM 1547 effectively simulates an environmental sample, and contains an uncertified, but well-documented, uranium concentration of 15 ng/g. The exercise provided a challenging test of low-level analysis capabilities and was an intermediate phase for laboratory assessment.

Arrangements were made with ABACC to have the laboratories obtain SRM 1547. The procedures used for the peach leaves analysis were extensively discussed with the participating laboratories. Each laboratory was instructed to conduct the analysis in triplicate on this standard. The isotopic composition of this standard was assumed to be natural (^{234}U 0.0055 percent; ^{235}U 0.720 percent; ^{238}U 99.2745 percent). The laboratories were instructed to use their ^{233}U spiking material (CRM 111A) from New Brunswick Laboratory and to use isotope dilution mass spectrometry (IDMS) to measure uranium concentrations in the standard. Each laboratory's performance was assessed on the basics of IAEA's criteria used in Exercise 1.

Results

All laboratories participating in this exercise used CRM 111A to perform IDMS measurements on SRM 1547. Table 4 contains a summary of the results from each laboratory. The mean value and standard deviation reported are the results of triplicate analysis on the standard material. The isotope ratios for $^{234}U/^{238}U$ and $^{235}U/^{238}U$ are reported for several participating laboratories.

Table 4. Isotope dilution mass spectrometry results for NIST SRM 1547, Peach Leaves Standard

Laboratory	Uranium (ng/g)			Uranium ratio	
	Process blank	SRM 1547	% Standard deviation	$^{234}U/^{238}U$	$^{235}U/^{238}U$
NIST SRM 1547		15 (Uncertified)		0.000055	0.00725
Lab 1 ICP-MS	0.262	16.07	0.41	-	0.007244
Lab 2 ICP-MS	-	13.7	Not Reported	0.000067	0.007232
Lab 3 ICP-MS	-	17	~10	0.00005	0.00726
Lab 4 TIMS	-	-	-	-	-
Lab 5-1 ICP-MS	0.451	8.71	0.2	-	0.00741
Lab 5-2 ICP-MS with ion exchange	0.1	7.84	Not Reported	-	-
PNNL TIMS Std Dev (1σ)	0.093	15.2 ±0.167	1.1	0.0000535 ±0.0000007	0.0072216 ±0.0000389

ABACC laboratories made significant progress in reducing their uranium background levels, which can be seen in the process blanks reported in Table 4. Process blanks, a measurement of uranium contamination, ranged from 0.10 to 0.45 ng. In most cases, this is an acceptable blank for environmental bulk analysis. Comparing the results for the first three laboratories in Table 4, the results are within ±2 ng of the uncertified uranium concentration published by NIST for SRM 1547. The other laboratories (laboratories 5-1 and 5-2 in Table 4) experienced two sample preparation problems that affected their results: (1) the samples were not completely dissolved and (2) the ^{233}U spike was added after the incomplete sample dissolution process. In general, the isotope dilution spike should be introduced as early as possible in the sample preparation process. In this case, the spike should have been introduced before sample dissolution to allow the spike material to come to chemical and isotopic equilibrium with the uranium in the sample. For comparison purposes, Table 4 also lists results from one of the DOE laboratories with many years of involvement in analysis of environmental samples for the IAEA.

ABACC Laboratory 1 measured the uranium concentration by isotope dilution ICP-MS, as well as by using a calibrated standard curve. The results are compared in Table 5. The relative percent difference between the mean values of the two methods was 8.3 percent, and the isotope dilution method provides slightly higher precision and accuracy as a result of the correction to variations in instrument performance inherent in the IDMS technique.

Results from ABACC Laboratory 4 were poor (data not reported in Table 4) because the samples were run on an old thermal ionization mass spectrometer (TIMS) that lacked the sensitivity for low-level uranium measurements. However, the laboratory has shown progress in reducing the uranium blank and expects to have a new Finnigan MAT 262 TIMS instrument installed and operating in the near future, which should significantly improve Laboratory 4's capability to analyze low-level environmental samples.

Table 5. Comparison of uranium content of NIST SRM 1547 by isotope dilution and standard curve methods

	Isotope dilution		Standard curve	
Sample no.	ng/g	Standard deviation	ng/g	Std Dev
Lab 1-1	16.7	0.09	18.7	0.2
Lab 1-2	16.2	0.06	15.8	0.1
Lab 1-3	15.4	0.05	18.0	0.09
MEAN	**16.1**	**0.07**	**17.5**	**0.1**

The results of the exercise demonstrated that three laboratories were capable of accurately determining the total uranium and uranium isotopic distribution in the peach leaves at typical levels for environmental samples (15 ng/g). Based on the demonstrated ability of several laboratories to control contamination and measure low-level uranium, another exercise with 15 IAEA-prepared test materials was conducted as Exercise 3.

Exercise 3: IAEA-Prepared Test Material Samples

Six laboratories in Brazil and Argentina and two DOE laboratories (PNNL and ORNL) participated in Exercise 3. This exercise was designed to test the ability of the participating laboratories to precisely and accurately measure uranium quantity and isotopic abundances at levels expected in typical environmental samples. As in the first exercise, arrangements were made with IAEA to provide sets of cotton swipes spiked with standard material used for QA/QC in its environmental sampling program. Each labora-

Table 6. Uranium data for IAEA prepared working standards for Exercise 3

Sample	Assay ng U/swipe	U-234 (atom %)	U-235 (atom %)	U-236 (atom %)	U-238 (atom %)
* LEU makeup	176.85 ±0.35	0.0276	3.0169	0.0006	96.9549
** NBL U030a	175.59 ±0.34	0.02778 ±0.00006	3.0404 ±0.0016	0.000599 ±0.000005	96.9312 ±0.0016
NBL U200 (1)	119.48 ±0.24	0.1246 ±0.0003	20.013 ±0.020	0.2116 ±0.0006	79.651 ±0.021
NBL U200 (2)	85.99 ±0.11	0.1246 ±0.0003	20.013 ±0.020	0.2116 ±0.0006	79.651 ±0.021
Swipe blank	0.535±0.03				

** LEU = Low-enriched uranium*
*** NBL = New Brunswick Laboratory*

tory received five sets of three swipes (fifteen swipes total). Each set contained three swipes with the same quantity of total uranium and isotopic distribution of uranium given in Table 6. One set contained only blank swipe material. One swipe within the three blank swipes was identified for the participating laboratories. As can be seen in Table 6, two sets of swipes were prepared with small differences in uranium isotopes (approximately 3 percent ^{235}U), and two sets were spiked with different quantities of a uranium standard that was approximately 20 percent ^{235}U.

Each laboratory was instructed to report the following data:

- Total uranium (ng U/swipe) + uncertainty*
- Atom percent ^{234}U + uncertainty*
- Atom percent ^{235}U + uncertainty*
- Atom percent ^{236}U + uncertainty*
- Atom percent ^{238}U + uncertainty*

*Uncertainty: Report total uncertainty (random + systematic) at 95 percent confidence level

Results

The results from the six ABACC laboratories, two DOE laboratories, and SAL's results are summarized in Table 7. SAL did not directly participate in this exercise but conducted analysis for its own QA/QC purposes. The values reported in Table 7 are mean values for triplicate samples and the resulting standard deviation. Generally, the uranium isotopic results compare favorably with the expected values provided by the IAEA. All ABACC laboratory results were performed in clean, controlled facilities employing ICP-MS. For comparison purposes, the DOE laboratories used both ICP-MS (PNNL) and TIMS (ORNL). As can be seen in the comparison, the ICP-MS and TIMS isotopic results are in close agreement for ^{235}U and ^{238}U. In fact, the results for the minor uranium isotopes, ^{234}U and ^{236}U, from three of the ABACC laboratories (IRD, Dioxitek and CNEN/SP-2) compare extremely well with the expected results. The other three ABACC laboratories experienced problems with background or lack of sensitivity on the minor isotopic concentrations. As the minor isotopic levels increased, this problem became less discernable. One laboratory experiencing this problem indicated a blank concentration approximately twenty times higher than the other five ABACC laboratories.

Four of the six ABACC support laboratories and both DOE laboratories reported low isotopic ^{235}U results for the low-enriched uranium makeup samples. This standard was prepared by mixing a CRM with natural uranium; the isotopic values were then calculated from the mixing makeup. The other isotopic results in Table 7 are in close agreement with the expected or certified values for all the participating laboratories.

The results from the swipes spiked with New Brunswick Laboratory CRM U030a and CRM U200 for all ABACC laboratories are summarized in Table 8. There were twelve data sets from the six ABACC support laboratories for CRM U200 and six data sets for CRM U030a. The ^{235}U isotopic comparisons with the certified values are: 20.1460 versus a certified value of 20.0129 atom percent, and 3.0343 versus a certified value of 3.0404 atom percent for the two New Brunswick Laboratory CRMs. These data compare favorably with the certified values, especially considering the relatively small sample size and that the data were obtained by ICP-MS.

The *Instituto de Radioproteção e Dosimetria (IRD)* performed extremely well for both isotopic measurements and uranium assay. The IRD uranium assay measurements were within 0.3 percent of the expected values. The DOE laboratory employing TIMS (ORNL) also demonstrated good quantitative recovery on all samples. The other laboratories demonstrated erratic uranium recovery to varying degrees; however, the recovery did not affect the quality of the isotopic measurements as can be seen by comparing the laboratory data with the expected values in Table 7. Poor recovery is often caused by lack of chemical equilibrium for the spike isotope (^{233}U). Data from one sample from the PNNL laboratory performing ICP-MS showed evidence of contamination and was not included in the averages in Table 7. PNNL also had a systematic bias associated with the total uranium content of the swipe samples. Their values were 72 percent of the expected value. This discrepancy was traced to the ^{233}U spiking solution, which was found to be 139 percent high. Blanks for all but one of the participating laboratories were less than 1-ng swipe. This is encouraging because it demonstrates that all of the laboratories participating in this exercise have developed effective contamination control programs, which is an absolute requirement for making precise and accurate low-level uranium measurements on environmental samples.

Conclusions

These exercises demonstrated that round-robin studies are extremely valuable and effective in identifying biases (e.g., variations from assigned spike or certified values) that can occur at any laboratory so they can be corrected. ABACC's support laboratories have shown significant progress in developing capabilities in environmental analysis with each of the exercises that began in 1998. These exercises demonstrated that laboratories in both Argentina and Brazil have the capability of accurately measuring both the amount and isotopic composition of uranium at the levels expected in typical environmental samples (i.e., sub-microgram quantities). A major factor in developing this capability is the fact that the laboratories have shown steady progress in contamination control and improvements in measurement capability.[1, 2, 3]

Future Plans

ABACC's support laboratories have successfully demonstrated an ability to analyze uranium in environmental samples. The next stages in the continued development of environmental sampling capabilities at ABACC laboratories are to:

Table 7. Comparison of uranium results for the participating laboratories for various working standard samples prepared by IAEA

LEU makeup										
U Isotopic (At. %)	Calculated value	IAEA (SAL)	IRD	ARN/ Dioxitek	Dioxitek	CTM-SP	IPEN-CNEN/SP-1	IPEN-CNEN/SP-2	PNNL	ORNL
234 1 σ Std Dev	0.0276	0.0285	0.02726 ±0.00079	0.0261 ±0.0008	0.0264 ±0.0003	*	0.029 ±0.0059	0.0261 ±0.0026	0.0268 ±0.0003	0.0276 ±0.0014
235 1 σ Std Dev	3.0169	3.0190	2.9823 ±0.035	2.9843 ±0.013	2.9925 ±0.0058	2.994 ±0.038	3.059 ±0.051	3.0258 ±0.1353	2.9519 ±0.0035	2.9871 ±0.0743
236 1 σ Std Dev	0.0006	0.0020	0.0006 ±0.0002	0.0006 ±0.0001	0.0006 ±0.0001	*	0.0029 ±0.0039	0.00068 ±0.0039	0.0011 ±0.0001	0.0009 ±0.0003
238 1 σ Std Dev	96.9549	96.9504	96.9898 ±0.035	96.9869 ±0.0216	96.9806 ±0.0058	97.006	96.922 ±1.05	96.9474 ±0.2133	96.6869 ±0.13	96.9845 ±0.0184
ng/swipe 1 σ Std Dev	176.85 ±0.35	-	177.21 ±1.8	144.4 ±4.6	163 ±2	151 ±7	241 ±3	165.9 ±1.2	128.1 3..3	166 ±7.5
Analytical System		TIMS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	TIMS

NBL U030a										
U Isotopic (At. %)	Certified value	IAEA (SAL)	IRD	ARN/ Dioxitek	Dioxitek	CTM-SP	IPEN-CNEN/SP-1	IPEN-CNEN/SP-2	PNNL	ORNL
234 1 σ Std Dev	0.02778 ±0.00006	0.0285	0.02748 ±0.0012	0.0280 ±0.0006	0.0280 ±0.0006	*	0.026 ±0.0049	0.0261 ±0.0045	0.0276 ±0.0003	0.0273 ±0.0010
235 1 σ Std Dev	3.0404 ±0.0016	3.0412	3.0099 ±0.043	3.0097 ±0.0086	3.0246 ±0.0086	3.022 ±0.030	3.076 ±0.074	3.0636 ±0.0804	3.0313 ±0.0030	3.0088 ±0.108
236 1 σ Std Dev	0.0006 ±0.000005	0.0020	0.0007 ±0.0002	0.0007 ±0.0001	0.0006 ±0.0001	*	*	0.0014 ±0.0039	0.0008 ±0.0010	0.0010 ±0.0004
238 1 σ Std Dev	96.9312 ±0.0016	96.9283	96.9617 ±0.044	96.9619 ±0.0108	96.9465 ±0.0088	96.978	96.937 ±1.3	96.9094 ±0.2132	96.9404 ±0.170	96.9162 ±0.1771
ng/swipe 1 σ Std Dev	175.59 ±0.34	-	176.10 ±2.1	135.5 ±1.7	157 ±2	160 ±8	240 ±2	160.4 ±0.6	11910.3	170 ±11
Analytical System		TIMS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	TIMS

Table 7. Continued

NBL U200 (1)										
U Isotopic (At. %)	Certified value	IAEA (SAL)	IRD	ARN/ Dioxitek	Dioxitek	CTM-SP	IPEN-CNEN/SP-1	IPEN-CNEN/SP-2	PNNL	ORNL
234 1 σ Std Dev	0.1247 ±0.0003	0.1248	0.1228 ±0.0028	0.1320 ±0.0021	0.134 ±0.0027	0.147 ±0.021	0.122 ±0.014	0.1215 ±0.0058	0.1223 ±0.0007	0.1222 ±0.0055
235 1 σ Std Dev	20.0129 ±0.020	20.0182	19.6822 ±0.12	20.6120 ±0.061	20.769 ±0.060	20.0419 ±0.060	20.094 ±0.25	19.9979 ±0.2843	19.8227 ±0.0865	20.7842 ±0.667
236 1 σ Std Dev	0.2115 ±0.0006	0.2112	0.2063 ±0.0033	0.2203 ±0.0026	0.224 ±0.0037	0.232 ±0.02	0.212 ±0.013	0.2107 ±0.0048	0.2046 ±0.0050	0.2104 ±0.0068
238 1 σ Std Dev	79.6509 ±0.020	79.6458	79.9887 ±0.12	79.0350 ±0.3506	78.881 ±0.057	79.572 ±0.27	79.572 ±0.91	79.6700 ±0.8599	79.8504 ±0.216	79.8832 ±0.1987
ng/swipe 1 σ Std Dev	119.48 ±0.24	-	118.78 ±1.4	104.3 ±1.1	105 ±1	93 ±5	133 ±2	117.3 ±0.6	82 4.3	114 ±7.4
Analytical System		TIMS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	TIMS

