Fall 2010 | Winter 2011 | Spring 2011 | Summer 2011 | Volume XXXIX, Number 3

JNMM Journal of Nuclear Materials Management

To Our Colleagues in Japan

The Executive Committee of the Institute of Nuclear Materials Management, on behalf of our membership, would like to express our sorrow to our colleagues in Japan for the devastating natural events in Japan that occurred as a result of the large earthquake and the resulting tsunami that followed, and the events that subsequently occurred at the Fukushima Dai-ichi reactor site. We felt the same concerns you felt as the events unfolded. We likewise felt proud, as you must have, of the responders who put themselves in harm's way to minimize the effects of the event. We recognize and appreciate your design capabilities that allowed the nuclear reactors to survive an extremely large earthquake apparently well above design basis, only to be unfortunately overcome by the tsunami that caused the loss of backup coolant capabilities. It was an unfortunate event, and again we express our concern, sorrow, and respect.

Respectfully,

Scott Vance, *President*
Ken Sorenson, *Vice President*
Chris Pickett, *Treasurer*
Robert Curl, *Secretary*
Stephen Ortiz, *Immediate Past President*
Cory Hinderstein, *Member At Large*
Teresa McKinney, *Member at Large*
Sara Pozzi, *Member at Large*
J. Michael Whitaker, *Member at Large*

Non-Profit Organization
U.S. POSTAGE
PAID
Permit No. 2066
Eau Claire, WI

JNMM (ISSN 0893-6188) is published four times a year by the Institute of Nuclear Materials Management Inc., a not-for-profit membership organization with the purpose of advancing and promoting responsible management of nuclear materials.

SUBSCRIPTION RATES: Annual (United States, Canada, and Mexico) $200; annual (other countries) $270 (shipped via air mail printed matter); single copy regular issues (United States and other countries) $55; single copy of the proceedings of the Annual Meeting (United States and other countries) $175. Mail subscription requests to *JNMM*, 111 Deer Lake Road, Suite 100, Deerfield, IL 60015 U.S.A. Make checks payable to INMM.

DISTRIBUTION and delivery inquiries should be directed to *JNMM*, 111 Deer Lake Road, Suite 100, Deerfield, IL 60015 U.S.A., or contact Jodi Metzgar at +1-847-480-9573; fax, +1-847-480-9282; or E-mail, inmm@inmm.org. Allow eight weeks for a change of address to be implemented.

JNMM Journal of Nuclear Materials Management

Topical Papers

Departments

INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Change is Good

By Scott Vance
INMM President

Some of you may remember the Strategic Planning initiated by INMM President J. D. Williams in 2002. Believing that INMM needed to develop a coherent strategy for growing the organization, J. D. began the process of looking at our mission and goals in a detailed manner. As a result, specific goals were established for INMM and these were pursued over subsequent administrations. Improvements implemented as a result of these efforts include, among others, the establishment of a Communications Committee to organize communication among our membership; a determination to increase the registration fees for our annual meetings by small amounts each year rather than larger amounts every three to four years, establishment of a Student Activities Committee to encourage student membership, and development of a leadership training class.

While improvements were made, motivation to continue these efforts naturally diminished over time. In 2009, President Steve Ortiz decided to reinvigorate these efforts. Recognizing the importance of recent political, regulatory, technological, and even attitudinal changes regarding our profession, he initiated an effort to identify the most crucial. He asked Grace Thompson of Sandia National Laboratories to facilitate this process.

In March 2009, Grace asked attendees at the Executive Committee (EC) Meeting in New Orleans to review the INMM vision and mission, evaluate the effectiveness and adequacy of past strategic planning efforts, and identify priorities to move INMM forward. Very useful information was developed from that meeting. Most significantly, evaluation of INMM's organizational structure, in terms of both effectiveness and reflection of the nuclear materials management profession, was identified as the highest priority for moving forward.

Following that meeting, Grace asked Ken Sorenson, our current vice president, to consider our organizational structure. Specifically, she asked Ken to identifying areas where our organizational structure failed to reflect the current nuclear materials management universe and ways that the structure might be changed to ensure greater coordination in accomplishing our stated mission. Ken assembled his own working group of INMM experts to look at this question.

To begin this analysis, Ken asked Jack Jekowski to conduct an "Externalities Analysis"—that is, identify the factors outside of INMM that are impacting its effectiveness. This analysis determined that, while there is a global concern for nuclear materials management, there was also a strong push toward the global expansion of commercial nuclear power. The analysis identified four major forces driving the future of nuclear materials management: concern over terrorism since September 11; the dramatic reduction in the nuclear weapons stockpile; concern over a growing number of potential nuclear-weapons-capable countries acquiring nuclear materials and capabilities; and a dramatic increase in commercial nuclear fuel cycle development. Looking at our organizational structure, the working group determined that the most significant need was to strengthen the overall Technical Division make-up, particularly in relation to the commercial fuel cycle.

INMM continues to consist of six technical divisions, but they look slightly different.

First, a completely new division has been formed, Facility Operations. This division will focus on the nuclear material management issues that operating facilities must deal with. Shirley Cox has been named as chair, and she has already enlisted the help of Rose Marie Martyn, who works for a commercial nuclear vendor. Shirley will assist in reaching out to nuclear facility operators, especially those in the commercial arena—a perspective that is vital to INMM's continued pursuit of global excellence in all aspects of nuclear materials management.

A second significant change is the combining of the Packaging and Transportation Division with the Waste Management Division. These divisions have worked closely in the past, as they often involve the same constituents and dealt with similar concerns. However, they have been maintained as separate divisions because there has been enough different and significant work in each area to justify their separation. As the future of final disposition of nuclear material, especially spent fuel, has become less politically certain, there has been less justification to maintain this separation. The new Packaging, Transportation and Disposition Division will be jointly chaired by the previous chairs of the separate divisions, Steve Bellamy and John Veilleux.

Finally, Nuclear Security has been added to the Physical Protection Technical division. David Lambert, chair of this Division, will expand the scope of his division to include discussions regarding the protection of nuclear material beyond the property boundary of a specific facility.

While these changes are healthy and exciting, they are by no means final. The nuclear environment will continue to change, and so will INMM. The EC has now established the Strategic Planning Committee as a permanent standing committee, with Jack Jekowski as chair. The EC is excited about the opportunity to maintain INMM's relevance to professional nuclear materials managers and looks forward to the only thing that can be guaranteed about our organizational structure: it will change.

Japan, Korea and INFCIRC225/Rev.5

By Dennis Mangan
INMM Technical Editor

In this issue of *JNMM*, we have three articles, one technical and two editorial in nature. The technical article, *High-Accuracy Measurement of Plutonium Mass by Non-Destructive Assay: An Improved Approach for the Effectiveness and Efficiency of Safeguards* is authored by Taketeru Nagatani, Shinji Nakajima, Takashi Asano, and Shigeo Fujiwara of the Japan Atomic Energy Agency, and Howard Menlove, Marytn Swinhoe, and Michael Browne of Los Alamos National Laboratory (LANL). The article summarizes the results of a joint effort between JAERI and LANL to improve the non-destructive assay of measuring the mass of plutonium, with the desire to enhance the effectiveness and efficiency of safeguards.

The second paper is by Chris Price of the Office for Civil Nuclear Security in the United Kingdom, *Development of the IAEA Nuclear Security Recommendations on Physical Protection of Nuclear Materials and Nuclear Facilities (INFCIRC/225/Rev.5).* This article focuses on how INFCIRC/225has evolved over the years into a standard reference document by member states of the International Atomic Energy Agency. Price provides a nice history of INFCIRC/225 and insights into the reason for revising it, discusses the revision process, and highlights the significant changes in Revision 5.

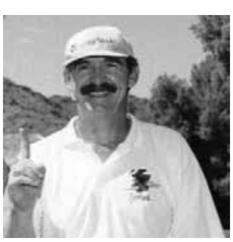
The third paper, *North Korea's Light-Water Reactor Ambitions,* by Siegfried Hecker, Chaim Braun, and Robert Carlin of the Center for International Security and Cooperation at Stanford University, is extremely interesting reading. I need say no more.

Also in this issue is a book review by Walter Kane, the *JNMM* Book Review Editor, and Industry News by Jack Jekowski, our Industry News Editor and the chair of INMM's new Strategic Planning Committee.

JNMM Technical Editor Dennis Mangan may be reached at dennismangan@comcast.net

In Memoriam

Donnie D. Glidewell
1948 – 2011



On January 29, 2011, Donnie D. Glidewell, a loving father and grandfather, and friend of the Institute, passed away after a heroic three-year battle against kidney cancer. He joined Sandia National Laboratories (SNL) in 1992 after a full career in the Unites States Air Force and became active in international safeguards, development and implementation of containment and surveillance systems, and remote monitoring systems. He was a leader in the establishment of regional monitoring and cooperation, border monitoring and security, with special focus on cooperation and collaboration in South East Asia and the Middle East. His involvement as a representative for SNL at the International Atomic Energy Agency and ESARDA had made him an active and much esteemed member of the nonproliferation community.

Don supported the Institute in Annual Meetings and Southwest Chapter Meetings as organizer, presenter, and session chair. Most of his INMM volunteer time had been devoted to the Southwest Chapter for which he served as president and on its executive committee.

Don received the INMM Vincet J. DeVito, Sr. Distinguished Service Award at the 51st Annual Meeting of the Institute in July 2010. The award plaque reads:

The Institute of Nuclear Materials Management recognizes Donnie D. Glidewell with the Vincent J. DeVito Sr. Distinguished Service Award at the 51st Annual Meeting for his leadership and accomplishments in the nuclear materials management profession.

Don is survived by his wife of forty-two years, Frankie, two daughters Tanya Glidewell and Tiffany Hall and her husband Christopher, and two grandchildren, McKenna and Noah.

High-Accuracy Measurement of Plutonium Mass by Non-Destructive Assay: An Improved Approach for the Effectiveness and Efficiency of Safeguards

Taketeru Nagatani, Shinji Nakajima, Takashi Asano, and Shigeo Fujiwara
Japan Atomic Energy Agency, Ibaraki, Japan

Howard O. Menlove, Martyn Swinhoe, and Michael C. Browne
Los Alamos National Laboratory, Los Alamos, New Mexico USA

Abstract

The Japan Atomic Energy Agency (JAEA) has worked on high-accuracy measurement of plutonium mass by non-destructive assay under a joint study program with the Los Alamos National Laboratory (LANL) in order to improve the effectiveness and efficiency of safeguards. As a part of this approach, we have developed the Epithermal Neutron Multiplicity Counter (ENMC) to improve measurement accuracy of ^{240}Pu effective mass (g) (m_{240e}) and improved the estimation accuracy of ^{242}Pu by the existing high-resolution gamma-ray spectrometer (HRGS) to improve measurement accuracy of ^{240}Pu effective mass (percent) (f_{240e}). Following these improvements, it was confirmed that the combined ENMC-HRGS could measure plutonium mass with high accuracy, providing an approximate total measurement uncertainty of 0.7 percent. This value is nearly equivalent to the International Target Value of Isotope Dilution Mass Spectrometry for plutonium mass in MOX samples of 0.72 percent, which includes the sampling error of the measurement.

It is expected that the combined ENMC-HRGS would improve the measurement accuracy of scrap samples with low homogeneity and reduce the number of required destructive analysis samples, and this would contribute to improvement of the effectiveness and efficiency of safeguards.

Introduction

The objective of safeguards is to detect the diversion of a significant quantity of nuclear material in a timely manner. An example of these safeguards activities is an inventory verification where samples from a subset of the inventory are randomly selected for safeguards measurement. During this inventory verification, the sample size is selected in order that diversion of a significant quantity of nuclear material can be detected with constant detection probability. Inventory verification is conducted in order to detect three types of defects, gross defect, partial defect, and bias defect. Gross defect and partial defect are verified by non-destructive assay (NDA), and bias defect is verified by isotope dilution mass spectrometry (IDMS), a standard destructive analysis (DA) method for determination of plutonium mass.

In the MOX fuel fabrication facility, MOX materials are mainly divided into product material and scrap material. Product material, which occupies a great part of MOX materials in the facility (such as feed powder, blended powder and pellet), has homogeneity. Scrap material, which is mainly recycled as feed material, has relatively less homogeneity than product material. The DA results are sensitive to the homogeneity of a sample because only a small sample quantity is dissolved (a few hundred milligrams), unlike for NDA in which the quantity of measurement sample is relatively large (a few tens to a hundred grams). Therefore, high-accuracy measurement of plutonium mass by NDA would improve measurement accuracy of scrap material with low homogeneity for which it is difficult to precisely measure plutonium mass by DA. This would contribute to improvement of the effectiveness of safeguards.