NBL U200 (2)										
U Isotopic (At. %)	Certified value	IAEA (SAL)	IRD	ARN/ Dioxitek	Dioxitek	CTM-SP	IPEN-CNEN/SP-1	IPEN-CNEN/SP-2	PNNL	ORNL
234 1 σ Std Dev	0.1247 ±0.0003	0.1248	0.1234 ±0.0043	0.1305 ±0.0024	0.131 ±0.0031	0.156 ±0.02	0.121 ±0.015	0.1230 ±0.0074	0.1228 ±0.0006	0.1224 ±0.0050
235 1 σ Std Dev	20.0129 ±0.020	20.0182	19.7279 ±0.133	20.3957 ±0.056	20.4570 ±0.0281	19.828 ±0.20	20.088 ±0.41	20.0586 ±0.4367	19.8006 ±0.0422	19.6627 ±0.665
236 1 σ Std Dev	0.2115 ±0.0006	0.2112	0.2050 ±0.0040	0.2259 ±0.0024	0.224 ±0.0028	0.250 ±0.020	0.215 ±0.019	0.2087 ±0.0143	0.2048 ±0.0006	0.2083 ±0.0059
238 1 σ Std Dev	79.6509 ±0.020	79.6458	79.9437 ±0.0136	79.2477 ±0.1206	79.187 ±0.0265	79.766 ±0.25	79.575 ±1.25	79.6101 ±0.1751	79.8720 ±0.136	80.0065 ±0.2916
ng/swipe 1 σ Std Dev	85.99 ±0.11	-	85.82 ±1.2	80.6 ±1.1	77.8 ±0.9	66 ±3	98.2 ±1.1	99.4 ±0.4	68.311.4	86 ±4.6
MS type		TIMS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	TIMS

BLANKS									
U Isotopic (At. %)	IAEA (SAL)	IRD	ARN/ Dioxitek	Dioxitek	CTM-SP	IPEN-CNEN/SP-1	IPEN-CNEN/SP-2	PNNL	ORNL
234 1 σ Std Dev	-	-	-	-	-	-	-	0.318	0.025
235 1 σ Std Dev	-	-	-	-	9.07±1	-	-	1.034	0.992
236 1 σ Std Dev	-	-	-	-	-	-	-	0.251	0.035
238 1 σ Std Dev	-	-	-	-	90.97±1	-	-	98.397	98.957
ng/swipe 1 σ Std Dev	0.54±0.03	0.64±0.03	0.38±0.04	0.30±0.02	0.9±0.1	19.9±0.1	0.06±0.0005	0.720.02	0.83±0.44
MS type	TIMS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	TIMS

Table 8. Summary of ABACC data compared to certified values

CRM U030a	^{234}U	^{235}U	^{236}U	^{238}U
Certified value	0.02778 ±0.00006	3.0404 ±0.0016	0.0006 ±0.000005	96.9312 ±0.0016
ABACC average	0.0271 ±0.0010	3.0343 ±0.0284	0.00085 ±0.0004	96.9491 ±0.0240
CRM U200	**^{234}U**	**^{235}U**	**^{236}U**	**^{238}U**
Certified value	0.1247 ±0.0003	20.0129 ±0.020	0.2115 ±0.0006	79.6509 ±0.021
ABACC average	0.1304 ±0.0111	20.1460 ±0.344	0.2195 ±0.01288	79.5040 ±0.3470

- Develop the capability to measure plutonium in environmental samples
- Develop the capability to separate plutonium and uranium from a single environmental sample
- Conduct an environmental sampling exercise in nuclear facilities in Brazil and/or Argentina and analyze the collected samples for total and isotopic uranium and plutonium

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An Expert System for Long-Term Monitoring of Special Nuclear Materials

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Abstract

The Continuous Automated Vault Inventory System (CAVIS™) is a system designed to continually monitor the status of special nuclear materials (SNM) at the Oak Ridge-based Y-12 National Security Complex. CAVIS consists of an integrated package of low-cost sensors used to continuously monitor weight and radiation attributes of stored items. The CAVIS system detects "changes-in-state" of the SNM and generates an appropriate alarm. Unfortunately, these types of monitoring systems can be subject to events that cause false alarms that do not coincide with the removal of nuclear material, but if not quickly reconciled, may initiate an expensive and disruptive operational response. These false alarms may be due to the random stochastic nature of the measurements, to failing components, or to external radiation sources. This paper presents the development of a monitoring system for CAVIS that reduces the costly responses caused by false alarms. The system merges advanced statistical algorithms, such as the sequential probability ratio test (SPRT), to extract features related to changes in the CAVIS sensors with an expert system that forms a hypothesis on the root cause of any anomaly.

Introduction

The Y-12 National Security Complex at Oak Ridge, Tennessee, currently houses the United States' supply of weapons grade uranium. The safe, secure, and reliable storage of this material is essential to national security. The Continuous Automated Vault Inventory System (CAVIS™) has been developed to monitor the status of this special nuclear material (SNM) by detecting "changes-in-state" of the material and generating an appropriate alarm.

CAVIS System

The CAVIS system monitors the radiation and weight attributes of the SNM using an integrated package of low-cost radiation and weight sensors. CAVIS continually receives the radiation and weight signals from a hierarchical network of components. The weight and radiation attributes are first measured by their corresponding sensors. The signals are sent to sensor concentrators, manufactured by ORSENS. The sensor concentrators process the radiation detector output pulses and weight sensor signals to calculate the radiation count rates and weight signals. These signals are then sent to a power and communication distribution unit (PCDU). The PCDUs provide power to the sensor concentrator and relays the radiation count rates and weights to a central computer system. The monitoring computer system can be a desktop personal computer running either a National Instruments LabView® (Windows® 95) application or the GraFIC™ software package on a Windows® NT system. The computer system logs the weight and radiation attributes and performs the calculation necessary to determine if a change in state of the SNM has occurred. Figure 1 is a block diagram of the CAVIS system.

The radiation sensors featured in the CAVIS system are RADSiP™ Photodiode Gamma Ray Sensors. These sensors are small, inexpensive, and are well-suited to monitoring stored nuclear materials for long periods of time. As suggested by their name, the sensors monitor the gamma ray emission of a radioactive source. The sensor continually monitors the SNM by detecting a change in the gamma ray emission radiation level. Due to the long half-life of the nuclear material, the radiation level remains approximately constant, so any deviation suggests an abnormal status. The weight sensors used in the CAVIS system are standard load cells.

In the instance of a detected change in state, the CAVIS system will alarm for the suspect sensor. The response to a CAVIS alarm may be an inventory check, which could involve a physical verification of the SNM status. Due to the workload involved, inventory checks can be extremely costly. In addition, workers are exposed to radiation during inventory checks. Thus, it is desirable to perform as few inventory checks as possible while still ensuring the safe, secure, and reliable storage of the SNM.

Problem Statement

The current CAVIS system is susceptible to alarms, which may not coincide with the removal of special nuclear material. Several factors can result in false radiation sensor alarms. First, the statistical nature of radioactive decay and counting may cause the count rate to fall outside of commonly used 95 percent confidence intervals. In such an instance, the state of the SNM has not changed and the CAVIS system incorrectly alarms. Secondly, the CAVIS system is composed of numerous components that may fail over time. Thus, the CAVIS system may generate alarms due to component failures, which are not correlated with changes in the SNM. Thirdly, the storage area is a functioning warehouse that may have radioactive material being moved. These external radiation sources may be detected by the CAVIS system causing an alarm in the region of the warehouse where the external radiation source is located. Fourthly, the radiation sensors used in the CAVIS system display a spike behavior when they are impacted. Forklifts and other heavy equipment moving in the warehouse may cause impacts that are transmitted to the CAVIS storage vaults inducing spikes in the count rates. Additionally, the weight sensors would be affected by impacts. Finally, the CAVIS system has displayed a dependence on environmental stimuli such as heat and humidity. Thus, the environmental conditions of the storage area may cause the CAVIS system to generate false alarms. These numerous conditions can all result in CAVIS false alarms, which may result in unnecessary and costly inventory checks, and over a longer period of time, may result in operators ignoring alarming indicators.

Methodology

A system has been developed to improve the CAVIS system reliability and eliminate unnecessary inventory checks. The system merges statistical algorithms, such as the sequential probability ratio test (SPRT), to extract features related to changes in the CAVIS sensors with an expert system that forms a hypothesis of the root cause of any anomaly. Other methods such as using X-bar (symbol for average) and R (range) charts are commonly used for quality control to detect changes in process mean and variation. Other sequential tests include Cumulative Sum (CUSUM), which is equivalent to applying a retrospective SPRT.

Sequential Probability Ratio Test (SPRT)

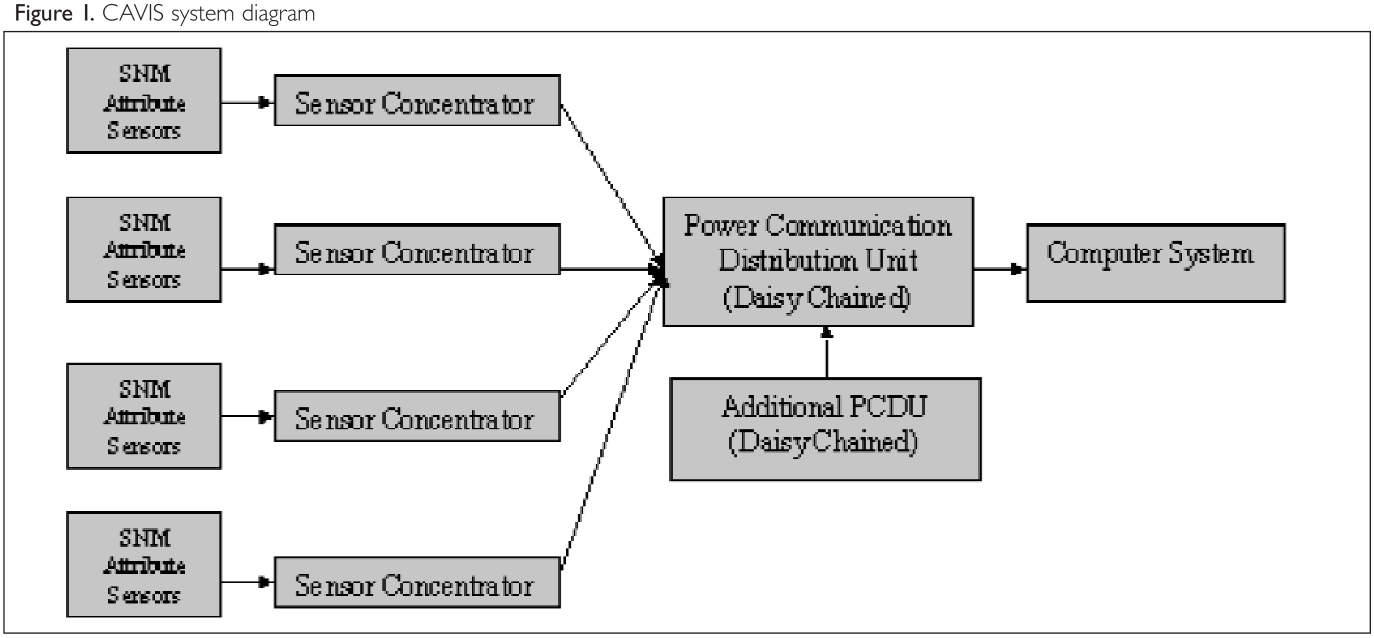
The SPRT is a statistical test developed by A. Wald in 1945 that is capable of monitoring statistical properties of a Gaussian distribution. There has been research to extend the technique to other distributions, but we will only use the original algorithm. The SPRT determines if a Gaussian input data stream was generated by a process with the expected mean and variance, or if there is a greater probability that the data stream was generated by a Gaussian distribution characterized by a shifted mean and/or altered variance. If the input comes from the alternate distribution, the SPRT is designed to generate an appropriate alarm with high probability. This technique is capable of monitoring two attributes of the radiation distribution: mean and variance, in contrast to previous techniques, which only monitored the mean. By monitoring two attributes of the radiation distribution, the SPRT-based system will be capable of identifying additional operational faults. Two examples that have been experienced are a communication failure in which the count rate does not change and the variance equals zero or an increase in variance caused by a poor connection.

The SPRT evaluates the likelihood that a radiation signal is sampled from the five hypothesized distributions:

- H_0: no distributional change
- H_1: mean shift up
- H_2: mean shift down
- H_3: variance shift up
- H_4: variance shift down

If the signal has a greater likelihood of having been sampled from a distribution corresponding to an alternative hypothesis rather than having been sampled from a distribution corresponding to the null hypothesis (H_0), the SPRT for that particular hypothesis alarms. For every data observation, the SPRT calcu-

Figure 1. CAVIS system diagram



lates the likelihood that the data stream belongs to the original distribution and the likelihood it belongs to one of the four alternative hypotheses. The ratio of the two likelihoods is give by Equation 1.

$$L_n = \frac{P(Y_n \mid H_j)}{P(Y_n \mid H_0)}, j = 1:4 \qquad \text{Equation 1}$$

where $P(Y_n|H_x)$ is the probability of an observed sequence Y_n given that H_x is true. The radioactive decay process is a Poisson process with a large mean (25-145) and therefore can be approximated by a Gaussian distribution. Empirical evidence validates this assumption for this measurement system.

The likelihoods can be put into a recurrent form and evaluated at each sampling instance (k) resulting in the likelihood ratios given in Equation 2.

$$\lambda_k = \lambda_{k-1} + \ln\left[\frac{P_1(y_k \mid H_j)}{P_0(k_k \mid H_0)}\right], j = 1:4 \qquad \text{Equation 2}$$

Using the Gaussian likelihood (see Equation 6 below), the likelihood ratio used to monitor for mean change is given by Equation 3 and that used to monitor for a variance change is given by Equation 4:

$$\lambda_k = \lambda_{k-1} + \frac{(y_k - \mu_0)^2}{2\sigma_0^{\,2}} - \frac{(y_k - \mu_1)^2}{2\sigma_0^{\,2}} \qquad \text{Equation 3}$$

$$\lambda_k = \lambda_{k-1} + \frac{1}{2}\left[\frac{1}{\sigma_0^{\,2}} - \frac{1}{\sigma_1^{\,2}}\right] y_k^{\,2} + \ln\left[\frac{\sigma_0}{\sigma_1}\right] \qquad \text{Equation 4}$$

where μ_0 is the expected mean count rate, μ_1 is the faulted mean, σ_0^2 is the expected variance, σ_1^2 is the faulted variance, and y_k is the count rate at sample k.

The statistical values for the alternative hypotheses (H_1-H_4): μ^1 and σ_1^2 are related to the expected radiation count rate mean m and variance σ^2. The amount by which the mean shifts up or down is set for three standard deviations. This mirrors a +/- 3σ band for the desired 99+ percent confidence interval and corresponds to criteria set by Y-12 personnel. The variance related to the alternative hypothesis is also related to the mean. For a Poisson distribution the mean m equals the variance σ^2, so the variance corresponding to the increased mean hypothesis is $\mu + 3\sigma$. Thus, the ratio of the new variance to the old variance is $1 + 3/\sigma$ for a variance increase and $1 – 3/\sigma$ for a variance decrease.

The hypotheses are evaluated for each count rate by evaluating the likelihood ratios against two set points: ln(A) and ln(B). A and B are defined as

$$A = \frac{\beta}{1-\alpha} \qquad B = \frac{1-\beta}{\alpha} \qquad \text{Equation 5}$$

where the parameters α and β are the false (Type I) and missed (Type II) alarm rates, respectively. The sensitivity of the SPRT depends on these false- and missed-alarm probabilities. This research sets α and β at 0.1 percent and 10 percent, respectively. The low value for α reflects the need to minimize the number of false alarms—roughly one false alarm per 1,000 data observations, or 99.9 percent accuracy in sounding alarms. Theoretically, this may result in fairly frequent SPRT false alarms if many containers are monitored; however, the expert system uses multiple features with which to base decisions and system false alarms were nonexistent in our tests. The value for β is set arbitrarily at 10 percent based on the assumption that if an actual alarm condition occurs but does not trigger an alarm, it will trigger an alarm at a future time step.

If the result of any SRPT equation is greater than ln(B), the SPRT alarms for that hypothesis then resets to 0 and starts a new collection sequence. If the result of any SPRT equation is less than ln(A), the SPRT resets to 0 and starts a new collection sequence. A complete, detailed derivation of the SPRT equations can be found in Wald [1945] and a more detailed application to SNM monitoring can be found in Harrison.

Expert System

An expert system is an intelligent computer program that uses knowledge and inference procedures to solve problems that may require significant human expertise. An expert system is comprised of a rule base, a knowledge base, and an inference engine. Knowledge or facts cause rules to *fire*, which in turn cause additional facts to be hypothesized. The inference engine controls program execution. When presented information about the state of a system, the expert system is capable of emulating the actions of an expert if the system has been programmed with the correct knowledge. Expert systems have been used for fault detection and isolation in several industries including nuclear power.

When applied to the CAVIS system, an expert system would reduce the number of unnecessary inventory checks by predicting the actual cause of sensor alarms. This will allow workers to investigate the alternate explanation first, which will save time, money, and possibly radiation exposure. The expert system uses a rule base that incorporates knowledge concerning the functionality of the radiation and weight sensors. Thus, for an expert system to work properly it requires a complete understanding of every component of the system it monitors. In other words, an expert system must embody an expert's knowledge of the system.

System Architecture

A monitoring and diagnosis system combining feature extraction, by an SPRT and other statistical measures, with an expert system was developed and optimized to monitor the CAVIS system in order to eliminate costly alarm responses and unnecessary inventory checks. The system extracts several features from the radiation count rates and weight sensor signatures and stores them in a database. The expert system analyzes the extracted features and maps them to possible causes. Figure 2 is a flow chart that illustrates the processes of feature extraction, fault detection and fault isolation.

The time and count rate of the radiation and weight signals are collected and stored in a database. Features, including the results of the SPRTs, are extracted and analyzed for variations from normality. Normal conditions are calculated from the first several hours of operation. If deviations from normality are detected, the features are processed by the expert system to determine the source of the fault. The expert system rule base knowledge will isolate the fault by analyzing what features were affected by the fault, and what faults had previously occurred. Information concerning the isolated fault will be sent to a graphical user interface.

Feature Extraction System

The feature extraction system (FES) acts as a data-miner for the collected data by extracting information useful to the expert system. It does so using several algorithms including the SPRT, which was discussed in the previous section. The SPRT assumes that each residual is independent; however, this assumption is not met for the weight sensor since two successive points are closer in value than two points separated by one, two, or three points. In other words, there is serial correlation that must be considered when evaluating the weight sensor signal. To combat this problem, wider alarm limits are needed. Figure 3 presents a common weight sensor output for a constant load. It is seen that there is an underlying disturbance in addition to the Gaussian noise component. This anomaly is within the specification of the sensor and may be due to environmental effects.

Additional processing is needed to detect changes in the noise characteristics of the weight sensor that may be due to system degradation. We first assume that the underlying disturbance of the signal does not affect the sources of variance outside the system (such as signal noise, gravitational field fluctuations, seismic activity, etc.). Therefore, by subtracting the disturbance portion of the load sensor we have a more realistic estimate of the noise component. A moving average is used to estimate the underlying trend and then used to compute the high frequency residuals as the distance between the observations and the smoothed value. The residuals have a stationary mean of approximately 0 and variance tests can be applied. An example appears in Figure 4. Checks, including those for skewness and kurtosis, have been used to verify the data can be accurately modeled with a Gaussian distribution. The statistical features extracted for the radiation sensors include:

- The SPRT status (Hypothesis 0-4)
- The number of all alternative hypothesis alarms over the last 100 and 1,000 data points and the interval since the last alarm for each hypothesis

Figure 3. Common load cell behavior

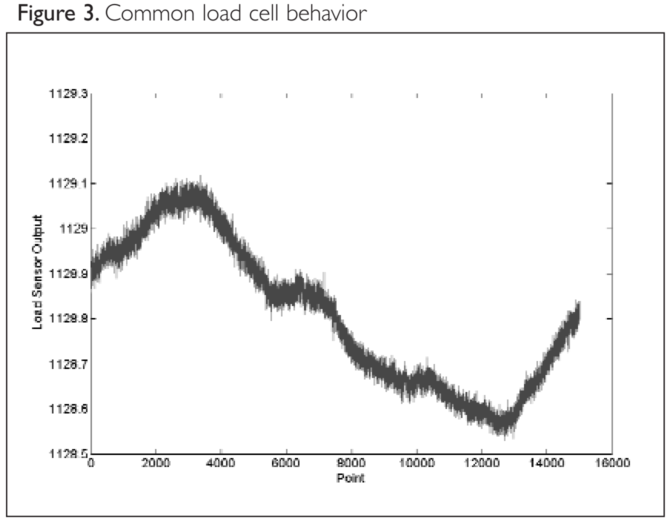
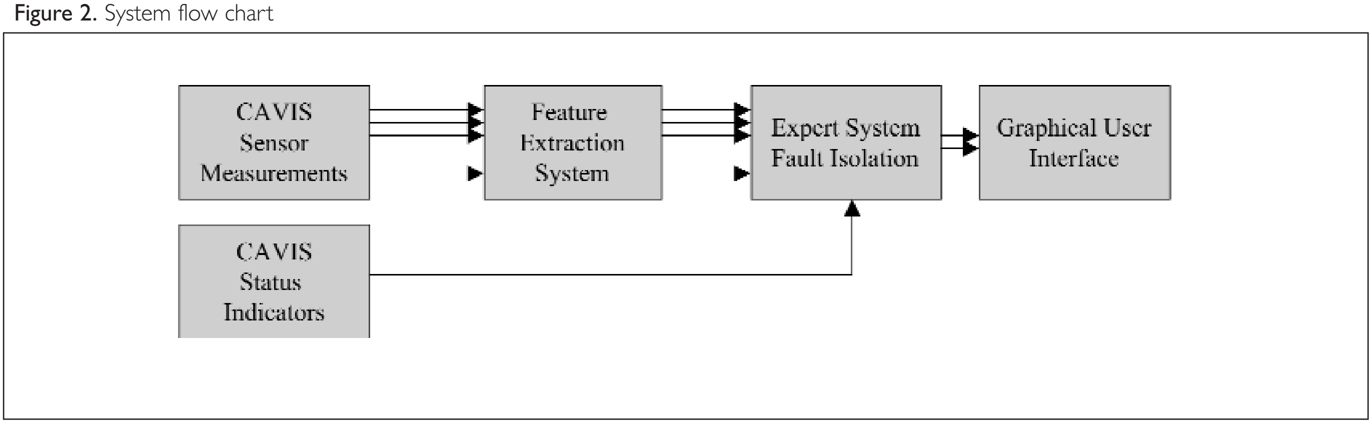


Figure 2. System flow chart



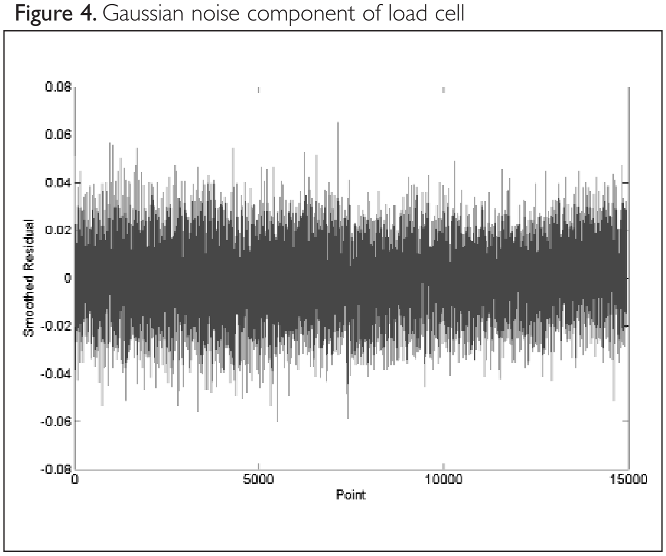
- The variance of the last five and the last fifty radiation count rates
- A sign test of the residuals to perform a Run Test 2: nine consecutive points same side of average [Western Electric Company 1958, Nelson 1984]
- The current count rate
- A built-in system status signal from the CAVIS hardware

The features for the weight sensor include

- The SPRT status for mean shift detection (H0, H1, H2)
- The SPRT status for noise component variance shift up and down

The expert system uses these extracted features to isolate and diagnose system faults.

Figure 4. Gaussian noise component of load cell



Fault Detection

The expert system compares the extracted features values with a set of tolerances to detect any faults that have occurred. The tolerances are set to ensure a 99 percent or greater confidence interval in the faulted state of the feature when possible. The tolerances for the SPRT alarms are set according to the results of several parametric studies. The tolerances for the remaining features are set using simple probabilistic calculations. A total of seventeen features for the radiation sensors and 14 features for the weight sensors are calculated. Table 2 contains a complete listing of the tolerances for the extracted radiation features. The weight sensor features are similar but do not include F9, F10, or F11.

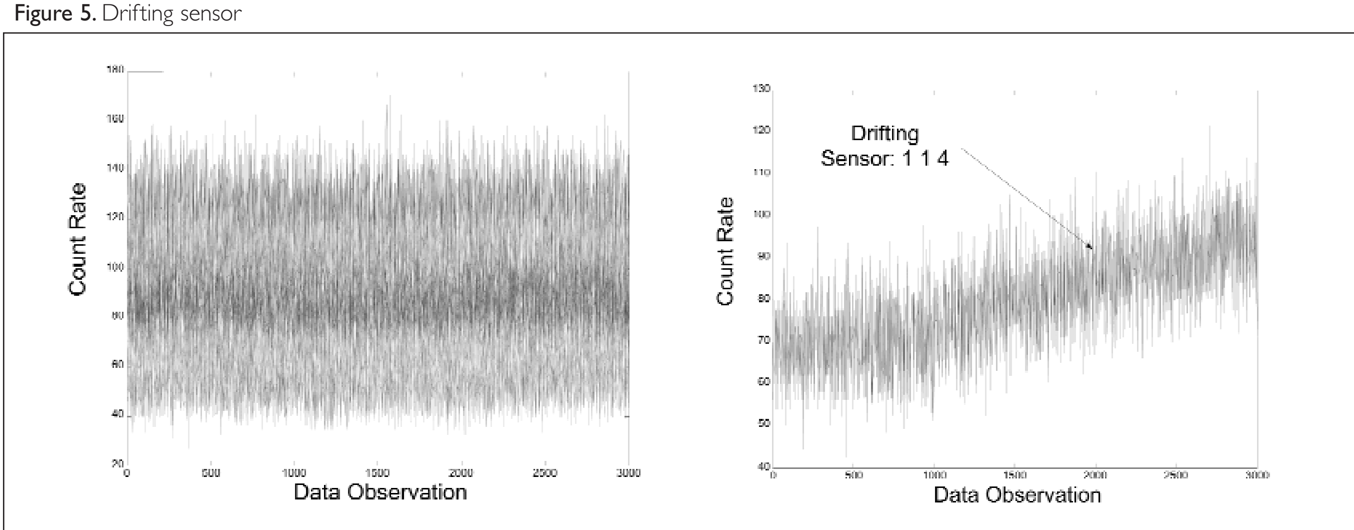
If any features value exceeds its tolerance, then a fault is generated. For example, if the radiation signal for a particular sensor experiences four SPRT mean shift up alarms in 1,000 data observations, then feature 1 is faulted for the particular sensor. A faulted feature for a sensor implies there is a 99 percent or greater confidence that the sensors radiation signal has experienced a "change in state" or CAVIS has experienced some failure.

The tolerances for the SPRT alarms have bases from different conceptual and experimental sources. The maximum number of SPRT alarms in the last 100 or 1,000 data points is set through experiments and theory. The remaining features tolerances were set according to probabilistic calculations. The SNM count rates range between 25-145; thus, the radiation signal can be approximated with a Gaussian distribution. Therefore, the likelihood of any particular count occurring is

$$P(x \mid \mu, \sigma) = \frac{1}{\sqrt{2\pi}} \frac{1}{\sigma} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \qquad \text{Equation 6}$$

where P = probability, μ = mean of the count rate, σ = standard deviation of the count rate ($\sigma = \mu^{1/2}$), x = count rate for which probability is to be determined. The tolerances for feature 10

Figure 5. Drifting sensor



(variance of last fifty observations), feature 11 (variance of the last five observations), and feature 16 (current count rate) are set using Equation 6 to ensure a 99 percent confidence.

When a fault is generated, the time of the fault, the culprit sensor, and the type of fault are recorded in a database. This database is used as a log to keep a record of all fault occurrences and as the working memory of the expert system. Also, a detected fault initializes the fault isolation expert system.

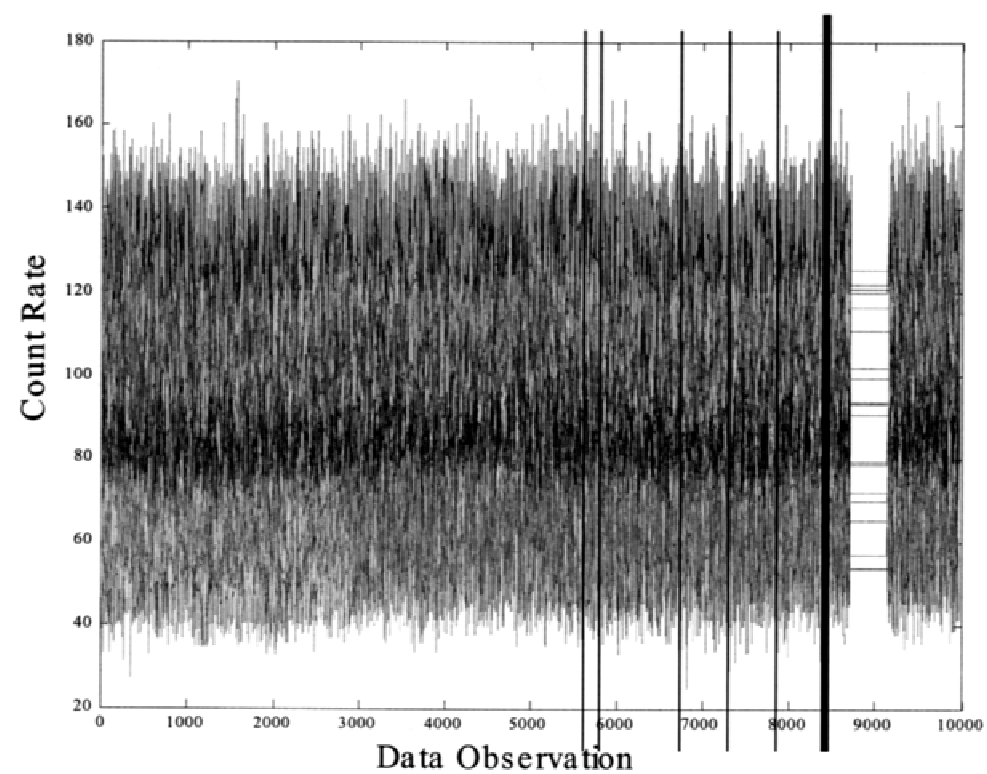
Fault Isolation

When a fault is detected in an extracted feature, the expert system attempts to isolate the root cause of the fault using its programmed rule base knowledge. The rule base knowledge is a collection of IF/THEN rules containing information mapping the feature space to the fault space and were developed through a failure modes and effects analysis coupled with empirical testing. The rule base contains a hierarchal collection of root causes and alarmed features that may be characteristic of certain faults. The hierarchal rule base allows physical component failures to be isolated by comparing the number of failed sensors to the total number of sensors that correspond to a certain component. An example rule is, "If all the RADSiP sensors that correspond to a certain component fail, then the fault exists in the component rather than in each of the sensors." In addition to the hierarchical rule base, the expert system can isolate faults based on what features are alarmed for a particular sensor. In many instances, certain faults may be characteristic of certain failures that a sensor may experience. For example, a sensor with a poor or loose electrical connection will have an increase in the radiation signal variance. Thus, the root cause of an increase in variance fault could be a loose electrical connection for the culprit sensor.

CAVIS testing has identified a number of abnormal behaviors that can occur in the reported radiation signals. These abnormalities are zero count rate, stuck count rate, count rate mean shift up and down, count rate variance shift up and down, and spike in count rate. Faults in certain features are characteristic of all of these abnormalities in the radiation signal. In addition, all of these abnormalities can be mapped to a root cause. Thus, it is possible to associate a set of faulted features with a root cause.

The logic contained in the rule base knowledge of the expert system is used to isolate the root causes of the abnormal conditions. The knowledge base enables the detection of characteristic faults such as dead or stuck sensors, which affect individual sensors, and hierarchical faults that affect CAVIS component such as the PCDU or the sensor concentrators.