In theory of design for sample size, the number of samples for bias defect can be reduced by improving the measurement accuracy of partial defect.[1] Therefore, high-accuracy measurement of plutonium mass by NDA would reduce the number of DA samples, and contribute to improvement of the efficiency of safeguards.

Especially in future large-scale plutonium handling facilities, an increase in the amount of scrap material with low homogeneity and an increase in the number of DA samples are predicted. Therefore, high-accuracy measurement of plutonium mass by NDA is expected to be an important technology to implement safeguards effectively and efficiently for the future large-scale plutonium handling facilities.

In NDA measurements, plutonium mass is determined by m_{240e} (^{240}Pu effective mass (g)) from a neutron detector and f_{240e} (240Pu effective mass (percent)) from a gamma-ray detector. However, the measurement accuracy of existing neutron detectors with sensitivity to thermal neutrons, and existing gamma-ray detectors is not sufficient for high-accuracy measurement. Therefore, we have worked to improve the measurement accuracy of

plutonium mass by NDA with the high-accuracy by following two approaches:
(i) Improving measurement accuracy of m_{240e} by developing a new type of neutron detector, the Epithermal Neutron Multiplicity Counter (ENMC) that precisely detects epithermal and thermal neutrons.
(ii) Improving measurement accuracy of f_{240e} by improving estimation accuracy of ^{242}Pu obtained by the High Resolution Gamma-ray Spectrometer (HRGS).

Background

In NDA based on neutron and gamma-ray measurements, plutonium mass is determined by m_{240e} measured from neutron detectors and f_{240e} measured from gamma-ray detectors. An overview of the NDA method for plutonium mass is as follows.

Assay for m_{240e} by a Neutron Detector

Neutron-based NDA systems utilize neutron multiplicity counting to measure m_{240e}, which consists of the even isotopes of plutonium, and is given in equation (1):

$$m_{240e} = 2.52\,^{238}Pu + ^{240}Pu + 1.68\,^{242}Pu \quad (1)$$

where m_{240e} is ^{240}Pu effective mass and ^{238}Pu, ^{240}Pu and ^{242}Pu are masses of ^{238}Pu, ^{240}Pu and ^{242}Pu, respectively.

A typical neutron detector for m_{240} assay in a MOX sample has been the Plutonium Scrap Multiplicity Counter (PSMC) and Total Measurement Uncertainty (TMU) of the PSMC for m_{240} is approximately 3 percent.[2]

Assay for f_{240e} by the HRGS

The HRGS is an NDA system for measuring plutonium isotopic compositions by detecting the gamma-rays emitted from plutonium isotopes. f_{240e}, which consists of the fraction of even isotopes of plutonium, given in Equation 2 is determined by isotopic compositions measured from the HRGS:

$$f_{240e} = 2.52 \cdot f_{238} + f_{240} + 1.68 \cdot f_{242} \quad (2)$$

where f_{240e} is ^{240}Pu effective mass (percent) and f_{238}, f_{240} and f_{242} are isotopic values of ^{238}Pu, ^{240}Pu and ^{242}Pu, respectively.

It was found from past measurement results that the TMU of the HRGS for f_{240e} was approximately 4 percent. The isotope ratio of ^{242}Pu cannot be measured directly by the HRGS because ^{242}Pu has only a few gamma-rays, similar in energy and branching ratio to those from ^{240}Pu. Thus empirical isotopic correlations are used to predict ^{242}Pu content from the other isotopic fractions. ^{242}Pu estimated from this correlation may be in error by up to 20-25 percent and it is the main factor reducing the measurement accuracy of f_{240e}.[3]

Evaluation of Plutonium Mass from m_{240e} and f_{240e}

Plutonium mass is evaluated by m_{240e} and f_{240e}, given in equation (3).

$$Pu_{mass} = m_{240e} / f_{240_e} \quad (3)$$

The TMU of plutonium mass is evaluated from the errors of m_{240e} and f_{240e}, given in Equation 4. The present TMU of plutonium mass by the PSMC and the HRGS is approximately 5 percent.

$$\sigma_{Pumass} = \sqrt{\sigma_{m240e}^2 + \sigma_{f240e}^2} = \sqrt{3.0^2 + 4.0^2} \fallingdotseq 5 \quad (4)$$

This value is larger than the International Target Value (ITV) of IDMS for product pellets including the sampling error, given in Equation 5.[4] The advantage of NDA is that, for homogeneous MOX samples, sampling error can be reduced to a negligibly small value because of the large sample size (a few tens to a hundred grams) compared with that of DA (a few hundred milligrams).

$$\sigma_{IDMS} = \sqrt{\sigma_{random}^2 + \sigma_{systematic}^2 + \sigma_{sampling}^2} = \sqrt{0.1^2 + 0.15^2 + 0.7^2} \fallingdotseq 0.72 \quad (5)$$

Improving the Measurement Accuracy of m240e

We developed the ENMC (Figure 1) to improve the measurement accuracy of m_{240e}. In addition, we have tackled reduction of the TMU in order to obtain optimal measurement performance of the ENMC and evaluated the measurement accuracy of the ENMC for optimal measurement performance.[5,6] This section describes improvements for the ENMC, methods for the reduction of TMU and the measurement accuracy results of the ENMC for homogeneous MOX samples.

Improvements for the ENMC

The ENMC was improved both in efficiency and die-away time compared with the existing system, PSMC, to improve the measurement precision. The improvements are summarized as follows.

(i) Reduction of die-away time

The neutron coincidence counting method is the measurement method for m_{240e} by evaluating the time correlation of detected neutrons. It is important to reduce the die-away time because a short die-away time reduces accidental coincidences and contributes to improve the time correlation analysis.[7] The ENMC detects neutrons before complete thermalization (epithermal neutrons) by using less moderator than the PSMC, and higher pressure 3He tubes (10 atm). As a result, the die-away time of the ENMC is shortened to 19 µs, whereas die-away time of the PSMC is 47 µs.

Figure 1. Photograph of the ENMC

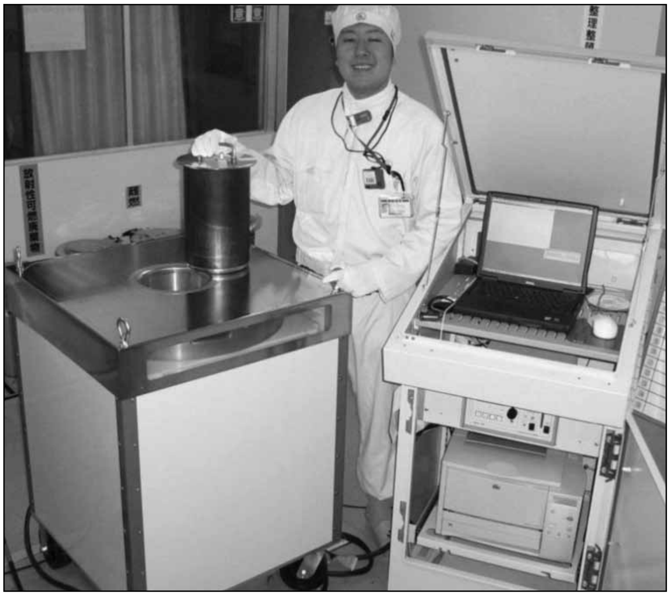


Figure 2. Variation of singles, doubles, and triples rates depending on the sample container

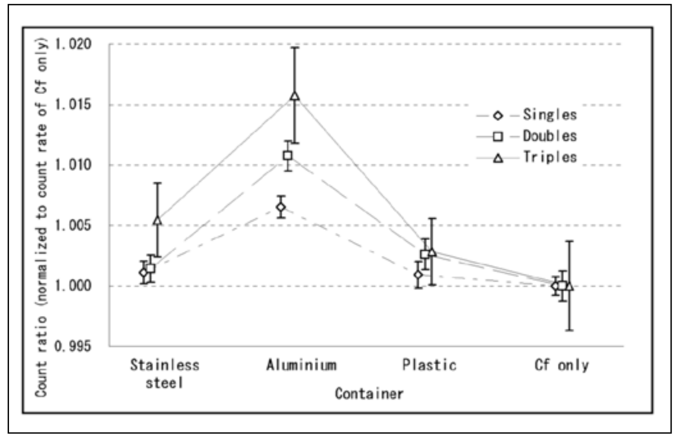
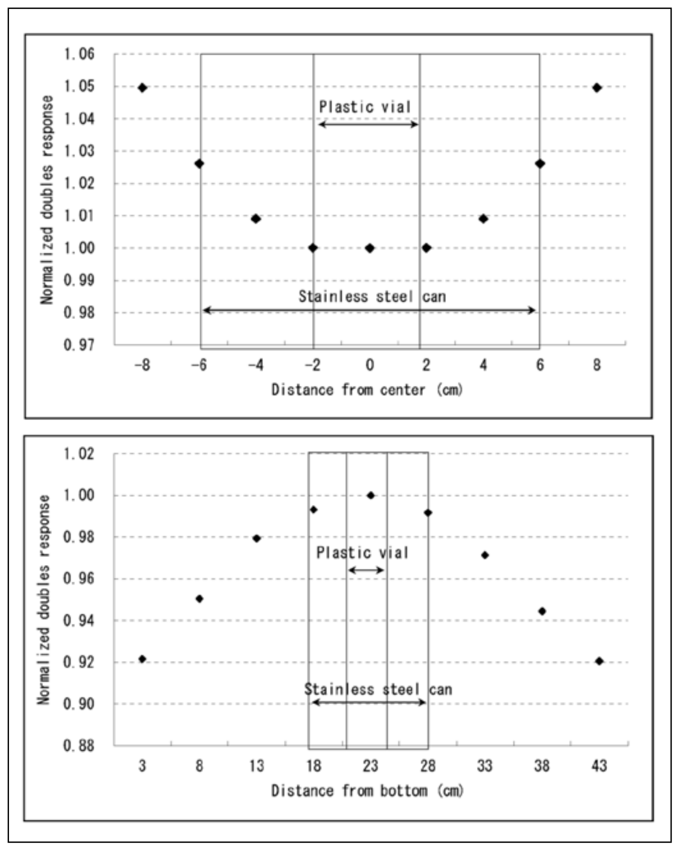


Figure 3. Normalized double response profiles (upper: axial; lower: radial)



(ii) Increase of efficiency

The probability of neutron capture by ^3He is largest when neutrons are moderated to thermal energy. To achieve high efficiency for epithermal neutrons, the number of ^3He tubes (80 tubes→121 tubes) and the pressure of ^3He gas in them (4 atm→10 atm) were increased. As a result, efficiency of the ENMC is 64.0 percent compared to that of the PSMC, which is 54.3 percent.

Approach to Mitigate Measurement Errors of the ENMC

Errors of neutron detectors are classified into a systematic error and statistical error. Major factors causing the systematic errors come from the "distribution of nuclear material in a cavity," "container effect" and "calibration parameter." The statistical error is the counting error, which varies depending on the neutron counting rate. Major variable factors are the measurement time and the amount of plutonium in measurement samples. We have approached the reduction in the measurement errors in order to improve the measurement performance of the ENMC for m_{240e}. Approaches to mitigation of the systematic error are shown as follows.

(i) Reduction of systematic error

Containers of different sizes and made of different materials (stainless steel, aluminum, and plastic) are used in storing and measuring nuclear material depending on usage. We evaluated the error that comes from the container effect and the distribution of nuclear material in a cavity.

The error from the container effect could be up to about 1.1 percent. Figure 2 shows the variation of singles, doubles, and triples rates depending on the sample container. The error of the distribution of nuclear material in the cavity was approximately 0.4 percent. Figure 3 shows the normalized doubles response profiles in the ENMC sample cavity.

To reduce these errors, it was decided that only a small plastic vial containing a small amount of nuclear material was used. This restriction reduced the error from the container effect to a negligible amount, and the error from distribution of nuclear material in a cavity was reduced to about 0.1 percent. Table 1 shows systematic error factors and the values of the ENMC. It is difficult to reduce the error from the analytical parameters of the ENMC because the error of the calibration sample cannot be eliminated.

(ii) Reduction of statistical error

The smaller the plutonium mass is, the greater the statistical error is due to the decreased number of counted neutrons. On the other hand, for a large plutonium mass, the statistical error is also increased due to correction for multiplication.[7] Therefore, the correlation between measurement precision and plutonium mass was evaluated to find out the amount of optimum plutonium mass for high-accuracy measurements.