Figure 6. Sensor concentrator communications failure



Results

The developed system is capable of detecting and isolating CAVIS faults including numerous types of component failures and environmental effects. The monitoring and diagnostic system was tested on several months of collected data and correctly detected and identified abnormal behaviors. Additional tests were conducted in the laboratory and CAVIS was able to correctly detect and identify all pre-enumerated faults. The following are several examples of the system's ability to properly detect and isolate faults.

Sensor Failure Detection

A data set collected by the CAVIS system was analyzed by the CAVIS monitoring system for abnormal behavior in order to validate system operation. This first test set was used to detect slowly degrading components. Any abnormal changes to the count rate indicate a system degradation or fault. Figure 5 presents count rate data from several sensors on the left and the sensor with anomalous behavior on the right. The data set's corresponding warnings and alarms are given in Table 2.

The CAVIS monitoring system detected one drifting sensor in the data set. The actual root cause could be any electrical component in the instrument chain but we will generally identify it as a drifting sensor. The count rate for the drifting sensor fell outside of a 99 percent confidence interval resulting in a CAVIS alarm. Because the CAVIS monitoring system is able to detect and isolate drifting sensors, it will provide an alternative response, which should reduce the frequency of manual inventory checks.

Communications Failure

This example illustrates the CAVIS monitoring system's ability to detect abnormalities that may be used for prognosis. Figure 6 presents data from an actual communications board failure that is characterized by the radiation readings from a specific sensor concentrator board being *stuck* at a constant rate. The CAVIS monitoring system experienced several stuck detector alarms prior to the common sensor concentrator communication failure at data observation 8,725. These single stuck count rates have been determined to be a precursor for this failure and can thus be used to predict future failures.

SNM Removal Detection

This example illustrates the CAVIS monitoring system's ability to detect and isolate the removal of SNM from a storage canister. The scenario is that a portion of the SNM has been removed, which results in a correlated mean shift down behavior in the weight and radiation signals common to the disturbed canister. This scenario was simulated in the laboratory by removing 50 grams of material from the weight sensor and moving the radiation source one half of a centimeter away from the radiation sensor. A plot of the resulting data is displayed in Figure 7.

A visual inspection of the data reveals that the corresponding weight and radiation sensors experience a mean shift down near data observation 150. It should also be noted that the weight sensor was very sensitive to this change and a much smaller change, on the order of a gram or two, could be detected. The warnings and alarms generated by the CAVIS monitoring system are presented in Table 3. The expert system concluded that the abnormality was caused by a removal of SNM.

Conclusions

The developed system is able to monitor the CAVIS system using the sequential probability ratio test, other key feature extraction algorithms, and the fault detection and isolation expert system. The SPRT and feature extraction system mines the necessary information from the radiation and weight signals to determine

Figure 7. SNM removal

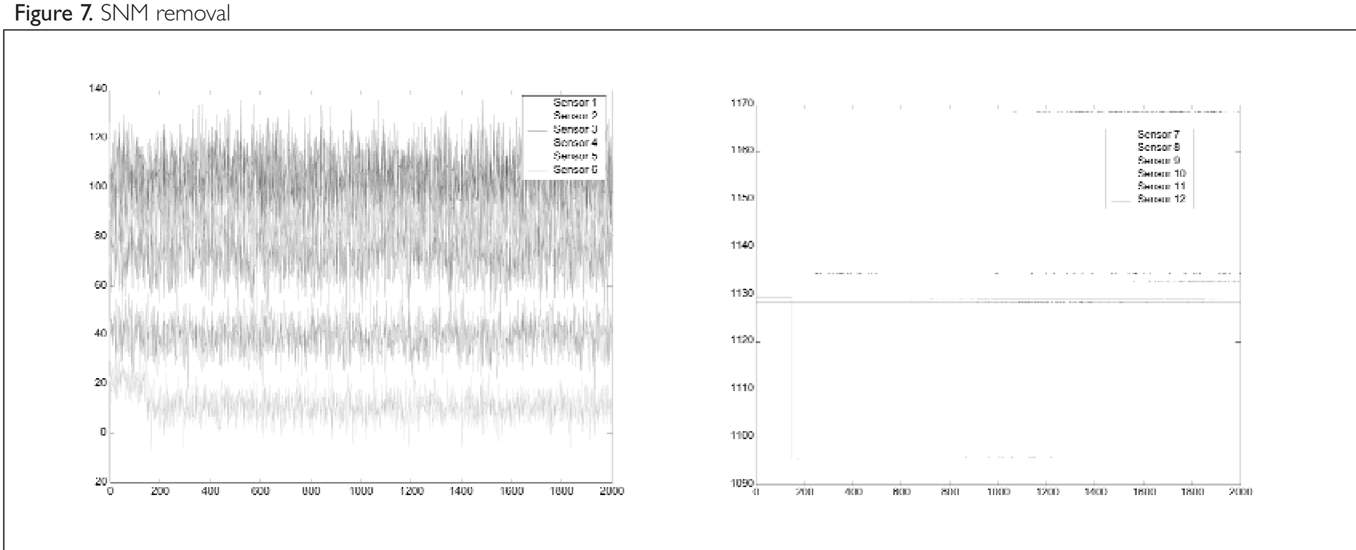


Table 1. Fault detection tolerances for extracted features

Feature	Fault Tolerance: Feature faulted if …
F1: Mean Shift Up SPRT (1,000 obs.)	4 SPRT MSU alarms in 1,000 obs.
F2: Mean Shift Down SPRT (1,000 obs.)	4 SPRT MSD alarms in 1,000 obs.
F3: Variance Shift Up SPRT (1,000 obs.)	4 SPRT VSU alarms in 1,000 obs.
F4: Variance Shift Down SPRT (1,000 obs.)	4 SPRT VSD alarms in 1,000 obs.
F5: Successive Mean Shift Up	MSU SPRT alarms for 2 cons. data obs.
F6: Successive Mean Shift Down	MSD SPRT alarms for 2 cons. data obs.
F7: Successive Variance Shift Up	VSU SPRT alarms for 2 cons. data obs.
F8: Successive Variance Shift Down	VSD SPRT alarms for 2 cons. data obs.
F9: Run Test 2	Nine cons. data obs. on same side of mean
F10: Variance of last 50 points	Variance of last 50 data obs. equals zero
F11: Variance of last 5 points	Variance of last 5 data obs. equals zero
F12: Mean Shift Up SPRT (100 obs.)	3 SPRT MSU alarms in 100 obs.
F13: Mean Shift Down SPRT (100 obs.)	3 SPRT MSD alarms in 100 obs.
F14: Variance Shift Up SPRT (100 obs.)	3 SPRT VSU alarms in 100 obs.
F15: Variance Shift Down SPRT (100 obs.)	3 SPRT VSD alarms in 100 obs.
F16: Current Count Rate	Current count rate equals zero
F17: Communication Status of CAVIS	Communication status of CAVIS is "bad"

Table 2. CAVIS monitoring system analysis of sensor failure data set

Ind.	Problem	Logic
1354	Warning: The RADSiP sensor may be drifting: 1 1 4	The sensor is experiencing SPRT alarms
1369	The RADSiP sensor is drifting: 1 1 4	The sensor is experiencing SPRT alarms

Table 3. CAVIS monitoring system analysis of SNM removal data set

Ind.	Problem	Logic
151	Warning: The CAVIS sensor may be drifting: 1 1 12	The sensor is experiencing SPRT alarms
152	The CAVIS sensor is drifting: 1 1 12	The sensor is experiencing SPRT alarms
155	Warning: The SNM may have been removed at canister common to CAVIS sensors: 1 1 6 and 1 1 12	Correlated mean shift down in weight and CR radiation signal
161	The SNM removal state no longer exists for canister common to CAVIS sensors: 1 1 6 and 1 1 12	The sensor is no longer experiencing a correlated mean shift down in weight and radiation signal
161	The CAVIS sensor is no longer drifting: 1 1 6	The sensor is no longer experiencing SPRT alarms
162	Possible removal of SNM at canister common to CAVIS sensors: 1 1 6 and 1 1 12	Correlated mean shift down in weight and radiation signal

the current state of the CAVIS system and the SNM. These data acts as the working memory for the expert system, which detects and isolates all pre-enumerated faults that may occur in the CAVIS system.

The system is capable of monitoring the condition of the CAVIS system, detect deviations from normality, isolate the root cause of the deviation, and can perform system prognosis resulting in early warning of component failures. Its operation will allow the implementation of economical, condition-based maintenance practices rather than more expensive reactive maintenance. The combination of CAVIS and its monitoring system will allow for the safe, reliable, and economical monitoring of SNM.

Future development may include expansion of the expert system rule base knowledge to incorporate currently unknown fault scenarios. If additional knowledge of the CAVIS system is gained, or if additional components are incorporated into the system, the rule base knowledge should be updated to account for these changes. Additionally, modification of the detection threshold tolerances will make the FDI system more or less sensitive to changes-in-state as needed. The optimal value for the thresholds may be different depending on need, as the values presented in this research were experimentally and empirically determined.

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Criminalizing WMD Proliferation: The Role of UN Security Council Resolution 1540

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Introduction

The United Nations Security Council unanimously passed Resolution 1540 in April 2004. This landmark measure legally charges all UN member states to enact and enforce effective measures to prevent the proliferation of weapons of mass destruction (WMD) and their means of delivery. The revelations regarding the expansiveness of the A. Q. Khan network contributed to the rapid passage of the resolution. Resolution 1540 is distinctive because it is the first time the UN Security Council has required all member states to act to prevent the illicit trafficking of chemical, biological, radiological, and nuclear (CBRN) materials and their means of delivery. It is also unique in that it specifically addresses the prevention of CBRN proliferation and trafficking among non-state actors.

The resolution has a direct impact on the management of nuclear materials and nonproliferation policy in the future. Consequently, the INMM Nonproliferation and Arms Control Technical Division and the INMM Northeast Chapter held a professional workshop on March 15, 2005, to engage topical experts in a discussion of UN Security Council Resolution 1540. Although Resolution 1540 is now more than one year old and the committee established to monitor its implementation has begun its work, many in the nonproliferation and nuclear materials management communities have not learned of the resolution or have not yet recognized its significance. This article provides a summary of and perspectives on the workshop discussion that was conducted on a not-for-attribution basis.

Summary of Resolution 1540

UN Security Council Resolution 1540 requires all UN member states to enact and enforce effective measures on the material control and accounting, physical protection, export, border security, and transshipment of chemical, biological, radiological, and nuclear (CBRN) materials and their means of delivery. The resolution requires states to incorporate criminal or civil penalties for violations. By October 2004, all member states were to have submitted country status reports on their legislative and regulatory infrastructure that related to the resolution. As of April 2005, 115 countries have submitted reports. Resolution 1540 also established a special committee with a two-year charter to monitor the Resolution's implementation and to review country reports.

The origins of Resolution 1540 are rooted in a statement by the Security Council on January 31, 1992, that "the proliferation of all weapons of mass destruction constitutes a threat to international peace and security." By defining WMD proliferation in such a way, the UN Security Council asserted its authority to act under Chapter VII of the UN Charter. Article 41 of Chapter VII provides the legal basis for the Security Council to employ measures to give effect to its decisions, and gives it authority to call upon UN members to apply such measures. These may include measures short of force, or if these are inadequate, the use of air, sea, or land forces as may be necessary to maintain or restore international peace and security. These measures may include demonstrations, blockade, and other operations by air, sea, or land forces of UN member states. Resolution 1540 by itself does not authorize the UN Security Council to take military action. An additional resolution would be necessary for such authorization, and it is very unlikely that the Security Council would take such action. However, invoking Chapter VII provided the UN Security Council the legal basis for subsequent enforcement of the provisions of the resolution and demonstrated its resolve on the issue.

Although Resolution 1540 is unique, it is not without precedent. Within a month after the September 11, 2001, terrorist attacks on the United States, the UN Security Council unanimously passed Resolution 1373, also invoking Chapter VII of the UN Charter, to require all member states to prevent and suppress terrorist acts and their financing. Both resolutions call for states to establish and enforce a national legal infrastructure to prevent terrorist acts. Both 1373 and 1540 require states to report on the status of that legal infrastructure within their countries. Like Resolution 1540, Resolution 1373 established a special committee of the UN Security Council—the Counter-Terrorism Committee

(CTC)—to monitor progress; however, the CTC was established as a standing body without an expiration date. All 191 UN member states submitted country reports to the CTC. In the ensuing four years, most states have submitted follow-up reports, in many cases up to four reports, and as a result of the iterative communications with the CTC, the quality of reporting has improved markedly.

In contrast, the 1540 Committee has received only 115 of 191 member state reports. The 1540 Committee, currently chaired by Ambassador Mihnea Motoc of Romania, has hired four experts, one each from the United States, Russia, Germany, and Brazil, and plans to hire three more in 2005 to review national reports. To ensure transparency, the committee translates and posts all of the country reports on the UN Web site. The committee's approach to assessing the reports is non-confrontational. Its goal is to identify gaps in states' regulations and then communicate constructive feedback to the member states. The committee experts are developing a matrix approach to analyze the reports in order to identify gaps in the national legal and regulatory structure of each member state, and to help foster remedial action.

A recent development that directly relates to Resolution 1540 is the adoption of UN General Assembly Resolution 59/290 the "International Convention for the Suppression of Acts of Nuclear Terrorism." This resolution, like Resolution 1540, addresses the threat of non-state actors in illicit trafficking and WMD proliferation. However, unlike Resolution 1540, this resolution is not legally binding solely by virtue of its passage. In order for Resolution 59/290 to become legally binding, a state must voluntarily sign the convention, and twenty-two countries must accede to the convention before it takes effect.

Perspectives and Implementation of Resolution 1540

The 1540 Committee has undertaken an important, but difficult task to be completed over the next year. It must complete its assessments of each nation's report and inform the Security Council by April 2006 of its progress. Although the 1540 Committee is set to expire in April 2006, the resolution does not expire. There are indications that the UN Security Council may act to extend the committee's mandate or reinforce the requirements of Resolution 1540 through a new resolution.

Resolution 1540 has the force of international law, and is enforceable by the Security Council because of the link to Chapter VII. It is complementary to existing treaties governing nonproliferation obligations. During debate on the resolution, several concerns were raised by member states:

- The validity of the approach used by the Security Council in passing Resolution 1540
- The appearance of the UN Security Council *legislating* requirements for the world
- The lack of a link to disarmament that is typically found in international agreements relating to nonproliferation
- Concern that Resolution 1540 creates a "global unfunded mandate"

To alleviate these concerns, the committee needs to develop a strategy for implementation of the resolution. Building upon the country assessments, the committee could encourage states to adopt best practices and could recommend model legislation. Although model legislation would have to be tailored to fit individual countries, it would be a first step toward filling the gaps identified by the country reports. While the reporting process itself can be useful for states because it forces them to examine their own legal and regulatory capabilities, some member states, particularly developing countries, have limited resources to compile and submit a national report, and develop and enforce the required regulations. For this reason, the committee should move quickly to match states that have offered assistance with those states that need assistance. A critical part of the implementation strategy should be leveraging existing organizations and regimes. Resolution 1540 has obvious links to export control regimes, nonproliferation organizations, interdiction and intelligence sharing activities (e.g., the Proliferation Security Initiative) and intergovernmental partnerships (e.g., G8).

Resolution 1540 has no clear monitoring or enforcement mechanism. Once the 1540 Committee completes its work, the task of monitoring compliance with the resolution will fall to the Security Council itself, unless it either extends the mandate of the 1540 Committee, creates a standing committee to follow the issue, or delegates responsibility to an existing committee or organization. International organizations with relevant expertise like the International Atomic Energy Agency and the Organization for the Prohibition of Chemical Weapons have offered their assistance. With respect to enforcement, most experts agree that the first order of business is to try to achieve universal compliance through a cooperative process. The first step will be the evaluation of the country reports, and responses to the states. A second step might be marrying those states that offered assistance with those states that might need it. Some member states have included requests for assistance in their national reports.