Table 1. Systematic error factors and values

Systematic Error Factors	Values (%)
Container effect	=0
Sample distribution	0.1
Analytical parameter	0.3
Total	0.32

Figure 4 shows the result of the correlation between measurement precision and plutonium mass. As a result, the amount of optimum plutonium mass was around 20 g, reducing the counting error to less than 0.15 percent.

Accuracy Evaluation of the ENMC for m_{240e}

As a result of accuracy evaluation of the ENMC, it was confirmed that, for homogeneous MOX samples, the TMU of the ENMC for m_{240e} was improved to less than 0.4 percent. Table 2 shows the statistical error, systematic error and TMU of the ENMC.

Table 2. Statistical error, systematic error and TMU of the ENMC

Statistical Error (%)	Systematical Error (%)	TMU (%)
0.15	0.32	Around 0.4

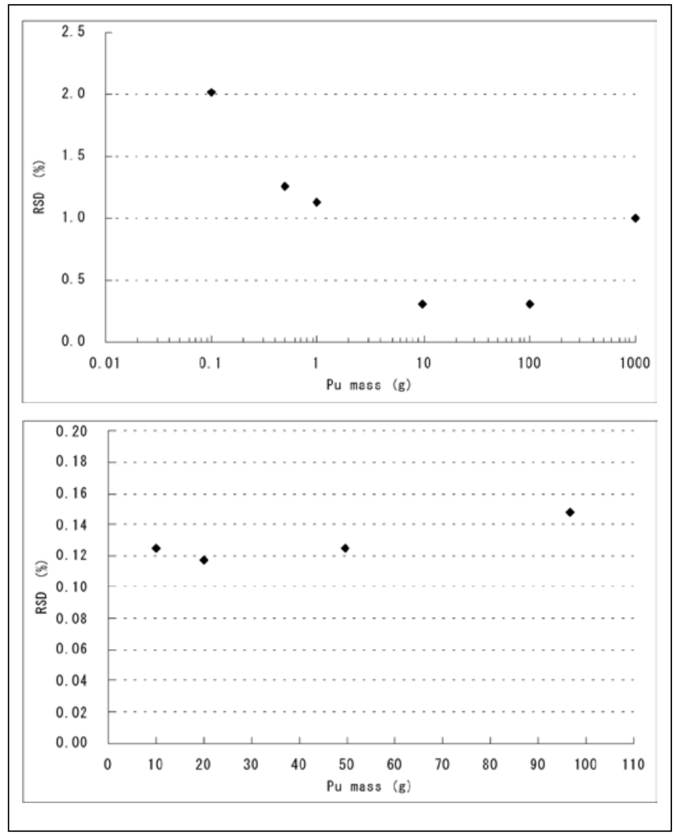
Improving the Measurement Accuracy of f_{240e}

We have improved measurement accuracy of the HRGS for f_{240e} by improving estimation accuracy of ^{242}Pu (percent) and evaluated the measurement accuracy of the HRGS by using homogeneous MOX samples. The results are shown in the following section.

Improving the Estimation Accuracy of ^{242}Pu

The Gamma-ray Multi-Group Analysis (MGA) code was adopted in order to evaluate the plutonium isotope composition from the gamma-ray spectrum measured by the HRGS. In this code, ^{242}Pu

Figure 4. Pu mass vs. RSD for MOX sample (Upper: Pu mass range 0.1g -1000g; measurement time = 10 min. Lower: Pu mass range 10g - 100g; measurement time = 100 min)



is evaluated by a formula that includes ^{241}Pu. The ^{241}Pu isotope may introduce ambiguities in any correlation because of its short half-life. Bignan et al. reported that it is possible to estimate ^{242}Pu with high-accuracy by using Equation 6, which excludes ^{241}Pu, and providing an adequate correction factor for target material. A correction factor C_0 included in Equation 6 can be applied uniformly to the nuclear material, which has similar isotope composition, by evaluating it appropriately depending on variation of isotope composition.[3]

$$\frac{Pu-242}{Pu-239} = C_0 \cdot \left(\frac{Pu-238}{Pu-239}\right)^{0.33} \cdot \left(\frac{Pu-240}{Pu-239}\right)^{1.7} \quad (6)$$

Therefore, the correction factor C_0 was evaluated using Equation 6 for 20 MOX pellet samples which were from the Japan Atomic Energy Agency (JAEA) MOX fuel fabrication plant. Table 3 lists the specifications of the MOX pellet samples. The correction factor C_0 was determined by the least squares method to minimize the differences between ^{242}Pu from Thermal Ionization Mass Spectrometry (TIMS), DA for determining Pu isotopic composition, and ^{242}Pu calculated from ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Pu obtained by TIMS by using Equation 6. As a result, C_0 was approximately 1.22.

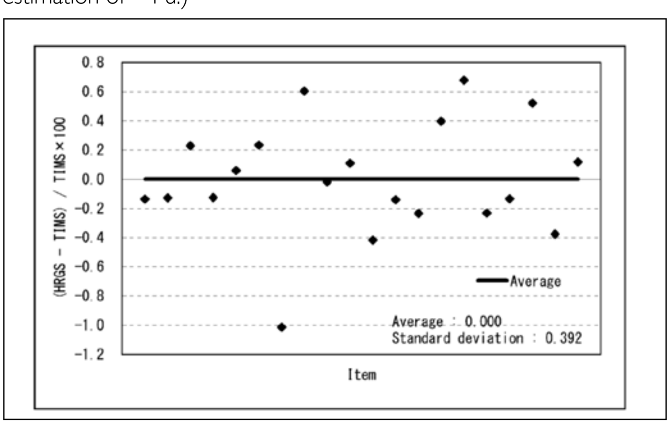
Table 3. Specifications of MOX pellet samples

Item	Net (g)	Pu conc. (%)	Pu mass (%)	Pu238 (%)	Pu239 (%)	Pu240 (%)	Pu241 (%)	Pu242 (%)	Pu240eff (%)
1	253.09	1.38	3.48	0.84	68.83	24.15	2.74	3.45	32.05
2	256.92	1.39	3.57	0.85	68.69	24.21	2.77	3.48	32.19
3	206.90	1.35	2.80	0.84	68.85	24.13	2.74	3.45	32.04
4	208.17	1.37	2.85	0.85	68.82	24.14	2.74	3.45	32.07
5	200.09	1.35	2.70	0.84	68.89	24.11	2.73	3.43	31.99
6	211.70	1.34	2.84	0.84	68.89	24.10	2.73	3.43	31.99
7	201.12	1.34	2.69	0.84	68.98	24.07	2.71	3.41	31.90
8	201.02	1.33	2.68	0.83	68.98	24.07	2.71	3.41	31.89
9	213.25	1.34	2.85	0.83	68.98	24.07	2.71	3.41	31.90
10	207.73	1.34	2.78	0.83	68.97	24.07	2.71	3.41	31.90
11	214.45	1.34	2.86	0.84	68.97	24.07	2.71	3.41	31.91
12	219.20	1.35	2.95	0.84	68.97	24.07	2.71	3.41	31.91
13	216.82	1.34	2.91	0.84	68.90	24.10	2.73	3.43	31.99
14	219.09	1.36	2.98	0.85	68.88	24.11	2.73	3.43	32.01
15	203.06	1.35	2.74	0.84	68.86	24.12	2.74	3.44	32.03
16	207.59	1.35	2.80	0.84	68.85	24.12	2.74	3.45	32.04
17	210.66	1.36	2.85	0.84	68.85	24.12	2.74	3.45	32.04
18	209.10	1.36	2.85	0.85	68.84	24.13	2.74	3.45	32.05
19	206.25	1.35	2.78	0.84	68.86	24.12	2.74	3.44	32.02
20	203.16	1.35	2.74	0.84	68.86	24.12	2.74	3.44	32.03

Evaluation of Accuracy of the HRGS for f_{240e}

We evaluated the measurement accuracy of the HRGS for f_{240e} by comparing assay results of the 20 MOX samples (Table 3), homogeneous samples, as obtained by HRGS and TIMS. The TIMS results were used as the true values because of the small error, and compared with the results of the HRGS measurement. Figure 5 shows relative differences for f240e between the HRGS and TIMS.

Figure 5. Relative differences for f_{240e} between the HRGS and TIMS (HRGS measurement time = ~ 120 min; reaching 100,000 counts for the 129keV peak of ^{239}Pu. The correction factor C_0 1.22 was used for estimation of ^{242}Pu.)



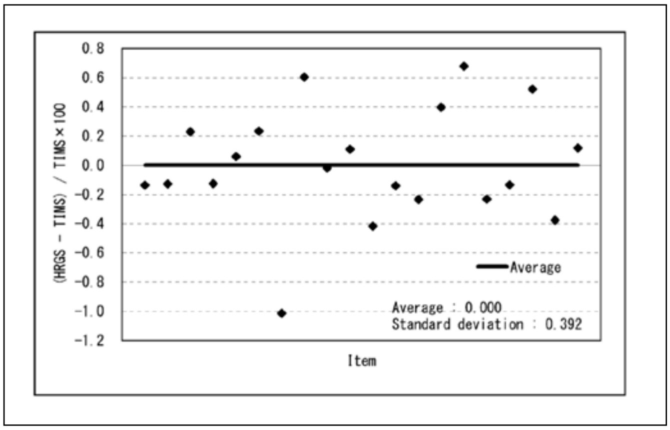
The average of the relative differences for f_{240e} between the HRGS and TIMS was almost 0 percent and its standard deviation was about 0.4 percent. Thus, it was confirmed that, for homogeneous MOX samples, measurement bias between the HRGS and TIMS was negligibly small and TMU of the HRGS for f_{240e} was approximately 0.4 percent.

In the actual situation of verification activities, measured samples would have various isotopic compositions. In order to carry out high precision measurement, measurement samples should be stratified based on their isotopic compositions, and an appropriate correction factor C_0 of each stratum should be evaluated.

Evaluation of Accuracy of the ENMC-HRGS for Plutonium Mass

We evaluated the actual measurement accuracy of the ENMC-HRGS for plutonium mass by comparing assay results of the 20 MOX samples (Table 3), homogeneous samples, obtained by the ENMC-HRGS and IDMS. The IDMS results were used as true values because of the small error, and compared with the results of the ENMC-HRGS measurement. Figure 6 shows relative differences for plutonium mass between the ENMC-HRGS and IDMS.

Figure 6. Relative differences for plutonium mass between the combined ENMC-HRGS and the IDMS (measurement times: ENMC = 100 min; HRGS = ~ 120 min; reaching 100,000 counts for the 129keV peak of 239Pu.)



The average relative difference for f_{240e} between the ENMC-HRGS and IDMS was almost 0 percent and standard deviation was approximately 0.7 percent. Thus, it was confirmed that, for homogeneous MOX samples, measurement bias between the ENMC-HRGS and IDMS was negligibly small and the TMU of the ENMC-HRGS for plutonium mass was approximately 0.7 percent. This value is adequate because it is approximately equivalent to the theoretical value (0.6 percent), which was evaluated from each measurement accuracy of the ENMC and the HRGS for homogeneous MOX samples, as shown in Equation 7.

$$\sigma_{Pumass} = \sqrt{{\sigma_{m240e}}^2 + {\sigma_{f240e}}^2} = \sqrt{0.4^2 + 0.4^2} \fallingdotseq 0.6 \quad (7)$$

Discussion and Conclusion

As a result of the above tests, it was confirmed that, for homogeneous MOX samples, the ENMC-HRGS can measure plutonium mass with high-accuracy equivalent to the ITV of IDMS by optimizing the measurement conditions. Based on this measurement performance of the ENMC-HRGS, the following two points are concluded.

(i) Contribution to improvement of the effectiveness of safeguards for scrap material with low homogeneity

Scrap material consists of most clean scrap which is recycled as feed powder and little dirty scrap including impurity (such as metallic dust and grease). Clean scrap made from rejected product material has relatively less homogeneity than product material. Dirty scrap made from recovered MOX material from equipment has low homogeneity. The ITVs of the sampling error of clean scrap (2x5g MOX) and dirty scrap (2x10g MOX) are 1 percent and 10 percent, respectively. Samples for NDA, up to around 200g MOX, would reduce the sampling error of clean scrap and dirty scrap to approximately 0.2 percent and 2.2 percent, respectively. In this case, for clean scrap and dirty scrap, the combined ENMC-HRGS would measure plutonium mass more precisely than IDMS as given in Equations 8, 9, 10, and 11, and this would contribute to improvement of the effectiveness of safeguards.