Whatever happens over the next year to the 1540 Committee and within the Security Council, the successful achievement of a unanimous resolution in the Security Council to criminalize trafficking in CBRN materials and their means of delivery is significant. By instituting the requirement that states are responsible for preventing WMD proliferation within their borders, Resolution 1540 has effectively codified an explicit sovereign responsibility of states to prevent trafficking of CBRN materials and their means of delivery. It reinforces existing obligations that apply to signatories of international treaties. What is new is that it captures those countries that have chosen to remain outside international nonproliferation treaties and holds those countries accountable. With further action by the Security Council, monitoring and enforcement mechanisms could emerge from the process that has begun in the 1540 Committee. Nonproliferation and nuclear materials management specialists should watch the evolution of this new nonproliferation tool for the international community with great interest.

The text of UN Security Council Resolution 1540 can be found at http://www.un.org/News/Press/docs/2004/sc8076.doc.htm.

Sandia National Laboratories' 14th International Security Conference—Strengthening the Nuclear Nonproliferation Regime: Focus on the Civilian Nuclear Fuel Cycle

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Introduction

Leaders around the world and across the ideological spectrum agree that the global nonproliferation regime is facing a serious test. The emergence of sophisticated terrorist networks, black markets in nuclear technology, and technological leaps associated with globalization have conspired to threaten one of the most successful examples of international cooperation in history. The rampant proliferation of nuclear weapons that was predicted at the start of the nuclear age has been largely held in check and the use of those weapons avoided. Nonetheless, with the thirty-fifth anniversary of the Treaty on the Nonproliferation of Nuclear Weapons (NPT), the threat of nuclear proliferation seems more serious than ever.

Although experts readily concede that there exist many pathways to proliferation, the threat posed by the misuse of the civilian nuclear fuel cycle has received considerable recent attention. While the connection between nuclear energy and nonproliferation has been a topic of discussion since the dawn of the nuclear age, world events have brought the issue to the forefront once again. U.S. President George W. Bush and International Atomic Energy Agency (IAEA) Director General Mohammad ElBaradei are among those who have highlighted proliferation risks associated with civilian nuclear power programs and called for revitalizing the nuclear nonproliferation regime to address new threats. From the possibility of diversion or theft of nuclear material or technology, to the use of national civilian programs as a cover for weapons programs—what some have called latent proliferation—the fuel cycle appears to many to represent a glaring proliferation vulnerability.

Just as recognition of these risks is not new, neither is recognition of the many positive benefits of nuclear energy. In fact, a renewed interest in exploiting these benefits has increased the urgency of addressing the risks. Global energy demand is expected to at least double by the middle of the century and could increase even more quickly. Much of the new demand will come from the rapidly expanding economies in China and India, but much of the developing world stands poised to follow the same path. This growth in demand is paralleled by concerns about global warming and the long-term reliability of carbon-based fuel supplies, concerns that expanded use of nuclear power can help to address. For these reasons and others, many countries in Asia have already clearly signaled that nuclear energy will play a key role for years to come.

Numerous proposals have been made in the last two years for reducing the proliferation risk of the civilian nuclear fuel cycle. These range from a ban on export of enrichment and reprocessing technology to countries not already possessing operational capabilities to multinational management of the nuclear fuel cycle and strengthening existing monitoring and security mechanisms. The need for international willingness to enforce nonproliferation commitments and norms has also been emphasized. Some of these proposals could significantly impact the production of nuclear energy.

Because the successful strengthening of the nonproliferation regime and the expansion of nuclear energy are so closely related, any successful approach to resolving these issues will require the creative input of experts from both the nuclear energy and nonproliferation communities. Against this backdrop, Sandia National Laboratories organized its 14th International Security Conference (ISC) around the theme: "Strengthening the Nuclear Nonproliferation Regime: Focus on the Civilian Nuclear Fuel Cycle." The goal of the conference was to begin a constructive dialogue between the nuclear energy and nuclear nonproliferation communities. The conference was held in Chantilly, Virginia—just outside Washington, D.C.—April 4–6, 2005, and was attended by approximately 125 participants from fifteen countries.

The ISC agenda was structured to produce a systematic review of the connection between civilian nuclear energy programs and the proliferation of nuclear weapons and to identify constructive approaches to strengthen the nonproliferation regime. The conference began by reviewing the energy and security context that has, once again, raised the profile of this issue. A discussion of the risks associated with the civilian nuclear fuel cycle was then used to inform the analysis of several potential risk-management tools. The conference concluded by looking for lessons from the past as well as looking forward to future opportunities, with a particular focus on East Asia.

In this paper we summarize the debates and ideas that emerged during the conference. Although we have drawn on material presented by speakers and comments made by participants, we do not quote or cite the specific contributions of individuals. More details on the conference agenda, as well as many of the presentations, are available at the conference Web site: http://www.intlsecconf.sandia.gov/.

Global Energy Demand and the Role of Nuclear Energy

Even conservative estimates predict that energy demand will double by the middle of the century and could grow much more rapidly. While increased energy efficiency could constrain this growth somewhat, the bulk of the demand will come from the developing economies of China and India, countries that most experts acknowledge will not be at the forefront of energy conservation efforts as they try to rapidly reach economic parity with the developed world.

The rest of the developing world will not be far behind in the demand for energy. By some estimates, as many as two billion people continue to live without reliable access to electricity, a key requirement for prosperity, health, and human welfare. As the link between prosperity and security is more widely recognized, it will be in the interest of all to find sustainable ways to provide energy to increase the global standard of living.

This growth in demand, coupled with growing concerns about the reliability of supply of carbon-based fuels and their long-term effect on the environment, has focused attention on sustainable alternatives. Although commonly associated with protection of the environment, sustainability also entails reliable access to energy at a reasonable and predictable price. Part of the solution to sustainability will be the expanded use of renewable energy sources, but most seem to agree that nuclear energy will also need to be a significant element in the global energy mix.

For nuclear energy to play a markedly increased role in supplying global energy needs, the challenges of cost, safety, waste disposition, and proliferation must be addressed. With the price of oil at record highs, nuclear energy has become more economically competitive on a relative basis than in the past. However, public concern about the safety of nuclear power has limited the expansion of nuclear energy in many countries. Concern about the link of nuclear power to nuclear weapons historically has not played such an important role in affecting public opinion, but this could change as the threat of nuclear terrorism and proliferation receive greater attention.

Issues of cost, proliferation, and safety all converge on the issue of nuclear waste, which may be the most serious impediment to the growth of nuclear energy. Dealing with the problem of waste not only requires addressing the safety and security of waste disposal sites but also requires exploring ways to minimize its volume and toxicity, to reduce the cost of long-term storage and altering its composition to limit its attractiveness to potential proliferators.

Assurance of nuclear fuel supplies is another critical element of the long-term viability of nuclear energy. Although currently abundant, uranium reserves are, like petroleum and natural gas, finite resources. A sustainable nuclear energy future will require extracting as much energy from these finite reserves as possible. This requirement, coupled with the requirement of reducing nuclear waste, led many nuclear energy experts to advocate a closed fuel cycle that includes the reprocessing or recycling of spent nuclear fuel. However, the nonproliferation community has generally opposed such recycling, since current methods result in the separation of plutonium that could be used to make nuclear weapons.

An Evolving Global Security Environment

In the last few years, concerns about nuclear terrorism and revelations of clandestine nuclear programs have provoked a reconsideration of the international nuclear nonproliferation regime. No longer is it just states that must be stopped from developing nuclear weapons: nonstate actors, unhindered by treaties and international norms, seek nuclear material for everything from dirty bombs to full-scale nuclear weapons. Nuclear black markets have been discovered that can provide services ranging from nuclear weapon design information to supplies of sensitive nuclear technology. The potential for such networks to supply weapons-useable nuclear material (or even nuclear weapons) cannot be ignored.

In addition, the NPT places no restrictions on the acquisition of enrichment and reprocessing technologies as long as they are subject to international safeguards, nor does it impose penalties on states that withdraw from the treaty. Consequently, some fear that the NPT has been or could be used to legally develop the knowledge and tools necessary for a nuclear weapons program. These latent nuclear weapon states could then withdraw from the NPT without consequence, a scenario referred to as breakout. Finally, a growing number of states outside the NPT possess nuclear weapons or the capability to produce them but are not subject to international obligations to control the export of sensitive nuclear technology or material.

In this context, the desire for nuclear energy, coupled with the increased access to technology and information, has heightened concern about the link between civilian nuclear energy programs and nuclear weapons programs. Weakening this link lies at the heart of many recent proposals for strengthening the nuclear nonproliferation regime.

The Proliferation Risk of the Civilian Nuclear Fuel Cycle

Whereas much attention is now focused on the civilian nuclear fuel cycle, its relative risk as compared to other paths to proliferation is not often discussed. Conference participants were asked to address the issue of relative risk, then, looking specifically at the civilian fuel cycle, to identify absolute risks that warrant particular attention.

There was general agreement that the civilian nuclear fuel cycle poses less risk than inadequately secured nuclear material or weapons or research reactors using highly enriched uranium. Clandestine military programs, distinct from civilian activities, were also acknowledged as posing a high risk.

Some argued that legitimate civilian fuel cycle programs pose a very small proliferation risk; that they have never been the basis of a weapons program. For example, they argued that the recently discovered black-market network in nuclear technology was rooted in the Pakistani nuclear weapons infrastructure rather than in legitimate civilian nuclear activities and that Iran's clandestine activities were not linked to its civilian program.

In addressing the absolute risk of the civilian fuel cycle, all agreed that creating or diverting weapons useable material poses the greatest risk, which focuses attention on enrichment and reprocessing capabilities. Traditionally, the risk of reprocessing has received greater attention than that of enrichment, primarily because of the perceived greater difficulty of procuring or developing enrichment technology. Although the availability of centrifuge technology through the black market has recently altered this assessment, concerns about reprocessing remain high in the nonproliferation community, most of whom regard an open fuel cycle, i.e., one that does not reprocess spent nuclear fuel, as posing the least risk.

However, several participants argued that reprocessing spent nuclear fuel could actually reduce proliferation risk if it were carried out under strict safeguards, since the time during which separated plutonium is available is relatively short. They argued that after plutonium is converted to mixed oxide fuel, it is much less attractive to potential proliferators than untreated spent fuel—particularly over time, as the radiation barrier of untreated spent fuel decays. They characterized the open fuel cycle as shifting the burden of proliferation to future generations, because untreated spent fuel becomes easier to access and the plutonium content becomes more attractive for use in weapons.

Some participants argued that assessing the risk of the civilian fuel cycle could not be done in the abstract, that the nonproliferation credentials of individual countries are an important factor in any consideration. They argued that not all states pose the same risk and that criteria for assessing risk should be developed. Japan was cited as an example of a low-risk country, based on several criteria: legal renunciation of nuclear weapons, an obvious need for nuclear power, transparency of its nuclear program, an exemplary record of compliance with nonproliferation rules and norms, and numerous proactive efforts to promote nonproliferation.

There was general acknowledgement that risk-assessment tools that would help establish consensus on the proliferation risk of the civilian fuel cycle would be of value. Such tools would be useful in building a global consensus about priorities for reducing the proliferation risk of the fuel cycle and could be an important confidence-building measure among states that question each others' intent and motivation.

Reducing the Proliferation Risk

Since the advent of nuclear energy, political and technical experts have been working to address the proliferation risk of the civilian nuclear fuel cycle. The creation of the IAEA, the signing and ratification of the NPT, the development of safeguards regimes, and multiple proposals for more formal international fuel cycle management tools are only a few of the many important efforts. In the last year numerous proposals have been made for changing, supplementing, and strengthening traditional approaches. Based on the preceding discussion of nuclear energy needs, proliferation threats, and the risks of the civilian fuel cycle, conference participants were asked to consider a variety of these approaches and to evaluate their effectiveness in reducing proliferation risk.

Changing the Regime

Many recent proposals from governments and the IAEA seem to imply that the current nonproliferation regime is fundamentally flawed and needs to be altered significantly. These proposals all share the idea that the best way to reduce risk is to prevent some states from having full control over the entire fuel cycle while still finding ways to confer the benefits of nuclear energy. Roughly, the proposals can be described as either strategies of denial or strategies of multilateral cooperation.

Denial Strategies

In their strongest form, denial strategies would prevent any country not currently in possession of enrichment and reprocessing technologies from acquiring them. Proponents argue that the only way to be certain that sensitive technologies are not misused is to prevent their continued spread by enforcing more stringent export controls.

Less restrictive approaches would deny access to only those states considered likely to misuse or irresponsibly safeguard nuclear technology and material. Such criteria-based export controls would require exporting countries to consider a set of factors prior to issuing an export license, such as whether the technology in question makes economic sense (i.e., does a country with a very small-scale nuclear energy program have a reasonable need for an enrichment facility), whether the requesting state has a strong history of nonproliferation compliance, and whether the region into which the technology would be imported is politically stable.

Related to the call for more stringent export controls are proposals for a moratorium in the development of additional enrichment and reprocessing capacity anywhere in the world, including those countries with existing capabilities. Justification for a moratorium is based on the fact that current supplies of enriched uranium outstrip demand and will continue to do so for several decades. With respect to reprocessing, the argument is that current methods are simply too risky and that until new proliferation-resistant recycling technologies are developed, reprocessing cannot be justified.

Regardless of their views on the merits of denial strategies, conference participants were generally skeptical that any of these ideas would be well-received at the upcoming NPT Review Conference. Stricter export controls are likely to draw protests and claims of discrimination and could lead some states to seek such capabilities clandestinely or to develop them indigenously. In addition, many argued that denial will be ineffective, since technical know-how is already widely disseminated and a growing number of countries now possess the indigenous capability to develop the full fuel cycle. They argued that denial strategies will have the greatest impact on legitimate industry and countries who play by the rules rather than on those that pose the real risk, namely states and nonstate actors who intend to misuse the technology in the first place.

In a similar vein, some participants argued against imposing a moratorium on new capacity development. Since enrichment facilities are extremely capital-intensive and require long lead times and long-term commitments, a moratorium could reduce confidence in the ability of existing market mechanisms to assure supply into the future. Lack of confidence in existing suppliers could result in states rushing to acquire their own enrichment capabilities now rather than risking supply shortages in the future.

Multilateral Cooperation Strategies

Advocates of multilateral cooperation argue that the way to discourage additional countries from acquiring the full fuel cycle is to assure adequate, cost-effective supplies of nuclear fuel in the future through international mechanisms. (It is worth noting that all of the technology denial approaches are closely coupled with some form of supply guarantee.) Some also argue that multinational oversight of sensitive technologies and facilities would reduce the risk of their misuse or diversion by a state seeking to break out of the NPT. Providing spent fuel and waste management services is often seen as an additional incentive for countries to accept a multinational approach.

Multilateral or multinational approaches (MNAs) have a long history dating back to the 1946 U.S.-initiated Baruch plan and have received regular reconsideration over the past sixty years. The most recent exploration was conducted by the IAEA Experts Group on Multilateral Nuclear Approaches, an effort chaired by conference speaker Bruno Pellaud. The final report of the Experts Group sets out a stepwise pathway through which greater international oversight of the civilian fuel cycle might be realized.

The report recommends beginning with strengthening fuel service supply assurances, particularly enrichment services, as an incentive for states with relatively small nuclear energy programs to voluntarily forgo national control of sensitive technologies. Supply assurances could be guaranteed by industry through long-term, transparent contracts and agreements or could include government- or IAEA-backed guarantees through the establishment of fuel banks.

A more ambitious step would involve putting existing fuel cycle facilities under some form of multinational control. Such control could be exercised either through joint ownership of a facility that would continue to be operated by a single country (i.e., the current Eurodif model) or through more substantial multinational involvement with different stages of R&D and operations occurring in several countries and involving a multinational staff (i.e., the current URENCO model). Underlying both scenarios is the premise that the system would be self-policing, with all partners scrutinizing the behavior of each other. Going one step farther, constructing and operating all new facilities under multinational control was noted as a possibility for the future.

The concept of voluntary MNAs that build on existing market mechanisms and do not involve establishing additional bureaucratic controls was widely regarded as valuable. However, even proponents of MNAs acknowledged that such arrangements would not address the full range of risks associated with the fuel cycle. States motivated to develop latent nuclear weapons capabilities would be unlikely to participate in such arrangements voluntarily, even with strong economic incentives. Multinationally controlled facilities could help in reducing the risk of breakout, and to some extent the risk of illicit diversion of material might be reduced because of the self-policing function and the existence of fewer total facilities to monitor. However, some argued that by involving multiple countries, technology diffusion might actually become more difficult to control. In addition, if new multinational facilities were constructed in states not already possessing nuclear weapons or fuel cycle facilities, new vulnerabilities could be introduced.