For clean scrap:

$$\sigma_{NDAforCS(g)} = \sqrt{{\sigma_{Pumass}}^2 + {\sigma_{sampling}}^2} = \sqrt{0.7^2 + 0.2^2} \fallingdotseq 0.7 \quad (8)$$

$$\sigma_{DAforCS(g)} = \sqrt{{\sigma_{Pumass}}^2 + {\sigma_{sampling}}^2} = \sqrt{0.18^2 + 1.0^2} \fallingdotseq 1.0 \quad (9)$$

For dirty scrap:

$$\sigma_{NDAforDS(g)} = \sqrt{{\sigma_{Pumass}}^2 + {\sigma_{sampling}}^2} = \sqrt{0.7^2 + 2.2^2} \fallingdotseq 2.3 \quad (10)$$

$$\sigma_{DAforDS(g)} = \sqrt{{\sigma_{Pumass}}^2 + {\sigma_{sampling}}^2} = \sqrt{0.18^2 + 10^2} \fallingdotseq 10 \quad (11)$$

(ii) Contribution to improvement of the efficiency of safeguards for homogeneous MOX

The combined ENMC-HRGS has high measurement accuracy equivalent to the ITV of IDMS. This makes it possible to apply them not only as a partial defect verification tool but also as a bias defect verification tool, and then to reduce the number of DA samples. This would provide benefits for the inspector such as cutting the cost of DA, shortening the period for getting results of the analysis and eliminating consumption of expensive standard samples. Also, there would be benefits for the operator such as reduction of burden for pre-treatment tasks for shipping DA samples and reducing the amount of contaminated waste. This proposed use of NDA would contribute to improvement of the efficiency of international safeguards.

On the other hand, DA will continue to play an important role in confirmation of the adequacy of the correction factor and the reliability of NDA measurement. Future consideration should be made with the inspectorate on how many DA samples could be replaced by NDA.

This NDA technology would be especially useful for future large scale facilities that treat large amounts of plutonium in order to implement safeguards effectively and efficiently. In the future, we would like to propose the use of this NDA technology and cooperate with the inspectorates to contribute to improvement of the effectiveness and efficiency of safeguards.

Taketeru Nagatani is an engineer in the nuclear material management section of the Plutonium Fuel Development Center at JAEA. He has an M.E. in chemical engineering from Yamanashi University, Japan.

Shinji Nakajima is an engineer in the nuclear material management section of the Plutonium Fuel Development Center at JAEA. He has a B.S. in physics from Rikkyo University, Japan.

Takashi Asano is deputy manager of the nuclear material management section of the Plutonium Fuel Development Center at JAEA. He has a B.S. in physics from Ibaraki University, Japan.

Shigeo Fujiwara is manager of the nuclear material management section of the Plutonium Fuel Development Center at Japan Atomic Energy Agency. He has a B.S. in nuclear engineering from Kobe University of Mercantile Marine, Japan.

Howard. O. Menlove is a Fellow at the Los Alamos National Laboratory working in the international safeguards area. He has a Ph.D. in nuclear engineering from Stanford University, USA.

Martyn Swinhoe is a technical staff member at the Los Alamos National Laboratory working in the international safeguards area. He has a PhD. in Applied Nuclear Physics from the University of Birmingham, UK.

Michael C. Browne is a technical staff member at the Los Alamos National Laboratory working in the international safeguards area. He has a Ph.D. in nuclear physics from North Carolina State University, USA.

Acknowledgements

This work was conducted at JAEA and LANL as joint research based on an agreement between JAEA and the U.S. Department of Energy Office for Cooperation in Research and Development Concerning Nuclear Material Control and Accounting Measures for Safeguards and Nonproliferation. The authors would like to express their gratitude to Director S. Takahashi and Deputy Director S. Asazuma of JAEA, for discussions and comments. The authors are also grateful for contributions to the experiments by Y. Kosuge, R. Nomura, and A. Takada.

References

1. IAEA. *1998. Statistical Concepts & Techniques for IAEA Safeguards Fifth Edition.* IAEA/SG/SCT/5.
2. Menlove, H. O., and T. D. Reilly. 2007. The Development and Implementation of NDA Equipment at the IAEA, *Journal of Nuclear Materials Management,* Vol. 35, No.4, 77-88.
3. Bignan, G., W. Ruhter, H. Ottmar, A. Schubert, and C. Zimmerman. 1998. Plutonium Isotopic Determination By Gamma Spectrometry: Recommendations for the ^{242}Pu content evaluation using a new algorithm, *ESARDA Bulletin,* No.28, 1-6.
4. International Atomic Energy Agency. 2000. *International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Materials.* STR-327.
5. Asano, T., J. Ninagawa, S. Fujiwara, and S. Takahashi, S. Nakajima, T. Sato, H. O. Menlove, C. D. Rael. 2006. Development of the Epithermal Neutron Multiplicity Counter. *Proceedings of an International Safeguards Symposium* Vienna, 16-20 October 2006, 247-255.
6. Menlove, H. O., C. D. Rael, K.E. Kroncke, and K. J. DeAguero. 2004. *Manual for the Epithermal Neutron Multiplicity Detector for Measurement of Impure MOX and Plutonium Samples.* LA-14088.
7. Ensslin, N., W. C. Harker, M. S. Krick, D. G. Langner, M. M. Pickrell, and J. E. Stewart. 1988. *Application Guide to Neutron Multiplicity Counting.* LA-13422-M.

Development of the IAEA Nuclear Security Recommendations on Physical Protection of Nuclear Materials and Nuclear Facilities (INFCIRC/225/Rev.5)

Christopher Price
Office for Civil Nuclear Security, Health & Safety Executive, UK

Abstract

Following more than three years of work, the International Atomic Energy Agency (IAEA) published in January 2011 the fifth revision of INFCIRC/225, its recommendations on *The Physical Protection of Nuclear Material and Nuclear Facilities* that will also be a Recommendations document in its Nuclear Security series. The previous revision of this document was published in 1999, since which time there has been a significant increase in the intent and capability of sub-national groups who pose a threat to nuclear material and facilities. INFCIRC/225 has been substantially revised to take not only this into account, but also the new international instruments related to physical protection, especially the 2005 Amendment to the Convention on the Physical Protection of Nuclear Material (CPPNM). INFCIRC/225 has achieved high international status through being referenced in many bilateral nuclear cooperation/supply agreements (and more recently in the International Convention on the Suppression of Acts of Nuclear Terrorism) as the standard to be taken into account in protecting nuclear material. This paper recalls the history of the development of INFCIRC/225 and describes the background to its most recent revision, as well as the process and approach adopted during this revision. This was considerably more complex than previously because of the need to agree on boundaries between it and two new IAEA Recommendations documents being developed concurrently, whilst ensuring a consistent approach to the development of all three documents. Significant changes to INFCIRC/225 are detailed, such as new sections on the location and recovery of missing or stolen nuclear material and mitigating the radiological consequences of sabotage. Restructuring the chapter on the state's regime against the Physical Protection Fundamental Principles and the essential elements identified in the draft IAEA Fundamentals has resulted in clearer and more comprehensive coverage of this aspect. Throughout the chapters on the protection of material during use, storage, and transport, more emphasis is now placed upon a performance-based approach. Revision 5 will facilitate ratification and implementation of the Amendment to the CPPNM by providing greater clarity on its provisions, as well as serve as a global reference point for physical protection for the next 10 years.

History of INFCIRC/225

The genesis for INFCIRC/225 appeared to stem from a recommendation by the Tokyo Panel on Safeguards Methods and Techniques in December 1969 that the International Atomic Energy Agency (IAEA) should develop a set of guidelines for the physical protection of nuclear material which could be applied at national level and form an essential background for the application of a national safeguards system. During 1970 the IAEA developed a draft of possible guidelines and in 1971 convened a working group of member state representatives to review them. Following several meetings, the panel of experts agreed the Recommendations for the Physical Protection of Nuclear Material in March 1972 and they were published by the IAEA later that year. Lacking any reference, they became known as the "Grey Book" after the color of its cover. These recommendations only addressed the theft of nuclear material and its recovery if stolen.

The IAEA convened an Advisory Group in 1975 to review these Recommendations. The outcome was a much expanded document (published as INFCIRC/225), which outlined the basis for concern as not only the theft of nuclear material that could lead to the construction of a nuclear explosive device, but also the risk that stolen nuclear material could be used as a "radiological contaminant" or that individuals might sabotage a nuclear facility or nuclear material in transit. The revised categorization table and guidance in this document formed the basis for the categorization table and levels of protection detailed in the Nuclear Supplier Group (NSG) guidelines (first issued in 1978) and (in a slightly modified form) in Annexes I and II of the Convention for the Physical Protection of Nuclear Material (CPPNM) opened for signature in 1980. As the NSG guidelines became the basis for legally binding bilateral nuclear cooperation agreements involving the transfer of nuclear material and as these guidelines also referenced INFCIRC/225 as a "useful basis for guiding recipient states in designing a system of physical protection measures and procedures," INFCIRC/225 quickly achieved international status as a document that needed to be taken into account. (More recently, the need to take these IAEA recommendations into account also arises from Article 8 of the International Convention for the Suppression of Acts of Nuclear Terrorism).

The 1975 IAEA General Conference welcomed the intention of the director general to review and bring up to date the physical protection recommendations regularly "to reflect advances made in the state of the art or the introduction of new types of facilities." As a result, INFCIRC/225 was subsequently revised in 1977, 1989, 1993, and 1998 (although it was not until 1998 that the document included detailed recommendations on the protection of nuclear power stations against sabotage, resulting in the addition of "nuclear facilities" to its title). As a result of requests from member states for further guidance on how to implement domestic requirements in a manner consistent with INFCIRC/225, the IAEA published guidance and consideration for the implementation of both Revisions 3 and 4 under the reference TECDOC-967.

Background to Fifth Revision of INFCIRC/225

Following the events of September 11, 2001, the IAEA launched a much expanded nuclear security program covering the protection of all radioactive material and the detection/response to such material out of regulatory control. This program clearly needed to be underpinned with a set of guidance documents and in 2005 the Nuclear Security series of documents was formally established, comprising the following four tiers:

- **Fundamentals** containing objectives and principles, including essential elements drawn from relevant international instruments
- **Recommendations** containing general approaches, concepts and strategies on what should be achieved
- **Implementing Guides** containing details of how recommendations can be implemented at a systems level
- **Technical Guidance** containing detailed reference material

In coming to a decision on the development of the two top tier set of the Nuclear Security series, the IAEA convened a Reference Group in October 2007 comprising member state representatives. It agreed that development should commence on three separate Recommendations level documents concurrently, one on nuclear material/facilities, one on radioactive material/associated facilities and one on the detection and response to material out of regulatory control. Importantly, it was also agreed that the one on nuclear material/facilities could also serve as Revision 5 of INFCIRC/225. A further meeting in March 2008 resulted in guidance on the drafting of the three Recommendations documents.

Development Process

The first consultancy meeting (CM) was held in July 2008 with a substantially larger group of experts than would normally be the case for a CM charged with drafting a revised version of a document. Such was the interest in the revision that representatives from twenty-three member states attended one or more of the six CMs held during the next sixteen months. The first meeting agreed to use a draft prepared by a small group of states as the basis for its work.

Due to its size, it was clear by the third CM that a small drafting group of seven representatives was needed to undertake the detailed revision of the document. The drafting group was assigned its work by the CM in accordance with agreed Terms of Reference and met following each CM, its work then being reviewed by the next CM. In this manner, the substantial revision agreed necessary was accelerated.

To ensure consistency in approach, content and definitions of the three Recommendations documents and further ensure that there were no gaps between them:

- A total of five Reference Group meetings were held, the last in January 2010 agreeing that, with some minor amendments, the three Recommendations documents were ready to be put before Technical Meetings (TM, to which all Member States are invited) commencing the following month;
- Two Harmonization Group meetings were held; and
- Three specific meetings on transport security were held in order to provide the specialised input needed for the transport sections of INFCIRC/225 and the Radioactive Materials Recommendations.

A TM was held in February 2010 attended by seventy representatives from forty states. Some fifty amendments were agreed to the draft developed by the process described above, but none required any substantive change to this draft. As there was insufficient time to consider minor editorial changes, participants were encouraged to submit such changes as part of the 120 review process.

The revised version was circulated under cover of a Note Verbale to all member states in April requesting that any comments be provided during the following 120 days. In the event, a large number of comments were submitted by member states, although some were repetitious. The Secretariat proposed how each comment might be resolved and its proposals were considered by a further TM in September 2010 convened to consider the comments received on all three Recommendations documents. The TM agreed many corrections relating to grammar, use of particular words and word order, ensuring such corrections were applied in a consistent manner throughout Revision 5. Importantly, it was noted that sections relating to state responsibilities for location and recovery of missing nuclear material, as well as mitigation of radiological consequences, had not been included in the transport chapter following the late decision to continue to have a separate chapter on this topic. The missing sections were inserted and, following agreement on a number of other minor but important changes, the TM was content for the document to be recommended to the agency for publication consistent with IAEA procedures. It was so published by the IAEA in January 2011.

Development Approach

It was important from the outset for all engaged to agree why INFCIRC/225 needed revision. It was noted that:

- There had been an increase during the past ten years in the intent and capability of subnational groups who posed a threat to nuclear material/facilities;
- A number of new international instruments related to physical protection were now in place, of which the Amendment to the CPPNM was the most relevant;
- Ten more years experience in methods and approaches to physical protection had been acquired, many gained in the context of increased international cooperation on the topic; and
- Some of this experience had been captured in lower tier documents in the Nuclear Security series already published by the IAEA, e.g. Security Culture and DBT.

It was equally important to try to agree to the structure of the revised document at an early stage, although in this respect there was less success. The CM agreed that the first four chapters of Revision 4 should remain, with the minor exception of re-titling state system to state regime. However, it also initially agreed that the next four chapters should effectively be merged into two; one dealing with the requirements for protection against unauthorized removal of nuclear in use, storage and transport and a further one containing the requirements for protection against sabotage of nuclear facilities and nuclear material during transport. The former chapter was to incorporate the Revision 4 chapter on categorization of nuclear material to rightly emphasise that the categorization table only applies to protection against unauthorised removal and not to sabotage.

Although INFCIRC/225 has recommended from the time of the "Grey Book" that one of the objectives of a state's regime should be to locate and recover missing nuclear material and has also recommended since Revision 3 that another objective is to minimize the radiological consequences of sabotage, no specific recommendations to help achieve these two objectives had been made in INFCIRC/225. It was agreed that these two topics should be addressed in Revision 5 through the addition, initially, of two new chapters, although in the end the relevant recommendations became a section of the unauthorized removal, sabotage, and transport chapters.

During the course of drafting, two key structural issues arose. The first related to Chapter 4, Elements of a State's Regime. The initial draft of this chapter was structured around the twelve Fundamental Physical Protection Principles endorsed by the IAEA Board of Governors in 2001 and subsequently incorporated into the Amendment to the CPPNM, thereby directly providing recommendations to assist states to implement these principles. However, it was noted that the Nuclear Security Fundamentals document, which was also being developed in parallel to Revision 5, contained a somewhat different set of "Essential Elements" of a state's overall nuclear security regime (of which physical protection is part). The eventual compromise solution was to structure Chapter 4 around the titles of these Essential Elements, but incorporate in full the Physical Protection Fundamental Principles under the appropriate Essential Element section.

The second structural issue arose from a desire to avoid duplicating recommendations on unauthorized removal of material in use and storage with those for the protection of nuclear facilities against sabotage when, in many cases, they were almost identical. It was submitted that nuclear facilities should adopt an integrated approach to protection against unauthorised removal and sabotage, rather than suggest separate measures need to be implemented for each. As this view had strong support in the CM, much time was spent drafting a generic chapter on protection of nuclear facilities.

At the conclusion of the CM's work, it was decided to revert to the structure of Revision 4, but with the categorization chapter still incorporated into the chapter dealing with unauthorized removal. This necessitated much late work by the Secretariat to ensure that all relevant content in the generic chapter was included in the chapters on unauthorised removal and sabotage and that all agreed text related to transport was moved from these chapters to a separate transport chapter.

There was much discussion during the CM and Reference group on the level of detail to be contained in Revision 5, especially now that other, lower tier, documents would be available within the Nuclear Security series for such detail. It was pointed out that:

- The main message should not be lost in too much detail;
- As INFCIRC/225 is directly incorporated into the national laws of some countries, it should not contain too much detail as these states needed some flexibility in adjusting the recommendations to their own particular circumstances; and
- Less detail would accelerate development of Revision 5.

On the other hand, it was clearly important not to lessen the requirements of Revision 4 in this revision process, whilst no implementing guide on protection against unauthorized removal currently existed. It was agreed that whilst INFCIRC/225 should focus on performance-based recommendations, some prescriptive content was necessary to illustrate how these recommendations can be achieved. As a result, Revision 5 contains more detail than the other two recommendations documents just developed, although in part this also reflects the maturity of INFCIRC/225 and the higher levels of protection required for nuclear material.

In terms of a general approach, the reference group and CM agreed that Revision 5 should:

- Be consistent, not contradictory to, the relevant international instruments (although such instruments would not be referenced in the document);
- Seek to strengthen the connection between the "3 Ss," secu-

rity, safety, and the nuclear material accountancy and control measures used for safeguards, especially as the latter could help detect loss of nuclear material or misuse of a nuclear facility for unauthorised purposes; and

- Consider replacing a prescriptive approach to a more performance-based one, with emphasis on testing, evaluating, and exercising in order to determine whether the physical protection system is "effective," as required by UNSCR 1540, whilst leaving it up to individual states to decide the precise mixture of such approaches.

Finally, it was agreed by the reference group that unauthorized removal of nuclear material for subsequent dispersal should now be addressed in the Radioactive Materials Recommendations, rather than INFCIRC/225. It was noted that the categorization table in INFCIRC/225 is not relevant in these circumstances, whilst states may wish to apply different thresholds for protection against this risk than those used for sabotage of nuclear material at facilities or during transport. However, it is important to note that it will still be necessary to apply the highest level of protection required by either document to nuclear material. Therefore the primary impact of this decision is likely to be in relation to very small quantities of nuclear material such as plutonium.

Significant Changes to INFCIRC/225

General

Although the IAEA now uses the term "Nuclear Security" to cover all activities relating to the prevention of, detection of, and response to criminal or intentional unauthorized acts involving or directed at nuclear and other radioactive material and associated facilities, the term "physical protection" continues to be used throughout the publication. A footnote has been inserted to explain that, historically, this latter term has been used to describe what is now known as the nuclear security of nuclear material and nuclear facilities. As the publication is also Revision 5 of INFCIRC/225, it is important the title is not changed as it is referenced in a number of international instruments and bilateral agreements.

Whereas the proposal for a general chapter on facility security was eventually not included, it did result in text being added at the beginning of both the unauthorized removal and sabotage chapters emphasising the need for a facility's physical protection system to be integrated and effective against both risks. Appropriate measures should be based on the more stringent applicable requirements to counter unauthorized removal and sabotage. It is acknowledged that some areas within a facility could require the same level of protection against both risks; for example an "inner area" could also at the same time be a "vital area."

It could be construed from Revision 4 that a public highway may run alongside the exterior boundary of a Protected Area containing Category II nuclear material. This would provide no defense in depth. Revision 5 now recommends that a Protected Area should be located inside a "limited access area," defined as a designated area to which access is limited and controlled for physical protection purposes. Category III nuclear material should also be used and stored at least within such an area.

Computer-based systems are increasingly being used globally, not only to hold sensitive information that could compromise the physical protection of nuclear material and nuclear facilities, but also to control physical protection measures (such as automatic access control systems), control process systems important to nuclear safety, and maintain nuclear material accountancy records. All of these systems are required to be protected to ensure their confidentiality, integrity and/or availability. Revision 5 recommends the protection of such systems against compromise (e.g., cyber attack, manipulation or falsification) consistent with the threat.

To avoid repetition of some of the same recommendations in the separate sections dealing with unauthorized removal of Category I, II, and of III nuclear material, the chapters dealing with in use/storage and transport now adopt a bottom up approach, starting with the common requirements for all three categories. Additional requirements are then added for Categories I and II and finally additional (or modified) requirements for Category I.

Because of the key role played by central alarm stations in monitoring and communicating information, it is now recommended that redundancy measures should be in place where they have a role in the protection of Category I nuclear material or at facilities where sabotage could lead to high radiological consequences. Such measures should ensure that the key functions of these stations can continue during an emergency, for instance through the duplication of these functions to an alternative backup station.

Location and Recovery of Missing or Stolen Nuclear Material and Mitigating the Radiological Consequences of Sabotage

As already mentioned, new sections on the location and recovery of nuclear material have been added to the chapters dealing with unauthorized removal and transport. The recommended measures include:

- The immediate action to be taken by operators and carriers if loss is suspected, including reporting the loss by both to the appropriate authorities; and
- The responsibility of the state, operator, and carrier (or other relevant entity) to develop contingency plans to locate and recover missing or stolen material and to exercise these plans.

It should be noted, however, that detailed recommendations once a loss is reported to state authorities are contained in the Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control.

Likewise, new sections on associated measures to mitigate or minimize the radiological consequences of sabotage have also been added to the chapters dealing with sabotage and transport. The new recommendations in this area only address the physical protection measures that should be taken in the immediate area of a successful sabotage act additional to those that will be taken for safety purposes. Again, much emphasis is placed on the need by the state, operator, and carrier (or other relevant entity) to develop appropriate contingency plans. The state should ensure that joint nuclear safety/physical protection exercises, which simultaneously test emergency and contingency plans, are regularly carried out in order to assess the adequacy of the interfaces and response coordination of emergency and security organizations involved in responding to various scenarios.

Definitions

Many new definitions have been added to Revision 5, even though some of the terms were used in Revision 4 without any definition. The number of definitions has increased from seventeen to thirty-nine. As a general rule, words or terms were only defined if their use in INFCIRC/225 differed, or had a more specialised meaning than that contained in a common dictionary.

An example of a term used in INFCIRC/225 to date without definition is "nuclear material." These words are defined in the CPPNM in terms that address the scope of that Convention, with the result that depleted uranium and thorium are excluded. A comprehensive definition breaking nuclear material into its constituent parts of special fissionable material and source material is contained in the IAEA Statute. There were proponents for both of the above definitions but a compromise solution was arrived at under which nuclear material is defined as material listed in the INFCIRC/225 Categorization Table, including material listed in the footnotes to this Table.

Revision 4 refers to both the state and facilities having a physical protection *system*, although clearly both are different, with the state-level one additionally including the legislative and regulatory infrastructure, as well as the state-level institutions and organizations responsible for ensuring its proper implementation. Revision 5 clarifies this by defining the state-level "Physical Protection Regime" accordingly and restricting the use of the term "Physical Protection System" to those maintained by the operator or carrier. It further clarifies that this Physical Protection System is an integrated set of "Physical Protection Measures," these measures being the individual personnel, procedures and equipment that, together, are designed to prevent the completion of a malicious act.

The terms *emergencies* and *emergency plans* are used frequently in Revision 4. The amended CPPNM refers to contingency (emergency) plans. This may be confusing, especially as nuclear/radiation safety has long used the word *emergency* to relate to any serious radiological release regardless of the cause and has required *emergency plans* to be in place to mitigate or minimize the consequences. All plans containing predefined sets of actions for response to unauthorized acts indicative of unauthorized removal of nuclear material or sabotage, including threats thereof, are now referred to as "contingency plans" in Revision 5.

Elements of a State's Physical Protection Regime

Although Revision 4 contained a much improved set of recommendations on the components of a state's physical protection regime, it was not well structured. The work carried out since on the Amendment to the CPPNM and the Nuclear Security Fundamentals has more clearly identified the essential elements of a state's regime and the fundamental principles governing physical protection. As a result, a better means to structure this chapter was now available to help ensure the topic was covered in a comprehensive manner. The outcome was a number of new recommendations, some of which are discussed below.

Whereas INFCIRC/225 has long recognized that predetermination of trustworthiness of all individuals permitted unescorted access to nuclear material or facilities would assist the achievement of physical protection objectives, it was silent on who should be responsible for instituting such arrangements. Revision 5 now recommends that it is the responsibility of the state to determine a trustworthiness policy that identifies the circumstances in which its application is required and how it is to be made, using a graded approach. It further indicates that such a policy should also apply to those with access to sensitive information.

Revision 4 introduced the concept of a design basis threat (DBT) as a common basis for physical protection planning by clearly identifying what a physical protection system needed to protect against. However, in doing so, it was left open how states should use the DBT in the context of a graded approach, whereby a higher level of risk is accepted as the consequences of a successful theft or sabotage act decline in seriousness. Revision 5 now clarifies that physical protection requirements to protect against the unauthorised removal of Category I nuclear material and sabotage that has potentially high radiological consequences should be based on the DBT. It is left open to states to decide whether to use a threat assessment or DBT to determine the appropriate protection requirements for other nuclear material and nuclear facilities.