Ultimately a major benefit of MNAs would be as confidence-building measures among states that have a legitimate interest in nuclear energy. This could be particularly valuable in conflict-prone regions, where perceptions and misperceptions about nuclear intentions might drive conflict and even proliferation. The economic benefits to be gained from MNAs could also decrease the demand for national control of fuel cycle services in states planning for expansion of nuclear power in the future. However, many expressed skepticism in the ability of the international community to actually guarantee fuel supply. Others noted that although the prospect of spent fuel and waste management services could be an important incentive for states to participate in MNAs, specific ideas for international spent fuel repositories have been plagued with both political and technical problems and a viable solution remains elusive.

Strengthening the Existing Regime

Conference participants all agreed that much progress could be made in the fight against proliferation simply by strengthening or better implementing tools that have already been developed. They also emphasized the critical need to enforce rules and norms more rigorously.

The IAEA Additional Protocol

Of all the tools considered during the conference, none received stronger support than the Additional Protocol. Because it offers far greater transparency and intrusiveness than traditional safeguards agreements, the Additional Protocol would significantly impede facility misuse and the construction of clandestine facilities and would offer advanced warning of activities that might lead to NPT withdrawal.

Even while voicing support, several participants noted that even universal adherence to the Additional Protocol would not substantially increase the ability to detect clandestine facilities nor would it speak to the question of enforcement of rules and norms.

Enhancing the Nonproliferation Culture Within Industry

Several participants, including representatives of the nuclear industry, noted that an added emphasis on creating a security and nonproliferation culture among industrial actors not only could reduce the proliferation risk but also could increase confidence in the system in much the same way that the nuclear industry created a robust, self-policing safety culture following the Three Mile Island accident. Industry was encouraged to take a leadership role in building a norm of vigilance at all levels. Such an approach would arguably be in the best interest of industry, since a single case of proliferation could have disastrous consequences for the business.

There was concern, however, over the issue of transparency. Representatives of industry felt that opening security measures to additional outside scrutiny, as is done with safety, might actually create vulnerabilities. More thinking needs to be done to identify ways to balance the value of transparency with the need for security.

Advanced Fuel Cycles

Some participants argued that in the long term, the most effective way to reduce the risk of the civilian fuel cycle would be a wholesale technology shift to make it far less transferable to weapons production. The IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) and the multinational Generation IV International Forum (GIF) are both devoting substantial resources to the development of new technologies and to methods for evaluating their proliferation resistance. The goal is to create fuel cycles and processes that are more easily monitored and that result in waste that is less attractive for use in weapons and more suitable for long-term disposal. Concepts for tamper-proof, disposable reactors that minimize fuel handling, are also being considered as ways to reduce proliferation risk. Such technologies would also enhance the long-term viability of the nuclear industry.

Under the best conditions, however, these new technologies will not be available for many years and thus offer no prospect for addressing the proliferation risks stemming from current and near-term nuclear energy production. Moreover, the most optimistic proponents of advanced fuel cycles and next-generation reactors agreed that preventing states from using older technology will be nearly impossible.

New Monitoring Approaches

To address current proliferation risks, new technologies to improve monitoring of both enrichment and spent fuel treatment processes might be considered. Existing monitoring techniques are imprecise in their measurement of both material quantity and composition, leave substantial portions of sensitive processes unmonitored, and incur significant time lags before the collected data can be analyzed. These weaknesses make misuse or diversion less detectable and fuel cycle activities less transparent. Real-time accountability tools could address these flaws and might also reduce the monitoring costs by automating measurement tasks that would otherwise have to be performed by inspectors.

While some participants thought that advanced process monitoring could provide a useful additional tool for the IAEA, others questioned whether it would truly be practical in large-scale industrial facilities and cautioned that it could divert attention from more pressing concerns. Not only could it produce false positives that would require attention from inspectors, but strict standards for acceptable levels of variability would need to be defined. Some suggested that the cost/benefit ratio of such detailed process monitoring might be too high.

Lessons Learned from the Past

In considering ways to manage the risk of proliferation in the future, lessons from the past should not be overlooked. Most participants who addressed this issue expressed the view that neither technology restrictions nor multinational management arrangements would have prevented past efforts to develop nuclear weapons.

Upon examination of cases in which governments have chosen to relinquish a nuclear weapons program, it is difficult to find common themes. A change in threat perception (in the case of South Africa), transition from military to civilian government (Brazil and Argentina), and pressure by powerful allies (Taiwan and South Korea) have all contributed to the decision to abandon military programs. Export controls alone were insufficient to effect change in all these cases. In the case of Brazil, restrictions on trade in nuclear technology resulted in a massive indigenous nuclear R&D program that made significant progress in developing full fuel cycle capabilities. Removal of the original reason for pursuing nuclear weapons (national prestige, perceived security threats, or domestic political posturing) was arguably the most important factor in bringing about change in policy.

In cases where states have successfully pursued a nuclear weapons program outside the auspices of the NPT, it was done independently of a civilian nuclear power program. Research reactors played an important role in the military programs of India, Pakistan, and Israel. Again, removing the motivation for developing nuclear weapons would be a prerequisite for any decision to disarm or even to restrict further development.

In applying these lessons to the case of Iran, participants observed that Iran bears certain resemblances to the case of Brazil: Iran now likely has the indigenous capability to develop nuclear weapons, and its leaders seem to perceive nuclear weapons as a symbol of modernity and prestige. Peaceful regime change, brought about by internal forces and accompanied by economic incentives to solve other pressing domestic problems, may bring about a change in policy. Technology denial is seemingly no longer an option, although the prospect of technical cooperation in selected areas might be an incentive to abandon military nuclear programs.

A Closer Look at East Asia

Although the concern about the proliferation risk of the civilian nuclear fuel cycle is clearly a global issue, the problem is more acute in East Asia than anywhere else. Northeast Asia is the only region in which nuclear generating capacity is expected to grow over the next twenty years. Capacity will actually decline everywhere else. Ambitious projections suggest that China alone could construct forty new reactors by the middle of the century and will almost certainly build enrichment and reprocessing capacity to match.

The increased demand for nuclear energy is a manifestation of the growth in demand for energy generally throughout the region. Demand is driving up prices, but it is also heightening tensions in a region already beset by conflicts and mistrust. With the exception of China, the region is poor in both uranium reserves and available land on which to construct spent fuel storage and disposal facilities. With energy security a growing concern and energy independence a much sought after goal, countries in the region will need to start making decisions very soon that will affect both the course of nuclear energy and nonproliferation regionally and globally.

China's possession of nuclear weapons and the fact that its nuclear energy program is young but poised to expand substantially in the near future, make it a special case in the region. Chinese researchers are on the forefront of advanced reactor technology, and plans are being developed for the construction of fuel cycle facilities. China's choices about export control and regional cooperation will be perhaps the most fundamental factor in determining the course of proliferation issues associated with nuclear energy. Most outside observers agree that for now, however, China's focus on economic development has taken priority over these longer-term questions.

Just as Northeast Asia is at a turning point, countries in Southeast Asia such as Indonesia and Vietnam are just starting to plan for a nuclear energy future. The opportunity to consider new approaches for the region is now. Facing the daunting task of initiating a nuclear energy program, countries in Southeast Asia might be particularly amenable to technology cooperation as an incentive to participate in new approaches. Decisions about national reprocessing and enrichment needs have not been made in these countries and could, under the right circumstances, be influenced.

Ideas for regional cooperation on nuclear energy issues are not new to East Asia. In the 1990s alone, more than twenty proposals were made by recognized scholars from both inside and outside the region. Most suggested an Asian analog to Euratom (commonly coined either Pacatom or Asiatom). While each proposal differed in scope and ambition, nearly all concluded that the most promising avenues for cooperation lay in regional cooperation on safety issues and on spent fuel and waste management.

For all the promise of regional cooperation, many speakers and participants warned of potential pitfalls. The details are extremely important, and no one should assume that the Euratom model can be transported wholesale to Asia, given the unique challenges of the region. As one participant noted, cooperation done badly could actually increase regional tensions. In sum, the general feeling was that, at least initially, the real value of regional cooperation would be in building confidence among players in the region.

Conclusions

The conference concluded with a roundtable discussion in which conference participants were asked both to highlight the most important points raised thus far and to propose specific actions for the future.

Key Points

Panelists again sought to put the proliferation risk of the civilian nuclear fuel cycle into a larger perspective and reiterated their concerns with several proposals for managing the risk.

The Civilian Nuclear Fuel Cycle is Not the Greatest Risk to Proliferation

There was general agreement that the civilian nuclear fuel cycle poses less risk than inadequately secured nuclear material or weapons or research reactors using highly enriched uranium. Although all agreed that enrichment and reprocessing facilities pose a risk, there was little enthusiasm for an overhaul of the nonproliferation regime at this point. Several panelists argued that attempts to fundamentally alter the regime distract attention from more important matters, namely implementing existing tools and enforcing existing norms. Developing risk assessment methodologies that would help achieve consensus on the risk of the civilian fuel cycle relative to other risks could be a useful endeavor.

Distinguish Between Positive and Negative Tools for Managing the Risk

The need to evaluate the risk associated with the nuclear fuel cycle in a much broader context was also emphasized. The world today faces many threats in addition to proliferation and terrorism, including insufficient energy resources and environmental degradation. When considering tools to manage the proliferation risk of the civilian nuclear fuel cycle, some participants suggested distinguishing between positive and negative tools. Positive tools are those that reduce the proliferation risk without increasing other risks, such as energy insufficiency or environmental degradation, and were viewed as having a greater likelihood of success.

Further Restrictions on Trade Could Be Counterproductive

Some panelists argued again that further restrictions on trade would be ineffective and perhaps counterproductive. They argued that increased controls on trade would neither reduce the risk of breakout by countries already in possession of the entire fuel cycle nor prevent indigenous development or clandestine procurement. In fact they could motivate states to rush to develop additional capabilities before restrictions are in place. According to this perspective, a better approach would be to demonstrate that the current market has the capacity to supply needs far into the future. They argued that because of the long lead times required even to maintain existing capacity, any moratorium on developing new capacity for enrichment and reprocessing would erode confidence in the long-term viability of supplies.

Technological Solutions Have Limited Value in Reducing Risk

In arguing for a pause before developing new enrichment and reprocessing facilities or additional enrichment capacity, some argued that it would provide time to develop new methods of process monitoring or to incorporate higher levels of proliferation resistance into the fuel cycle. They suggested that real-time process monitoring could give the international community additional tools that would stiffen resolve to deal with noncompliance quickly and resolutely. Others, however, expressed skepticism that technical fixes would markedly reduce the proliferation risk in the short term, since older technologies will remain available, and since process monitoring cannot prevent misuse. Some expressed the view that pursuit of new technological solutions often is used to justify political inaction and that the focus should be on fully implementing existing technical monitoring and protections tools. The general sentiment seemed to be that political will was far more important than new technology.

Multinational Approaches as Confidence-Building Measures

Multinational approaches received mixed reviews. Some viewed MNAs, particularly in their most ambitious forms, as unlikely to be accepted for a host of reasons. Others argued that MNAs failed to directly respond to the most urgent proliferation threats and vulnerabilities. Defenders of the concept, however, argued that MNAs might be a good vehicle by which to encourage greater acceptance of other tools. Responding to critics who dismissed MNAs as lacking relevance, proponents pointed out their potential value as confidence-building measures to increase transparency and reduce regional tension—both important factors in reducing the demand for nuclear weapons.

Reducing Demand for Nuclear Weapons is Critical

There was also general agreement that the efforts to prevent proliferation ultimately hinge on removing the motivation for countries to develop nuclear weapons. Reducing demand deserves much more attention and will be required to prevent indigenous or clandestine military nuclear programs.

Recommendations for the Future

Recommendations for practical steps that could be taken in the near term fell into three general categories: reinforce and strengthen existing mechanisms, increase incentives for countries not to develop the entire fuel cycle, and decrease the risk of breakout.

Reinforce Existing Mechanisms

Pushing for universal compliance with the Additional Protocol and strengthening states' abilities to implement and enforce existing export control mechanisms were recommended as being important near-term priorities. Offering technology cooperation that could advance nuclear energy programs or enhance nuclear security in exchange would be in the interests of all parties and was viewed as more likely to succeed than negative tools that focus only on prohibition and denial.

Strengthening the physical security for facilities containing sensitive material and technology should also be pursued. In addition, some suggested that more robust use of the Proliferation Security Initiative for interdiction of suspicious shipments would be more effective than imposing additional restrictions on trade.

Increase Incentives for Not Developing the Entire Fuel Cycle

Some argued that the highest priority should be placed on the development of solutions for spent fuel disposition as a way to reduce incentives for near-term reprocessing. They argued that overcoming political barriers to new international approaches should be a near-term goal.

Others argued that a high priority should be placed on developing methods to increase confidence in the ability of the existing market to provide fuel supplies well into the future. They also suggested encouraging trade within the legitimate nuclear market as a way to limit clandestine activities.

Some suggested that the prospect of increased technical cooperation could be an incentive to forgo development of the entire fuel cycle. Topics for technical cooperation could include proliferation-resistant fuel cycles, physical security, and nuclear safety.

Decrease the Risk of Breakout

Most participants agreed that the problem of states withdrawing from the NPT after acquiring the means to produce fissile materials was a threat that the tools discussed during the conference largely failed to address.

Systematically looking at breakout scenarios for fuel cycle states and assessing the institutional, legal, and security mechanisms that might inhibit withdrawal, or at least limit its consequences, was suggested as a worthwhile exercise.

Negotiating and implementing a fissile material cutoff treaty was suggested as a means to universally ban the production of fissile material for weapon purposes. Its associated verification regime could also allow increased monitoring of enrichment and reprocessing facilities.

Some also suggested developing another addition to IAEA safeguards that would make safeguards commitments irreversible. This would preclude states from keeping unsafeguarded material or facilities after withdrawal from the NPT.

Value of Continuing Dialogue

Although there was much debate about the best path forward, disagreements did not always divide nuclear energy and nonproliferation experts. On several points, including the need to reduce demand for weapons, the importance of enforcing existing norms, the value of voluntary, incentive-based approaches, and the importance of positive tools that reduce proliferation risk while not damaging prospects for sustainable nuclear energy, the two communities were in strong agreement. Additional work involving both communities, particularly focused on the specific issues affecting East Asia, offers the promise of a growing international consensus on the most useful, sustainable paths to reducing the proliferation risk of the civilian nuclear fuel cycle.

Control of Proliferation and the Challenge of Sensitive Nuclear Technology

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For more than a half century the world has struggled with the challenge of reconciling the development of nuclear energy for peaceful purposes with preventing states using their nuclear knowledge, technology, and assets to acquire nuclear weapons. The first means proposed to address this challenge was the U.S. Baruch Plan in 1946. Based on the conclusion of the Acheson-Lilienthal report of March 1946, that safeguards on nationally owned and operated facilities alone would not be adequate to achieve the objective of preventing the spread of nuclear weapons, the Baruch Plan proposed establishing an International Atomic Development Authority for international ownership or managerial control of nuclear fuel cycle activities that were judged to be potentially dangerous to world security. That plan was too ambitious to gain the support necessary to make it a reality and it remains so today, although ideas along similar lines have recently emerged.

The second approach, following President Eisenhower's 1953 Atoms for Peace initiative that opened the way to international cooperation in civil nuclear activity, was the gradual emergence of an international nonproliferation regime based on nationally owned and operated nuclear activity subject to bilateral agreements. This led to multilateral treaty-based undertakings in which states agreed not to seek or acquire, through any means, access to nuclear weapons or other nuclear explosive devices, and to accept international safeguards implemented by the International Atomic Energy Agency to ensure that peaceful nuclear activities would not be diverted to weapons or explosive purposes. The legal and political foundation of that regime is the 1968 Nuclear Nonproliferation Treaty (NPT), the core purpose of which is halting the spread of nuclear weapons.