It has become common practice for nuclear facilities to develop security plans detailing their physical protection system and to develop contingency plans to address security events. Likewise, it is common for transport security plans to be developed for more sensitive movements of nuclear material, where physical protection arrangements are more complex, often involving a number of separate entities. However, Revision 4 was silent on such plans and only linked licensing to compliance with regulations, supported by security surveys. Revision 5 recommends that submission by the operator of a satisfactory security plan (including associated contingency plans) is a prerequisite for the granting of a licence by the competent authority. Implementation and regular review of the approved security plan (including approval by the competent authority of any amendments to it) should be a condition of the licence. Similar arrangements should be put in place for the advance approval by the competent authority of all Category I and II nuclear material transportation.

The chapter also explains how risk can be managed, through reducing the threat and potential consequences of malicious acts and improving the effectiveness of the physical protection system. A section on security culture has been added in recognition of this being a fundamental principle. Finally, recommendations have been added on the establishment of sustainability programs for physical protection, including configuration management.

Unauthorized Removal, Sabotage, and Transport

Many small but important amendments have been made to these three chapters. Some of the more significant amendments to Revision 4 are detailed below.

The term "prudent management practice" has long been used in INFCIRC/225 in relation to measures required for the protection of nuclear material in quantities following below the Category III threshold. The term is also used in the amended CPPNM whereby it is an obligation to protect such nuclear material in this manner that the state decides should not be subject to the full physical protection regime because of its nature, quantity, relative attractiveness, and radiological inventory. However, the term has never been defined. Revision 5 now addresses this by recommending that such material should be secured against unauthorized removal and unauthorized access. In doing so, it is consistent with the measures recommended in the IAEA Basic Safety Standards for the security of all sources.

Revision 4 recommended that an evaluation should be carried out of the radiological consequences associated with the sabotage of a nuclear facility and nuclear material with a view to identifying the material or systems that needed to be protected because of their potential for causing "unacceptable radiological consequences" if sabotaged. Detailed recommendations were only provided for nuclear power reactors leaving it open to states to determine the level of protection needed for other nuclear installations and material.

The process for grading consequences, identifying the plant and any radioactive material which could cause these consequences and designing a physical protection system to protect against unacceptable radiological consequences caused through an act of sabotage is more clearly addressed in Revision 5. It however has been left to states to define how many levels of protection are needed and their thresholds. An Implementing Guide on Sabotage that will provide more guidance on a graded approach to protection against sabotage. is expected to be published by the IAEA shortly.

Revision 5 does however recommend that in all cases states should define a threshold above which the potential unacceptable consequences are graded *high*. It then provides a detailed set of recommendations, modified from those provided in Revision 4 for nuclear power reactors, for the protection of nuclear facilities, the sabotage of which could lead to these high radiological consequences. It also clarifies that vital areas (and the consequential associated physical protection measures) only require to be established within a facility that has the potential for these high radiological consequences. Thus, Revision 5 recognizes that there are a variety of installations and inventories of radioactive material within nuclear facilities (other than nuclear power stations) which need high levels of protection against sabotage.

A similar graded approach to sabotage is recommended for nuclear material during transport and advice is provided on some additional measures to which consideration should be given if the threat of sabotage warrants.

Summary

The revision of INFCIRC/225 was an extremely lengthy process, partly due to the need to agree boundaries between it and the other two new Recommendations documents being produced concurrently and the need to adopt, insofar as possible, a consistent approach to the development of all three. As a result, the time provided and the stimulus arising from wider consideration of Nuclear Security meant this was by far and away the most comprehensive revision ever undertaken. The result is a much improved set of recommendations, comprehensive in nature and hopefully more understandable. Revision 5 should be capable of serving as a global reference point for physical protection for the next ten years.

Although parts of Revision 5 may appear still to be prescriptive in nature, there has been a considerable move towards it adopting a performance-based approach. The need for testing and evaluation of effectiveness is emphasised in many places, together with the need for the establishment, maintenance and exercising of a variety of contingency plans.

The outcome of the process, Revision 5 of INFCIRC/225, represents a broad consensus among Member States of the requirements which should be met by a state's physical protection regime and the operators/carriers' physical protection systems.

Finally, the document will facilitate ratification and implementation of the amendment to the CPPNM by providing greater clarity on the amendment's provisions, particularly those in Article 2A which deals with a state's physical protection regime and contains the twelve Fundamental Principles that parties are required to apply insofar as is reasonable and practicable.

The views expressed in this article are those of the author and do not necessarily reflect those of the UK Government or the Health & Safety Executive.

Christopher Price joined what is now the Office for Civil Nuclear Security (OCNS) in 1987 and has been its deputy director since 1997. OCNS regulates the security of UK civil nuclear facilities, nuclear material in transport and sensitive nuclear information.

Price was heavily involved in ensuring modern physical protection legislation and regulations were put in place in the UK during the period 2001-2006. He has led some dozen IAEA IPPAS missions since their inception in 1996 and was a founding member of the DG IAEA's Advisory Group on Nuclear Security (AdSec) from 2002 until 2008. He represented the UK at all the meetings which led to the 2005 adoption of the Amendment to the CPPNM, as well the meetings which led to the third and fourth revisions of INFCIRC/225. He chaired the consultancy meetings that developed INFCIRC/225/Rev.5. He was a member of the UK delegation to President Obama's April 2010 Nuclear Security Summit.

North Korea's Light-Water Reactor Ambitions

Siegfried S. Hecker, Chaim Braun, and Robert L. Carlin
Center for International Security and Cooperation, Stanford University

Abstract

On November 12, 2010, Pyongyang chose to reveal the construction of a new light-water reactor (LWR) and a recently completed pilot uranium enrichment centrifuge plant.

The LWR is meant to modernize North Korea's nuclear power program to finally produce much-needed electricity by nuclear means. Its construction represents a major shift in North Korea's nuclear strategy. Pyongyang abandoned its twenty-five-year pursuit of LWRs from foreign sources—first from the Soviet Union and later from the United States. But its attempt to build one now raises a series of critical questions: Will North Korea be able to build a light-water reactor without external help? Will it be safe? And will indigenous LWRs and centrifuge enrichment enhance its nuclear weapons program—based primarily on gas-graphite reactors—which Pyongyang is now apparently ready to abandon? We trace the evolution and prospects of North Korea's reactor programs, particularly its LWR ambitions, which resulted in Pyongyang joining the Nuclear Nonproliferation Treaty (NPT) in 1985, then becoming the center piece of the Agreed Framework aimed at ending enmity between Pyongyang and Washington, and continued to be featured as a critical part of Pyongyang's Six Party negotiations—all before the 2009 decision to pursue LWRs on its own.

Soviet Atoms for Peace and Indigenous Gas-graphite Reactors

Kim Il-sung began the first phase of nuclear development cultivating a base of technical expertise under the Soviet Atoms for Peace umbrella. Over several decades, beginning in the 1950s, North Korea sent students and researchers to Soviet universities and nuclear research centers to be educated and trained. The Soviet-North Korean nuclear cooperative treaty in 1959 led to the construction of a small Soviet research reactor, the IRT-2000, and other key nuclear facilities at the newly created nuclear research complex in Yongbyon in the 1960s.

The late 1960s were turbulent times in Pyongyang's relations with the West. South Korea's military was bolstered by U.S. troops and U.S. nuclear weapons on its soil. Pyongyang watched the Cuban missile crisis unfold in a manner that shed doubt on Soviet commitments to its allies. The North witnessed the Sino-Soviet split and the Chinese Cultural Revolution. Each of these developments reinforced the notion in Pyongyang that it could not rely on others for the country's security. Although the North fielded an immense conventional army, and its deadly artillery along the Demilitarized Zone (DMZ) was poised to destroy Seoul, Pyongyang became convinced that ultimately nuclear weapons were necessary to balance the U.S. nuclear presence in the South.

In the 1970s and 1980s, Pyongyang focused on building an indigenous nuclear capability, driven partly by Kim Il-sung's interest in nuclear weapons and his inability to get help from either China or the Soviet Union in achieving that goal. The North established domestic institutions to educate nuclear specialists and used Soviet-supplied research facilities to train them. Pyongyang stopped inviting Soviet specialists and scoured Western nuclear literature to become masters at reverse engineering. Although Soviet engineers and technicians had built the IRT-2000 reactor, North Korean specialists were quick studies and modified the reactor to boost the power level from 2 megawatts-thermal (MWt) to 8 MWt by converting the reactor core to use highly enriched uranium (HEU) instead of the original low-enriched uranium (LEU) fuel.[1] The Soviet Union continued to supply fuel, first at a level of 80 percent enriched in Uranium-235, then at a level of 36 percent after 1986, before ceasing all shipments after the dissolution of the Soviet Union.

As a next step, Pyongyang decided to build gas-cooled, graphite-moderated reactors. It was a logical choice at the time for an indigenous North Korean energy program because gas-graphite reactors can operate with natural uranium fuel and, hence, do not require enrichment of uranium.[2] North Korea has ample indigenous uranium resources for its reactor program. Although North Korea may have experimented with enrichment technologies, commercial enrichment capabilities were beyond its reach and difficult to acquire at the time. North Korea's ambitious program began with an experimental five megawatt-electric (MWe) reactor, which became operational in 1986. That was followed by a scaled-up 50 MWe reactor and a 200 MWe power reactor, although neither was ever completed.

North Korea quickly mastered all aspects of the gas-graphite reactor fuel cycle. It built fuel fabrication facilities and a large-scale reprocessing facility, which enabled extraction of plutonium from spent fuel.[3] Unlike the Soviet-built research facilities, the new facilities were built and operated without being declared to or inspected by the International Atomic Energy Agency (IAEA). Pyongyang had no legal obligation to declare these facilities when they were built because it was not yet a member of the NPT. The North's nuclear program caused international concern because although gas-graphite reactors generate electricity and heat, they also produce weapons-grade plutonium. So, whereas Pyongyang's choice of gas-graphite reactors was logical for its energy program, it was also the best choice to develop a nuclear weapons option.

In parallel with the gas-graphite reactor program, Pyongyang asked Moscow to build LWRs to help meet North Korea's energy demands. The North joined the NPT in 1985 (although the safeguards agreement with the IAEA was delayed until 1992) because Moscow made consideration of LWRs at that time contingent upon the North becoming an NPT member. The Soviet Union initially promised assistance in the construction of four 440 MWe VVER-440 type LWRs. As a result of a seismic survey, the reactors were to be located in the Kumho region near Sinpo on the shore of the East Sea, to be completed in the early 1990s. These reactors never materialized because of the demise of the Soviet Union. Pyongyang kept IAEA inspectors out of its new nuclear facilities until 1992, by which time it had an operating reactor and all necessary facilities in place for the plutonium fuel cycle. Allowing access to the inspectors coincided with a diplomatic initiative toward the United States and followed President George H.W. Bush's decision to withdraw all American nuclear weapons from South Korea. By this time, the 5-MWe experimental reactor was producing electricity and heat for the local town, as well as approximately six kilograms (roughly one bomb's worth) of weapons-grade plutonium per year. The fuel fabrication and reprocessing facilities were operational, and the two larger gas-graphite reactors were under construction.

Everything was in place for Pyongyang to launch the third phase of full-scale gas-graphite reactor development, but that phase never materialized. The end of the Cold War changed Pyongyang's security environment and eliminated Soviet financial assistance and the LWR offer. Reinforcing the North's suspicion of Beijing's reliability, China abruptly normalized diplomatic relations with South Korea. In this rapidly changing security environment, Pyongyang began to seriously explore accommodation with the West, especially the United States.

From 1993 to 1994, with some frustrating moments as well as a brief detour to the brink when the North unloaded the plutonium-containing spent fuel rods contrary to U.S. expectations, intense maneuvering and negotiations between Pyongyang and Washington led to the Agreed Framework,[4] which changed North Korea's nuclear technical trajectory dramatically. Pyongyang agreed to give up its indigenous gas-graphite reactor program for the promise of two LWRs to be supplied by the United States, South Korea, and Japan. The spent fuel rods unloaded from the 5-MWe reactor were repackaged by an American technical team and stored in the cooling pool for eventual removal from North Korea. Operation of the 5-MWe reactor, fuel fabrication plant and reprocessing facility were halted and monitored by IAEA inspectors per special arrangement under the Agreed Framework. Construction of the two larger gas-graphite reactors was stopped.

Although Pyongyang halted its plutonium program from 1994 to 2002, it continued to expand its missile program and turned to uranium enrichment as an alternate means of producing fissile materials for bombs, apparently as a hedge against what it saw as slow and incomplete fulfillment of Washington's Agreed Framework obligations.[5] The Bush administration came to office adamantly opposed to the Agreed Framework. During its first formal encounter with Pyongyang in October 2002, it accused Pyongyang of covertly pursuing the alternative HEU path to the bomb. This altercation effectively ended the Agreed Framework and changed Pyongyang's technical and political trajectory again.

In 2003, after the North formally withdrew from the NPT, the Yongbyon technical team was able to restart the 5-MWe reactor and operate it until July 2007, when the reactor was again shut down, this time as part of a Six-Party Agreement. During this period, there was considerable activity in Yongbyon. Besides unloading and reloading the reactor core in the summer of 2005, the North conducted three reprocessing campaigns. The first, in 2003, was to extract roughly twenty-five kg plutonium from the 8,000 spent fuel rods that were stored during the Agreed Framework. The second campaign in 2005 extracted roughly ten kg from the 2003 to 2005 reactor operations cycle. The third campaign in 2009 extracted roughly eight kg of plutonium from the 2005 to 2007 reactor cycle. Based on his four visits to Yongbyon, Hecker estimates that the North's current plutonium inventory is twenty-four to forty-two kilograms of plutonium.[6]

So, nearly forty years after Pyongyang began to lay out its ambitious plans for nuclear power with an option for nuclear weapons, and twenty-four years after the 5-MWe reactor began operations, Pyongyang has produced enough plutonium for four to eight bombs. It conducted two nuclear tests; the first only partially successful and the second apparently successful. Currently, there is no plutonium being produced because it voluntarily shut down the reactor in July 2007 and it has no plutonium in the pipeline to be reprocessed. The two larger gas-graphite reactors, which could have produced dozens of bombs worth of plutonium per year, have turned to scrap since they were stopped during the Agreed Framework. The electricity production over the years is even more abysmal—the 5-MWe reactor has produced electrical power for local use, but equivalent to a paltry twenty-three days of a modern LWR's power. Pyongyang bet on the gas-graphite reactor technology for nuclear power and lost. Most of the rest of the world had long ago turned to LWRs. No wonder that energy starved North Korea has been keenly interested in the acquisition of LWRs.

The Agreed Framework, LWRs, and KEDO—Designed for Much More Than Electricity

The Agreed Framework negotiated in three substantive sessions (July 1993, August 1994, and September/October 1994) produced an agreement to construct two modern 1,000 MWe LWRs in North Korea as part of a consortium eventually known as the

Korean Peninsula Energy Development Organization (KEDO). Although an LWR is a large electricity generating plant, both sides loaded the provision of the two reactors with heavy political significance. For the North Koreans, involving the Americans in a long, expensive construction project was considered a good test of Washington's commitment to improving bilateral relations. For South Korea, choosing the "Korean Standard Nuclear Plant" (KSNP, i.e., the LWRs version then being built in South Korea by Korean corporations) as the reactor of choice was deemed an important psychological victory over the North, as well as an additional business opportunity. It was no less important to Washington because it ensured that Seoul (and also Japan) rather than the United States would pay the lion's share of the costs for building the reactors. Finally, there was a generally shared hope among three, later four, governments participating in KEDO, that exposure to thousands of foreign workers on the site would both spread benign influence from the outside and convince the leadership in Pyongyang that interacting more openly with the world was a good thing.

The Agreed Framework also contained a series of linkages intended to deal, more or less simultaneously, with each side's primary concerns about the other. For example, the freeze at Yongbyon was linked to an annual supply of heavy fuel oil. The staged dismantlement of the graphite-based facilities was linked to stages in the construction of the two light water reactors. The supply of critical components for the LWRs was linked to the North's satisfying the IAEA about the history of its nuclear program, which in those innocent years before the North's nuclear tests was actually one of the major U.S. concerns.

It should be noted that the Agreed Framework was not, strictly speaking, a legal agreement between the governments of the United States and North Korea. It was not negotiated as such, and it was clear to both sides that the obligations they undertook under the agreement were not, in a strict sense, legally binding. Rather, the linkages described above were meant to be mutually reinforcing to get them through expected difficulties. As it turned out, implementation proved difficult (in some ways more difficult than the negotiations themselves) because both sides at various times held back on their commitments as leverage in order to achieve better performance from the other side. Inevitably, that fed existing deep mistrust.

Even so, on balance, the overall report card looks relatively good, especially compared to the situation that exists today. One major U.S. goal was accomplished quickly. The North promptly froze the fissile production facilities at the Yongbyon complex and allowed IAEA inspectors to install monitoring equipment. From 1995-2002, the IAEA was at Yongbyon virtually year around, a presence far beyond what would have been the case under normal IAEA safeguards protocols.

It is a common misunderstanding that the Agreed Framework stopped the North's nuclear weapons program. It did not, and certainly did not claim to do so in the first stages. The goal was first to stop the production of fissile material, and only in the next stage dismantle the production facilities while returning the North to the NPT. It was also meant to uncover or stop a potentially bigger weapons program by opening the North to broader, more intrusive inspections and by having it reveal the history of its nuclear project. The agreement did not address the question of uranium enrichment because U.S. negotiators stuck to a simple rule—don't demand anything that cannot be verified by National Technical Means. The freeze of plutonium production at Yongbyon could be verified, whereas an unknown enrichment program at unknown sites could not.

Central to the Agreed Framework was the construction of the light water reactors. Quite early in the negotiations, at the second meeting in July 1993, the North Koreans had introduced the idea of replacing their graphite-moderated nuclear reactor program with LWR technology, arguing that they had adopted graphite technology because they were unable to get assistance in obtaining LWRs for their electric power needs, and that if the gas-graphite reactor program struck outsiders as threatening, they would be willing to give it up if they received LWRs in return. The United States felt it could not supply and pay for such reactors on its own, and so was born the idea of a multilateral KEDO consortium.

KEDO's experience is instructive for both the limitations of diplomacy in dealing with the North Korean nuclear issue and the realistic possibilities. From the beginning, the common wisdom held that KEDO was formed primarily to build nuclear reactors. In fact, KEDO was not at its core a technical or a construction organization (even though it had a large technical department) but rather a political one. It was an instrument meant to implement an agreement that the United States thought would address its security concerns vis-a-vis the North. In particular, KEDO was seen as one of the main tools for regular, sustained, and long-term engagement with the North. In addition, it was specifically designed to broaden the scope of engagement with the North, to involve South Korea and Japan as well as the United States.

KEDO turned out to be a complicated mix of goals, expertise, and headaches. It was supposed to build one of the most technically complex modern facilities (a nuclear power station with two large reactors), employing standard commercial practices (financing, contracts, construction, quality assurance, legal liability, etc.), all the while pursuing a web of difficult political, diplomatic, and security goals. What this meant is that though KEDO had a clear political purpose, functionally it had to operate within technical and, to a lesser extent, commercial realities and constraints. It needed to secure financing for the reactors' construction (about $4.6 billion, provided by the non U.S. members) as well as funds to pay for 500,000 tons of heavy fuel oil a year (provided mostly by the United States). This intersection of the commercial, technical and diplomatic worlds was frequently contentious and messy.

Over time, KEDO developed a working relationship with its

North Korean counterparts different and apart from the relations each of the KEDO governments themselves had with Pyongyang. This allowed an element of flexibility that proved useful, giving KEDO space to move ahead in dealing with the North even in the teeth of a number of diplomatic gales. It also sometimes caused tensions between the KEDO secretariat and the home governments.

After a slow start and several years spent preparing the site in the North while manufacturing reactor components in the South, by 2002 there was clear progress underway, with the containment structure of the first reactor visible to any North Koreans (including, apparently, Kim Jong-il) who rode on the east coast train line, passing within a few hundred yards of the KEDO site. It was just at that stage that the Bush Administration put on the brakes. KEDO's work on the reactors slowed and then, as funding dried up and political support withered, the work stopped. In January 2006, KEDO abandoned the Kumho site, along with its construction equipment and scores of apartments and other facilities used by the workers.

LWRs and the Six Party Talks

Despite the demise of KEDO, Pyongyang did not give up on LWRs. During the first phase of the fourth round of the Six Party talks in August 2005, the North Korean delegation insisted that provision of an LWR be part of any denuclearization agreement. Hecker visited Pyongyang a few weeks later with an informal proposal to revitalize the energy infrastructure and electrical grid *without* nuclear reactors. Kim Kye-gwan, vice Minister of Foreign Affairs and head of Pyongyang's Six Party delegation, made an impassioned plea for an LWR, claiming that it would not represent a nuclear weapon risk. Hecker was permitted to conduct a joint proliferation assessment with Yongbyon technical officials to compare the proliferation risks of LWRs with continued operation of North Korea's gas-graphite reactors. In the joint technical assessment, they reported that either could be diverted to produce plutonium for weapons, but that gas-graphite reactors posed a considerably greater risk. Technical measures could be implemented to reduce the risk of either option, but some residual risk remained with both options. They concluded that the level of tolerable risk is a political, not technical, decision. Vice Minister Kim thanked them for their analysis, but concluded the dinner conversation with "no LWR, no deal."

Hecker took that message back to Secretary of State Condoleezza Rice and her staff. The staff was convinced that Pyongyang's nuclear motives were purely military and did not support the LWR option; besides this option appeared to be repeating what the staff believed to be the flawed path of the Agreed Framework. Nevertheless, Washington approved the conditional wording that an LWR could be considered at an "appropriate time." That compromise led to the six parties signing the Joint Statement on the Denuclearization of the Korean Peninsula on September 19, 2005. Within twenty-four hours, however, Washington announced that KEDO—the organization actually engaged in building LWRs—was to be disbanded, further diluting what the North considered a key section of the Joint Statement.

Virtually simultaneously, the U.S. Department of Treasury sanctioned North Korea, prompting Pyongyang to leave the Six Party talks and in October 2006 conduct its first nuclear test. The test and U.S. domestic political developments convinced the Bush administration to change its negotiations strategy and to engage Pyongyang bilaterally on the margins of the Six Party talks. These diplomatic moves resulted in the February 13, 2007, Initial Actions agreement to discuss a first phase of shutting down and sealing the Yongbyon nuclear complex. A few weeks later, Vice Minister Kim visited Stanford University to discuss potential paths for denuclearization. This time he concurred with Hecker that LWRs could constitute a nuclear weapons risk. He proposed that the United States provide an LWR while Pyongyang take appropriate actions to reduce proliferation concerns. Specifically, he stated that Pyongyang was willing to forego enrichment and reprocessing since these two steps posed the proliferation risk. Kim stressed that the LWRs had both practical and symbolic importance. It was crucial, he stated, that after spending decades on nuclear development, Pyongyang had something to show for its efforts.

Little additional progress was made toward an LWR during the remainder of the Bush administration. An agreement was reached on October 3, 2007, to implement the second phase of the 2005 Joint Statement, namely the disablement of the Yongbyon nuclear facilities. In June 2008, Pyongyang blew up the reactor's cooling tower to demonstrate it was prepared to shut down Yongbyon's plutonium production.[7] However, the rest of 2008 was marred by disagreements over declaration of past programs and verification. The discovery of HEU particles on two sets of items given by the North to the United States raised again the concern that Pyongyang was secretly enriching uranium. No progress was made toward dismantlement of Yongbyon and no serious discussions took place about the prospects of provisions of an LWR. Following its April 2009 rocket launch and UN condemnation, Pyongyang left the Six Party talks and declared that it would now build its own LWR.

Prospects for Indigenous North Korean LWRs

During the November 2010 visit by Carlin, Hecker, and Stanford University colleague John W. Lewis, North Korean diplomats and technical officials announced that because of their inability to obtain LWRs from the United States, they were forced to build their own LWRs along with the requisite fuel-cycle facilities, which will require uranium enrichment. At Yongbyon, they showed us the construction site for a small experimental LWR.[8]

We were told that they will first build a small, experimental reactor designed for 100 megawatts-thermal power output.[9] They will start small, they said, because LWRs represent a new technology for them. Once they have mastered the technology, they will build bigger LWR power reactors. This is precisely the same path they followed with the gas-graphite reactors. For the LWR project, they told us that they commissioned an entirely new, young design team because they believe the new technology requires different skills and capabilities, and this team would be unencumbered by the gas-graphite reactor legacy. Our hosts also stated that they will not use the nuclear specialists who worked on the KEDO project for the design or construction phase of the LWR. We were surprised by how few of the design details appeared to have been finalized. For example, the pressure vessel material was not fully specified and neither was the fuel cladding material.

North Korea's decision to construct its own LWRs raises three critical questions: 1) Are the reactors and associated fuel-cycle facilities designed for electricity or bombs? 2) Can North Korea build the reactors and can they do it indigenously? 3) Can the reactors be built and operated safely?

We believe the LWRs are intended to produce electricity, although, as is the case for all uranium-fueled reactors, LWRs produce plutonium that could potentially be used for nuclear weapons. The experimental reactor being built can theoretically produce ten to fifteen kilograms of reactor-grade plutonium annually, but this plutonium is not well suited for bombs.[10] If North Korea were to change the typical LWR operational cycle to produce better weapons-grade plutonium, it would be easily detected and electricity generation would be curtailed. Besides, if it is more plutonium that Pyongyang wants to produce, it could do so much more easily by restarting its gas-graphite reactor.