Reaching agreement on the text of the treaty entailed two *bargains*. One was that although the treaty made a distinction between five recognized nuclear weapon states and the rest of the world, the nuclear weapon state parties committed themselves to reduce their nuclear arsenals and negotiate in good faith toward the elimination of nuclear weapons (Article VI). The other was that in obligating themselves not to acquire nuclear weapons the non-nuclear state parties would maintain the "inalienable right….to develop research, production and use of nuclear energy for peaceful purposes without discrimination ***and in conformity with article I and II of this Treaty."*** (Article IV.l) (emphasis supplied). Furthermore, responding to the concerns of developing nations, the treaty acknowledges an "undertaking to facilitate…a right to participate in the fullest possible exchange…for peaceful uses of nuclear energy."(Article IV.2). Supplier states emphasize *in conformity with* and *possible* whereas recipient states, especially in the developing world, focus on *inalienable* and *fullest.*

Article IV did not exclude any specific activities, even those that could potentially put a state in a position to produce weapons-usable material. From the outset, the nuclear fuel cycle has been understood to include facilities for enriching uranium for nuclear power plant fuel—a process that can also provide highly enriched uranium for nuclear weapons—and reprocessing spent nuclear power plant fuel to obtain plutonium—material that can also be used for nuclear arms. David Bergmann, a former Israeli Atomic Energy Commission chair made explicit what was always implicit when he declared that "…by developing atomic energy for peaceful uses, you reach the nuclear weapon option. There are not two atomic energies." Whether or not a state would decide to pursue a weapons option is a matter of motivation, incentive, and political decision—all considerations that largely derive from factors outside the realm of technical capability although ultimately dependent on it.

India's nuclear test in 1974, a surge of interest in nuclear energy following the 1973 oil crisis, and growing interest in the transfer of reprocessing technology (to which some suppliers were responsive), led the key nuclear suppliers, at U.S. urging, to meet and consider principles and practices that should serve as guidelines for nuclear export policy. While most of the agreed provisions related to nonproliferation, safeguards, physical security, and conditions for the retransfer of material, equipment and technology provided by the suppliers, two related to the matter of the Article IV language on "inalienable right" and "fullest possible exchange." The United States argued unsuccessfully for a presumption of denial of sensitive technology transfers, but the suppliers did agree to exercise restraint in considering the export of enrichment, reprocessing, and heavy water production technology, and to "encourage recipients to accept, as an alternative to national plants, *supplier involvement and/or other appropriate multinational participation in resulting facilities."* (INFCIRC/254, para. 6(a)).

In practice, none of the seven original members of the Nuclear Suppliers Group have transferred sensitive technologies since agreeing the guidelines in 1976. France cancelled a reprocessing plant agreement with Pakistan and URENCO declined to allow Germany to transfer centrifuge technology to Brazil. As the nuclear supplier group has increased in size to more than forty today, this continues to hold true. At the same time development of multinational arrangements were few and far between—URENCO and EURODIF being the two principal examples. Legally binding political undertakings subject to verification of national activities through safeguards, including enrichment and reprocessing, have been the mainstay of the NPT regime.

At the 1974 IAEA General Conference, with reprocessing and plutonium access in the spotlight, the issue of establishing internationally approved facilities to handle spent fuel arising from power reactors as an alternative to individual countries developing their own technology for this purpose was raised. The Final Declaration of the 1975 NPT Review Conference included the finding that "regional or multinational nuclear fuel cycle centres may be an advantageous way to satisfy, safely and economically, the needs of many states, while at the same time facilitating protection and the application of safeguards." Multinationalism was advocated by U.S. Secretary of State Henry Kissinger in a speech before the UN General Assembly in September 1975. He stated that "the greatest single danger of unrestrained nuclear proliferation resides in the spread under national control of reprocessing facilities…The United States, therefore, proposes as a major step to reinforce all other measures, the establishment of multinational regional nuclear fuel cycle centers." One immediate consequence of this was U.S. endorsement of an IAEA study of regional nuclear fuel cycle centers, one of the first efforts to explore systematically multinational options for fuel cycle activities.

At the national level, even stronger measures were introduced. Of all supplier states the United States was the most energized in attempting to deal with sensitive nuclear technology transfers. This was true in both the executive and legislative branches of government. Beginning in 1975 Congress passed resolutions expressing concern over the proliferation threat posed by the possibility of the development of independent reprocessing and enrichment facilities and argued in support of U.S. initiatives for the development of regional, multinational fuel cycle centres. The 1976 Symington Amendment to the Foreign Assistance Act called for a cut-off of economic and military assistance to any country that imported or exported reprocessing or enrichment materials, equipment, or technology unless it agreed to place all such items *under multilateral auspices and management when available.* The Nuclear Nonproliferation Act of 1978 (NNPA), the most comprehensive and far-reaching legislation on peaceful nuclear cooperation and non-proliferation since the Atomic Energy Act of 1954, discouraged transfers of sensitive nuclear technology and enjoined the President to seek international agreement by which enrichment, reprocessing and fabrication of fuels using weapons-usable material should be carried out only in *facilities "under international auspices."* The NNPA also called for the possible establishment of an international nuclear fuel authority (INFA), one element of which would be the creation of an institution that would control a stockpile of nuclear fuel to serve as a back-up guarantee to suppliers' fuel supply commitments for non-nuclear weapon states under comprehensive safeguards that did not establish national enrichment or reprocessing facilities and placed any existing facilities under effective international auspices and inspection. From the mid-1970s until the mid-1980s, a series of initiatives were pursued; they will be briefly discussed below in conjunction with institutional proposals currently being discussed.

Stimulated by revelations in 2002 that Iran had failed to report 1) the construction of a pilot plant to enrich uranium, 2) the import and subsequent processing of natural uranium, including enriching uranium and separating plutonium in the absence of safeguards, and 3) the construction of a heavy-water plant presumably to service plutonium-producing reactors that would have little if any justification in a civil nuclear program, the issue of reconciling peaceful and military uses of the atom once again took center stage. The Iranian situation called into question the adequacy of the NPT and the IAEA safeguards system, upon which the nonproliferation regime has rested for decades, to foreclose further nuclear proliferation. Such concern had already been raised following the discovery in 1992 of a substantial clandestine nuclear weapon development program in Iraq and lessons being drawn from experience with North Korea.

The discoveries in Iran set in motion a number of suggestions, recommendations, and initiatives to deal with the challenges confronting the international nonproliferation regime. One of the suggestions related to safeguards was the need for Iran to adhere immediately to the strengthened safeguards system that was embodied in the Additional Protocol to NPT comprehensive safeguards agreements. Such adherence would increase the transparency of the Iranian program. While seen by all as a necessary step for Iran to take, many questioned whether strengthened safeguards alone are an adequate response to proliferation risk since, under the cover of safeguards, a state could develop the full nuclear fuel cycle and then invoke the NPT withdrawal clause (Article X). Once such a state had withdrawn from the NPT it could apply its nuclear capabilities to weapons purposes. This possibility raised important questions regarding other consequences of withdrawing from the NPT, such as disposition of materials, equipment and technology acquired for civil purposes.

Two main approaches have dominated discussions of the nuclear fuel cycle in the past year and a half, each of which has antecedents in the brief historical overview just presented. One approach focuses on restraint or denial in the transfer of technology; the other is centered on the idea of de-nationalizing sensitive nuclear fuel cycle activities and bringing them under some form of multinational or multilateral arrangement. The former approach is reflected in the proposals that President George W. Bush outlined in a speech at the National Defense University on

February 11, 2004. Referring to the loophole in the NPT (Article IV) that enables countries to acquire facilities capable of producing nuclear material that can be used to build nuclear explosives under the cover of civilian nuclear programs, Bush proposed that:

- the members of the Nuclear Suppliers Group refuse to sell enrichment and reprocessing equipment and technology to any state that does not already possess full-scale, functioning enrichment and reprocessing plants
- the leading nuclear exporters ensure that states have reliable access, at reasonable cost, to fuel for civilian reactors so long as those states renounce enrichment and reprocessing
- that by the following year, only states that have signed the additional protocol be allowed to import equipment for their civilian programs

Another initiative in the president's speech was to expand cooperative threat reduction programs to secure sensitive materials and prevent former weapons scientists from marketing their skills to potential proliferators. He also called for early adoption of a UN Security Council resolution requiring all states 1) to strengthen laws and international controls that govern proliferation, 2) to criminalize proliferation, 3) to enact strict export controls, and 4) to secure all sensitive materials within their borders. This proposal was adopted in April 2004 as UN Resolution 1540. (See "Criminalizing WMD Proliferation: The Role of UN Security Council Resolution 1540" on page 22.) The president also recommended the creation of a special committee on safeguards and verification within the IAEA Board of Governors. These proposals were made in conjunction with a more proactive counter-proliferation approach symbolized by the Proliferation Security Initiative (PSI) for interdiction of the transfer of dangerous technologies or their components.

The second approach, embraced by IAEA Director General Mohamed El Baradei, focuses on the feasibility of institutional strategies and on exploring arrangements that would forestall the spread of state-controlled sensitive nuclear fuel cycle activity. The director-general has made the same general point on numerous occasions by expressing concern that "wide dissemination of the most proliferation sensitive parts of the nuclear fuel cycle could be the Achilles heel of the nuclear nonproliferation regime," and pointing out the need to consider seriously how this might be brought under control. He has spoken in terms of multilateral or multinational approaches and appointed an ad hoc group of independent experts to identify and analyze plausible institutional and technical possibilities for managing the nuclear fuel cycle that go beyond purely national control. He has also proposed a five-year moratorium on new construction of sensitive fuel cycle facilities.

Similar ideas have been explored in the past. The Baruch Plan of 1946 was the first, but a second wave came in the 1970s. Each of these initiatives addressed ways to ensure access to civil benefits of nuclear energy while averting proliferation, and each entailed to some extent going beyond strictly national activity. Initiatives included:

- **Regional Nuclear Fuel Cycle Centers.** A study was launched in 1975 to identify economic, safety, safeguards, and security aspects of a multinational approach to nuclear fuel cycle facilities. This study was initiated because of concern regarding the emergence of a large-scale plutonium economy that, in fact, did not happen. No follow up action was taken.
- **International Plutonium Storage.** A study explored possibilities for implementing the IAEA statutory provision on agency storage of excess fissile materials. The study was completed but key disagreements over defining "excess," and mechanisms for releasing material from storage, led to a stalemate and ultimately no outcome.
- **Assurance of Supply.** The Committee on Assurance of Supply was established to explore a guaranteed supply of nuclear material, equipment and technology to cooperating states. The approach included a role for the IAEA but consensus could not be reached on the principles for international nuclear energy cooperation, nuclear non-proliferation, and emergency or backup mechanisms. The committee came to an end in 1987. Parallel to this exercise was the United Nations Conference for the Promotion of International Cooperation in the Peaceful Use of Nuclear Energy—UNCPICPUNE). This conference addressed concerns of developing nations in particular. No substantive product resulted.
- **International Nuclear Fuel Cycle Evaluation.** Initiated by the Carter Administration in 1977, INFCE sought to address the technical relationship between civil and military nuclear programs, and ways to preserve nuclear energy development without putting nonproliferation at risk, with particular emphasis on finding ways and means to avoid plutonium separation.

Historically most multilateral or multinational initiatives have been driven by nonproliferation considerations. However, some multinational ventures in sensitive nuclear fuel cycle activities, such as EUROCHEMIC, URENCO, and EURODIF, have been motivated primarily by economic, technical, commercial, or resource considerations. While nonproliferation may not have been a driving force behind these initiatives, the latter two, in particular, were cognizant and supportive of nonproliferation and brought nonproliferation benefits with their establishment. These demonstrate that nonproliferation, economic, and commercial considerations can coincide and be mutually reinforcing. This is a prospect upon which one may seek to build policy.

No existing nuclear fuel cycle, and perhaps no future fuel cycle, will be entirely free of proliferation risk. However, the nuclear activity in virtually all the non-nuclear-weapon states prior to the mid-1970s was generally regarded as fitting within the capabilities of the IAEA safeguards system. The dissemination of materials and facilities that could pose a serious proliferation risk (plutonium, highly enriched uranium, reprocessing facilities, enrichment plants) was very limited. International nuclear commerce was conducted on the basis of political commitments, reinforced by the NPT that extended safeguards to all peaceful nuclear activities undertaken by participating non-nuclear-weapon states. Such safeguards applied regardless of whether the peaceful nuclear activities were based on imported or indigenously developed materials. There was high confidence in the system of international safeguards to verify compliance with these commitments.

What is different today that might necessitate revisiting the strategy for reconciling civil nuclear energy with nonproliferation? Four factors explain the difference between the world of 1976, when supplier guidelines were first elaborated, and today's world.

First, the once predominant Cold War and the discipline it imposed on state behavior have been displaced by regional political-security agendas. For states whose sense of security is more tenuous under these changed conditions the prospect of developing a nuclear deterrent may have become attractive. For others, aspirations to regional predominance and/or international standing may motivate a similar interest. In either event, regional and international stability stand to suffer if those incentives translate into concrete action. In other words, incentives to acquire or to be in a position to quickly acquire nuclear weapons is greater today than heretofore.

Second, over time sources of supply of sensitive nuclear technologies or their components, particularly dual use items, have multiplied and expanded to illicit, black market transfers. This was underscored in the recent revelations of the activities of A.Q. Khan in relation to Iran and Libya. Furthermore, not all states adhere to the nuclear supplier guidelines or exercise effective controls on the transfer of sensitive technologies by companies, industries, or individuals under their jurisdiction. It remains to be seen whether UNSC Resolution 1540, which seeks to remedy this situation in important respects, will be successful.

Third, the IAEA has discovered clandestine, weapons-relevant activities that states party to the NPT have conducted. Even more ominous is the possibility of states using their NPT status to acquire fuel cycle capabilities openly and legally that could put them in a position to transition rapidly to nuclear weapon status, should they decide at some point in time to invoke the NPT withdrawal clause (Article X). It is critically important that facilities and activities be declared and placed under international safeguards, but such actions speak only to capabilities and not to motivation and intent. Whereas in the past the challenge for non-proliferation was states that were not party to the NPT, today the more serious problem is the threat of proliferation from within.

Fourth, national security and international stability is now threatened not only by the risk of state proliferation but by the potential of organized transnational terrorist groups obtaining access to weapons-usable materials. The larger the number of potential sources of such material, the greater the risk to the social order.

These considerations and the conditions and circumstances they reflect are not amenable to solution by any one strategy alone, be it strengthened safeguards, counter-proliferation measures, or new institutional arrangements. By the same token none of these approaches to the proliferation threats of today can be ignored or discounted. While institutional approaches may be seen as more problematic since they entail moving states to higher levels of structured coordination, and/or the delegation or forsaking of authority traditionally exercised by sovereign states, states still may conclude that the benefits of such measures would justify the costs incurred. The answer to the current proliferation challenge cannot be presumed but must come from concrete analysis of the many dimensions involved—political, economic, financial, technical, organizational, managerial, and security.

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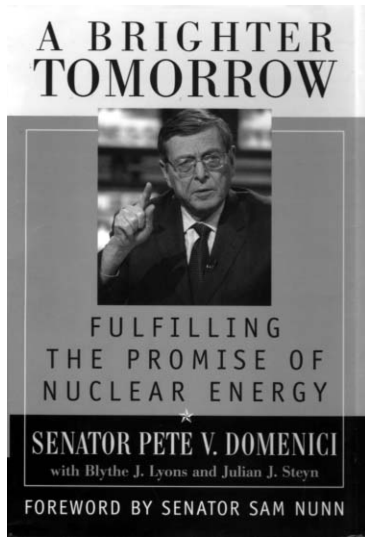
A Brighter Tomorrow: Fulfilling the Promise of Nuclear Energy

U.S. Senator Pete V. Domenici with Blythe J. Lyons and Julian J. Stern
Rowman & Littlefield Publishers, 2004.
ISBN No. 0-7425-4188-6

It has long been said of democracies that when faced with an oncoming crisis they do nothing to head it off until they are overwhelmed by it. At this time it is clear that the United States is facing two major crises, and that strong and immediate measures must be taken to avoid their consequences. The first is the impending shortage and increasing cost of energy, with its consequences for the U.S. economy. The second, and related crisis, is global climate change, brought on by increasing world consumption of fossil fuels, which will produce increasingly violent storms, a rise in sea levels that will inundate heavily populated coastal areas, and the probable disappearance of the gulf stream within decades, with catastrophic consequences for Western Europe. U.S. Senator Pete Domenici, in his important and timely book, *A Brighter Tomorrow: Fulfilling the Promise of Nuclear Energy*, makes a compelling case for nuclear energy as the best solution to these problems.



For the past thirty years nuclear energy has had a "bad press" for both genuine and specious reasons. The public has legitimate concerns about reactor safety, especially after the Three Mile Island and Chernobyl accidents, nuclear proliferation, and the disposal of nuclear waste, a highly exaggerated fear of nuclear radiation, and a subliminal association of nuclear reactors with nuclear weapons and their effects. As one of a small group of scientists and engineers who strove in vain to save the Shoreham reactor on Long Island from destruction, I heard the advice of a member of Congress to our group, "In politics, the perception is the reality." Clearly, these issues will have to be addressed in the political arena. Domenici's book provides a solid basis for a factual approach to the issues. Ironically, if the Shoreham reactor had been allowed to operate, by now it would have prevented the venting of more than 100 million tons of carbon dioxide to the atmosphere from the generation of electricity by burning fossil fuels as a replacement for Shoreham.

A Brighter Tomorrow begins, after some introductory pages, with a personal statement by the author on the history of his family, his own career in political life, and his involvement over decades with nuclear energy questions.

The main content of the book begins with a detailed chapter on world energy supplies, today and in the future. The principal conclusions are that world energy consumption will increase by approximately 2 percent per year, of which more than 90 percent will be fossil fuels; that world oil production will reach a peak within ten years and then start to decrease (U.S. oil reserves constitute 3 percent of total world reserves); and that renewables, by the year 2025, will provide less than 10 percent of total supplies. The environmental impact of various energy sources is also treated, in particular, coal, but other sources as well. For example, to replace one 1,000 megawatt nuclear plant with either wind turbines or solar photovoltaics would require the carpeting of forty square miles of land with these systems, and the substitution of biomass, the dedication of 6,000 to 12,000 square miles of land area for this purpose. The message of this chapter is that prospects for fulfilling future world energy needs from conventional sources are grim indeed.

The fourth chapter, "Nuclear Power in the World Today" summarizes the existing status of the nuclear power industry in the United States and other countries. As is well known, the United States has 104 licensed power reactors capable of producing approximately 100 gigawatts of electric power, about 20 percent of our total generating capacity at a current cost of 1.7 cents per kilowatt-hour, slightly less than that of coal-fired plants and one-half to one-third of the cost of plants burning natural gas. By comparison, total world capacity is 437 plants. The leading success story here is France, where 77 percent of the country's electric power is provided by nuclear reactors. The French system is highly cost-effective because of the early adoption of a standardized pressurized water reactor design, providing economies of scale and greatly simplifying the licensing process; and because of their closed fuel cycle (reprocessing), which leads to far more efficient utilization of their nuclear materials and far simpler disposal of nuclear waste. By comparison, the first generation of power reactors in the United States tended to be "one-of-a-kind" designs with high construction costs and complicated licensing procedures, and anti-nuclear activists were highly successful in delaying the completion and startup of many reactors by litigating successive issues at a time when interest rates were ruinously high. In addition, the adoption here of a once-through fuel cycle and the virtual paralysis of the system for disposing of spent reactor fuel have been costly. The discussion of prospects for a new generation of reactors is interesting, but since it depends so heavily upon the political and business climate, prospective licensing requirements, and other factors, it is probably a "moving target." The prospect for the direct production of hydrogen in a new generation of high-temperature reactors is of great interest.

The fifth chapter, "Regulatory Roadblocks to Nuclear Power," deals largely with the author's interactions with the U.S. Nuclear Regulatory Commission in attempting to simplify and expedite the regulatory process, and hence is largely of historical interest. More current, however, is the question of radiation protection standards. These are extremely conservative, based on the "Linear No Threshold" dose response relationship, which essentially assumes that a very small radiation dose to a large number of individuals will produce the same number of fatalities as the same total dose to a much smaller group of individuals. The adoption of this assumption, which is impossible to verify, is essentially a policy decision. Contrary evidence exists in that there are regions of the earth where natural radiation background, because of the presence of naturally occurring radioactive materials in the soil, is several times higher than in other locations, and studies of populations living in these areas show no excess of cancer over other areas. As a consequence of this policy, about $1 million is spent to prevent one death from radiation exposure, as opposed to the expenditure of about $35,000 to prevent one traffic fatality. The author also points out that we are currently spending $5 billion annually to clean up radioactivity at U.S. Department of Energy sites down to a level of 5 percent of natural background. This raises the question of whether the United States is allocating its national resources in the best possible way when, for example, its infant mortality rate is higher than in many other countries that possess more modest resources.

The sixth chapter, "Uranium Resource Issues," deals with the question of assuring adequate supplies of uranium in the event that there is a substantial expansion in the utilization of nuclear power in the United States and other countries. The author, as the senator from the state that furnished approximately 50 percent of U.S.-produced uranium, has been concerned with this issue for decades. The conclusion of this chapter is that if more efficient use is made of the uranium, for example through reprocessing, supplies should be adequate for some time to come. In this respect it should also be mentioned that by other means, for example, breeder reactors and mixed oxide (MOX) fuel, it should be possible to extend our uranium resources substantially. Furthermore, it is possible and affordable to extract uranium from seawater, and a fuel cycle based on thorium, which is much more abundant in the earth's crust than uranium, would extend our resources still farther.

The seventh chapter, "Revitalizing the U.S. Nuclear Infrastructure and Workforce," deals with the serious question of the current and future availability of personnel qualified to maintain, operate, and renew and extend our nuclear infrastructure. With nuclear energy in the doldrums for three decades, a number of universities have terminated their nuclear engineering programs and a number of university reactors have been shut down. Very few young workers have entered the field, so that a graying work force, nearing retirement age, is now running our nuclear energy system. The author proposes the enactment of a number of measures at our universities, national laboratories, and in the private sector, to come to grips with this problem.

The eighth and ninth chapters, "Dealing with Nuclear Proliferation Effectively," and "The Waste Disposal Conundrum," deal with topics that should be familiar to many members of the INMM. The author describes his long-term support for nonproliferation measures, including the Nunn-Lugar program, the agreement to purchase highly enriched uranium (HEU) from the Russian Federation, and measures to dispose of plutonium in MOX fuel. The eighth chapter ends with a set of specific proposals for strengthening the nonproliferation regime. The ninth chapter recounts the history of U.S. nuclear waste programs and then puts forward a logical agenda for dealing with this grave problem. This involves reprocessing of the fuel elements and the management of each constituent of the spent fuel in an appropriate manner. The uranium can be recycled in new fuel or enrichment plants, the plutonium put into MOX fuel, and fission products with short half-lives and those with half-lives up to a few decades such as cesium 137, strontium 90, and iodine 131 can be sequestered for several hundred years. The long-lived transuranic elements, which constitute the principal problem in disposing of spent fuel, can be transmuted in reactors or by particle accelerators into short-lived species which can be sequestered for a comparatively short time. By this means the time required for the fuel to decay to the toxicity of natural uranium is reduced from 300,000 years to less than 1,000. This regime effectively addresses all of the concerns about nuclear waste, utilizes the valuable energy content of the spent fuel effectively, and reduces by a large factor the quantity of material that must be sequestered in Yucca Mountain.

The final two chapters, "The Case for Nuclear Power" and "Roadmap for the Future," sum up the powerful arguments for the adoption of nuclear power as the best solution for current and oncoming energy needs, and provide an action plan for achieving that goal. INMM members who share this conviction can make a substantial contribution to our national welfare by helping to achieve this goal.

Walter Kane is JNMM *Book Editor and a consultant at Brookhaven National Laboratory in Upton, New York U.S.A. He may be reached by e-mail at wkane@bnl.gov.*

DOE Cites CH2M Hill Hanford for Violating Nuclear Safety Rules

In March, the Department of Energy (DOE) fined the CH2M Hill Hanford Group Inc. $316,250 for violations of the department's nuclear safety requirements. CH2M Hill is the department's contractor responsible for storage of highly radioactive and hazardous liquid waste at the Hanford Tank Farms near Richland, Washington, U.S.A.

The Preliminary Notice of Violation (PNOV) cites four events that took place in 2003 and 2004 including the contamination of several workers while removing equipment from a valve pit (June 2003) and the exposure of a worker to radiation while removing equipment from a tank (July 2004). As a result of the July 2004 event, the worker received an exposure of 22 rem to his hand (as compared to an annual DOE limit of 50 rem). In both events, no regulatory limit was exceeded. However, the exposures could have been much higher because effective controls were not in place.

CH2M Hill had thirty days to respond to DOE's concerns. Unless the contractor denies the violations with sufficient justification, the PNOV will become final and the contractor will have to pay the $316,250 fine. Additional details on this and other enforcement actions are available at http://www.eh.doe.gov/enforce.

DOE Awards Hanford River Corridor Contract to Washington Closure, LLC

Washington Closure, LLC was awarded the contract to manage the clean up and remediation of the Columbia River Corridor at the U.S. Department of Energy's Hanford Reservation in the state of Washington.

The five-member team includes the Washington Group International Inc., Bechtel National Inc., CH2M Hill Inc., Eberline Services Inc., and Integrated Logistics Services Inc.

The Columbia River Corridor is composed of roughly 210 square miles along the outer edge of the Hanford Site. The contract calls for cleaning up and taking down hundreds of excess facilities, remediating waste sites and burial grounds, and placing deactivated plutonium production reactors into safe and stable condition. Work will include projects in Hanford's 100 Area, where nine plutonium production reactors created material for nuclear weapons; the 300 Area, where uranium fuel was fabricated and laboratory facilities reside; facilities in the 400 Area (except the Fast Flux Test Facility); and two complex and highly-radioactive burial grounds in the 600 Area (618-10 and 618-11).

The "cost-plus-incentive-fee" contract is valued at approximately $1.9 billion over a seven-year period, a savings of $2 billion to $3 billion over previous Hanford Site cleanup estimates. For every dollar the work comes in under Washington Closure's "target cost," the company will receive $.20 in additional fee; for every dollar in increased expense, it will lose $.20 in fee. There are also enforceable contractual requirements for small business participation. Sixty percent of the work must be subcontracted—with 50 percent of that subcontracted work going to small business. A minimum of three of every 10 contract dollars will flow to small business.

The goal is to clean up this area of the Hanford Site by 2015, with incentives for Washington Closure to accelerate completion to 2012. Regulatory cleanup agreements will be met and early cleanup priorities will focus on those projects that pose the greatest risk to the environment.

Energy Department Announces $2.9 Billion Contract for Idaho Site Cleanup

The U.S. Department of Energy selected CH2M-WG Idaho LLC as the contractor responsible for the Idaho Cleanup Project through the year 2012 at the Idaho National Laboratory (INL).

The contract, which runs through September 20, 2012, is valued at about $2.9 billion. The contract specifically states that more than 2,600 employees currently employed in the cleanup effort will be offered employment by CH2M-WGI.

Under the contract, CH2M-WGI will be responsible for the treatment and disposal of radioactive waste; retrieval, disposal and other remediation related to buried waste; safe management of spent nuclear fuel; disposition of nuclear materials; disposition of reactor and non-reactor nuclear facilities; and other environmental remediation activities.

Canada and U.S. Cooperate on Russian Weapons-Grade Plutonium Production Reactor Shutdowns

In March, the United States and Canada signed a memorandum of understanding (MOU) to assist with the permanent closing of one of the final operating weapons-grade plutonium production reactors in Russia.

Under the MOU, Canada will contribute $9 million Canadian (U.S. $7 million) to the U.S. Department of Energy's Elimination of Weapons-Grade Plutonium Production (EWGPP) program. The Canadian contribution to this initiative is part of its $1 billion pledge under the G8-led Global Partnership Against the Spread of Weapons and Materials of Mass Destruction.

The goal of the EWGPP program is to permanently shut down three Russian nuclear reactors and replace them with fossil energy plants. These reactors, which provide heat and electricity to two regions in Siberia, also generate a significant amount of plutonium that could be used to make nuclear weapons. The Russian government has agreed to permanently shut down the reactors once replacement energy is provided.

Canada is currently contributing to projects in all four of its priority areas: dismantlement of nuclear submarines; destruction of chemical weapons; re-employment of former weapons scientists; and disposition of fissile materials. The United States pledged approximately US$1 billion annually for activities under the Global Partnership.

DOE Announces Preferred Alternatives For Moab Uranium Mill Tailings

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

These preferred alternatives will be included in the DOE's Final Environmental Impact Statement (EIS). No preferred alternatives were named in its draft Environmental Impact Statement.

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

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

Two U.S. University Research Reactors to be Converted From Highly Enriched Uranium to Low-Enriched Uranium

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

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

U.S. Helps Russia Build a Temporary Spent Fuel Storage Site

Russia has built a temporary storage site for spent fuel from scrapped nuclear submarines at the Zvezdochka shipyard in northern Russia. The site has received more than $60 million dollars in aid from the United States. Five nuclear-powered Murena-class submarines have been dismantled there.

The project doubled the temporary spent fuel storage capacity at Zvezdochka shipyard.

James Griggs

James Griggs died on March 3, 2005. He was 52.

Mr. Griggs worked in the area of international nuclear safeguards. His career included work at the International Atomic Energy Agency in Vienna, Austria, and at Pacific Northwest National Laboratory in Richland, Washington, U.S.A. Since 2002, he and his family have lived in Chicago. He traveled extensively for his work including frequent trips to Russia. He was a member of INMM since 1975.

He served as chair of the INMM Communications Committee since 2001 and created the INMM's Yahoo e-mail discussion list to facilitate communication among and between the members of the INMM. He was a also a senior member of INMM.

In his personal life, Mr. Griggs was an avid astronomer and was active in several astronomy groups locally and through the Internet. He was the father of five girls, Joyce, Agnes, Helene, Hanna, and Molly, and was married to Anne Bansley Griggs.

His friends and colleagues describe him as an extremely helpful and creative person who had a wonderful sense of humor.

James W. Lee

INMM Member James W. Lee died on February 25, 2005. Mr. Lee joined INMM in 1961.

Mr. Lee devoted his long career to the safeguards and security of nuclear materials, specifically in the area of the transportation of nuclear material. He helped develop the foundation of the INMM before management firms supported the administration of the Institute. He once served on the INMM Membership Committee and on the Executive Committee. Through his employment with Tri-State Motors, he sponsored meeting materials, coffee breaks, and companion/spouses breakfasts at the INMM Annual Meeting. He was a Fellow Emeritus of the INMM and received the Institute's Distinguished Service Award in 1986.

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 sixty 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. Jones, F. T. and L. K. Chang. 1980. Article Title. *Journal* 47(No. 2): 112–118.
  2. Jones, F. T. 1976. *Title of Book*, New York: McMillan Publishing.
- Author(s) biography

Peer Review: Each paper is reviewed by at least one associate editor and by two or more reviewers. 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.

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Calendar

August 7–11, 2005
ANS Topical on Decommissioning, Decontamination, and Reutilization
Hyatt Regency Hotel
Denver, Colorado, U.S.A.
Sponsor:
American Nuclear Society
Web site:
http://ddrd.ans.org/index_meetings.html

October 30–November 2, 2005
Changing the Safeguards Culture
Hotel LaFonda
Santa Fe, New Mexico, U.S.A.
Sponsor:
INMM International Safeguards Technical Division, INMM Southwest Chapter and ESARDA
Contact:
Jim Larrimore
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December 11–14, 2005
European Nuclear Conference (ENC) 2005
Palais des Congres
Versailles, France
Sponsor:
French Nuclear Society (SFEN)
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January 25–27, 2006
INMM Spent Fuel Management Seminar XXIII
Loews L'Enfant Plaza Hotel
Washington, D.C., U.S.A.
Sponsor:
Institute of Nuclear Materials Management
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http://www.inmm.org

July 16–20, 2006
47th INMM Annual Meeting
Renaissance Nashville Hotel/Convention Center
Nashville, Tennessee USA
Sponsor:
Institute of Nuclear Materials Management
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Northbrook, Illinois 60062
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