Of much greater concern is the uranium centrifuge facility. Although the 2,000-centrifuge facility we saw was sized properly to supply sufficient quantities of LEU fuel for the experimental LWR, it can readily be reconfigured to produce HEU for bombs. Moreover, we believe that another centrifuge facility of unknown size has existed elsewhere for many years to allow them to perfect centrifuge operations of multiple cascades so that they could build and operate them in less than a year in the new Yongbyon facility we visited. Such an undeclared facility could easily be configured for HEU production.

As for the LWR construction, our North Korean hosts claimed that they will build the reactor indigenously. They were able to build the 5-MWe gas-graphite reactor themselves and nearly complete one of the much larger reactors. However, the LWR has different reactor components and balance of plant requirements, plus the fuel-cycle requirements are different. The steel pressure vessel is the most demanding fabrication challenge. North Korea reportedly has an operational 10,000 ton forging press at the Ch'o'llima Steel Complex,[11] which would allow it to forge the requisite pieces for the experimental reactor. We were told that the experimental LWR will be a pressurized water reactor, which operates at higher pressures to avoid boiling and steam formation in the primary system. Thus, thicker pressure vessels and primary steam pipes are required to withstand the higher pressures, which, in turn, require more complicated welding to ensure system integrity. Also, such reactors require large steam generators and intricate welding of the steam tubes to the tube sheet within the high-pressure steam generators. The pressure vessel head also contains many penetrations for control rod guide tubes for which welding integrity is essential. We do not know whether or not North Korea has the requisite experience and proper inspection procedures in place.

There are many other major challenges for the LWR construction compared to gas-graphite reactors. Nuclear-grade steam generators, primary pumps, and a pressurizer are required. The control rods and drive mechanisms are different because they must be leak-tight and operate under the higher pressures of an LWR. Nuclear-grade water-water steam generators have not been manufactured before in North Korea. We do not know if they have experience with the design and operation of a boron reactivity control system. The reactor safety protection control system is different for the higher energy-density LWRs that operate in a base load mode. The turbine generators for producing electricity, especially for the planned, larger LWRs, may present a major limitation because we suspect that the indigenous expertise to manufacture large turbine generators is limited. The balance of plant thermal system is also different and challenging.

Fuel requirements for LWRs differ from those for gas-graphite reactors. The fuel must be enriched to roughly 3.5 percent in uranium-235. In addition, the fuel is typically in the form of ceramic uranium dioxide fuel pellets, clad in either zircaloy or stainless steel. By contrast, the technology perfected by Yongbyon specialists for the gas-graphite reactor required natural uranium metal alloy fuel clad in magnesium alloy tubes. We believe that North Korea has no previous experience with zircaloy. It could turn to stainless steel, with which it has greater familiarity, but the stainless steel cladding will yield poorer reactor performance, thus requiring fuel with somewhat higher enrichment levels. The fuel assemblies are also different; the clad fuel pellets, longer fuel rods, spacers, and end-fittings must all be assembled into complete fuel assemblies.

On the back end of the LWR fuel cycle, the uranium dioxide spent fuel assemblies can be stored much more readily and for much longer times than the magnesium clad gas-graphite reactor spent fuel. It can be done in pool storage, or be eventually transferred to dry cask storage, which has now been demonstrated to be very effective in other nuclear power countries. LWR spent fuel, which can be stored for long times represents less of a proliferation concern. Should North Korea decide to reprocess the fuel, it will require some changes on the front end of the reprocessing facility because the decladding and chopping procedures differ for LWRs and gas-graphite reactor fuels, and criticality accident concerns are greater because of higher plutonium concentrations. Although these changes require some facility modifications, we believe they can be readily accomplished by Yongbyon specialists.

These are among the many challenges that North Korean specialists will face in the construction and operation of the experimental LWR. They have chosen a reasonable path of beginning small and expanding once they have gained sufficient experience. Based on their ability to build and operate the gas-graphite reactor successfully and the fact that they retrofitted the small Soviet-built IRT-2000 reactor for different levels of HEU enriched fuel, we believe they will most likely be able to construct the experimental LWR successfully. The modern instrumentation and controls we saw in the uranium enrichment facility in November 2010 also gives us some confidence that reactor controls for the small LWR might be adequate.

However, we have serious concerns about North Korea's ability to build and operate an LWR safely, particularly in the stated time frame of two years to completion. The construction cycle for the gas-graphite reactors was five to six years. Nuclear-grade welding and adequate inspection of the pressure vessel and the many penetrations that must be leak tight under high pressures and intense radiation is a demanding task, as is the construction of the concrete containment structure to meet nuclear requirements. The concrete structure needs to be effectively isolated from seismic hazards, properly reinforced with steel, and poured in large sections to ensure proper curing of the concrete. We were not reassured by what we saw at the Yongbyon construction site. There appeared to be little preparation for seismic isolation; the concrete foundation pad appeared quite thin. The concrete containment shell, which was about one meter high at the time, appeared to be poured in small batches from one small concrete mixer. Proper construction requires continuous, large-scale concrete pouring and temperature control to allow the concrete to cure properly. What we saw was not consistent with such practice.

The global nuclear industry has learned over the past three decades, particularly following the Three Mile Island and Chernobyl accidents, that nuclear reactor safety is paramount. Safe construction and safe operations require an effective and independent regulatory authority, as well as extensive international cooperation.[12] The chief engineer told us that the State Nuclear Safety Regulatory Commission has project oversight responsibilities and has approved their plans. He also assured us that the standing committee of the commission has nuclear specialists and that the commission inspects the site. The only insight that the West has had into the North's regulatory system is that gained during the KEDO project. The KEDO team engaged the commission on nuclear safety-related issues and worked to strengthen the North's regulatory infrastructure. The commission's specialists participated with KEDO in safety inspections at the LWR construction site at Kumho. KEDO also established a training program and made provisions for technical documents in support of the Commission's own reviews.

Based on what little we know about the North's regulatory authority, we are concerned that it may be technically weak and not independent. The fact that the North's nuclear program is under UN sanctions compounds the problem. The type of safety cooperation begun during the KEDO project is unlikely to continue and, hence, it is unlikely that the North's regulatory body and its reactor specialists will be able to benefit from international organizations such as the IAEA and the World Association of Nuclear Operators (WANO), which have been instrumental in helping to improve reactor operations safety around the world by sharing best practices and lessons learned

If North Korea overcomes the construction challenge and is able to operate the experimental reactor safely, it will certainly attempt to build larger power reactors. The KEDO-class 1,000 MWe reactors may well be beyond their reach, but in any case these were never well suited for the North's transmission grid. The North may decide to focus on LWRs of roughly 500 MWth (100 to 125 MWe), which would be much better match for its electricity grid. We are not convinced that North Korea could manufacture all the equipment for the larger sized LWRs at quality standards that will allow long-term, continuous and safe operation as electricity generating plants.

The final and perhaps most important issue resulting from Pyongyang's decision to pursue its own LWR program is that in their minds it provides legitimacy for its uranium enrichment program. Pyongyang will likely continue to deny that they developed centrifuge technologies during the Agreed Framework and while the Six Party talks were being held. Yet, the evidence that it did is now overwhelming. The centrifuge facility we were shown in November likely resulted from a long-standing indigenous program, aggressive and apparently successful procurements of export-controlled materials and components that the North was not able to produce, substantial help from A.Q. Khan prior to 2003,[13] and clandestine construction and testing of a centrifuge facility that served as the prototype for the Yongbyon plant. Nevertheless, we expect Pyongyang to insist that it is their sovereign right to pursue centrifuge technologies for the LWR program. The Yongbyon centrifuge facility will most likely produce LEU reactor fuel, but Pyongyang could be producing HEU bomb fuel at an undisclosed facility using the same technologies.

Where Do We Go from Here?

North Korea successfully developed the complete plutonium fuel cycle for gas-graphite reactors over a time span of approximately thirty years. It had developed the technical capacity to make plutonium bomb fuel by the early 1990s.[14] However, it gave up its indigenous capacity to generate significant nuclear electricity as part of the Agreed Framework.[15] Following the Bush administration's decision to terminate the Agreed Framework in late 2002, Pyongyang built plutonium bombs and demonstrated the first one in 2006. Pyongyang's continued attempts through the Six Party process to bargain for an LWR were unsuccessful. In 2009, it greeted the Obama administration with a second nuclear test and a different reality—it would keep its nuclear weapons and build its own LWRs.

For an indigenous LWR program, Pyongyang has chosen a sensible approach of starting with a small, experimental LWR before building larger power reactors. Although this new technology will be quite challenging for North Korea, it may well be able to build the experimental LWR with indigenous resources, but not in the projected time frame for operation by 2012. However, without the benefit of external safety consultation and review, we have serious concerns about the design and whether or not North Korea can operate it safely. These concerns will increase dramatically if Pyongyang proceeds with plans for larger power reactors. Operating LWRs with inadequate construction and operational safety standards and practices poses risks to neighboring countries as well as to global nuclear power.

Pyongyang's decision to build an LWR and unveil its enrichment facility complicates the diplomatic process by in effect redefining what is meant by denuclearization. Not only is it unlikely that Pyongyang will give up its nuclear arsenal anytime soon, but its likely insistence to proceed with LWRs and continue to increase its enrichment capacity as its fuel requirements increase, carries the specter of a covert augmentation of its nuclear weapons program. The risk of clandestine export of highly enriched uranium also increases considerably. Previously it was difficult to verify existing stockpiles of plutonium, but relatively easy to assess that no more is being produced, which is the case today. For the case of HEU, not only will Pyongyang deny that it has made any, but we will not know whether or not it is making more. Detection of enrichment facilities is significantly more difficult than reactors because the centrifuge plants have smaller footprints and few easily detectable signatures.

Pyongyang's categorical denial of any enrichment activity during a time when they surely existed will make diplomatic reengagement more problematic. Yet, there are few options but to reengage. We believe that the immediate objective should be to prevent a build-up of Pyongyang's nuclear weapons program. Specifically, we advocate what we call the three no's: No more bombs, no better bombs (which means no nuclear testing), and no export, in return for one yes—U.S. willingness to seriously address Pyongyang's fundamental security concerns. Since our ability to monitor uranium enrichment is limited, it would require greater cooperation from Pyongyang and a more intrusive inspection regime to have any confidence that it is not producing HEU clandestinely. Likewise, the export threat is much greater because the signature for HEU detection is so small. Containing it requires close cooperation from the international community, especially from China. So far, no one has been able to figure out how to convince Beijing that Pyongyang's nuclear program seriously threatens the peace and security in Northeast Asia and in the world at large that China repeatedly says it wants to preserve.

For the one yes, we do not really know what Pyongyang wants, but it surely will seek in exchange for cooperation on the nuclear front normalization of relations with the United States. An appropriate starting point might be a policy based along the lines of the October 2000 Joint Communiqué between Washington and Pyongyang, which stated that neither government would have hostile intent toward the other and confirmed the commitment of both to make every effort to build a new relationship free from past enmity. We can also be sure that the right to have LWRs will be on Pyongyang's list, but it will be difficult to accept uranium enrichment without much greater cooperation and transparency in North Korea.

Siegfried S. Hecker is co-director of the Stanford University Center for International Security and Cooperation (CISAC) and Professor (Research) in the department of management science and engineering. He was director of the Los Alamos National Laboratory from 1986-1997. His professional interests include plutonium research, cooperative nuclear threat reduction with Russia, global nuclear nonproliferation, and counter terrorism. He has made seven trips to North Korea, including four to the Yongbyon nuclear complex.

Chaim Braun is a CISAC consulting professor specializing in issues related to nuclear power economics and fuel supply, and nuclear nonproliferation. Braun pioneered the concept of proliferation rings dealing with the implications of the A.Q. Khan nuclear technology smuggling ring and the re-evaluation of nuclear fuel supply assurance measures, including nuclear fuel lease and take-back. He previously worked for Bechtel Power Corporation, United Engineers and Constructors Corporation, the Electric Power Research Institute (EPRI), and in private consulting.

Robert Carlin is Visiting Fellow CISAC. He spent more than thirty years in the U.S. intelligence community concentrating on North Korea. From 1989-2002, he was a division chief in the State Department's Bureau of Intelligence and Research, also serving as intelligence advisor to the chief U.S. negotiators with North Korea. As such he participated in all of the key U.S.-DPRK negotiations. From 2002-2006, he was political advisor to the Executive Director of KEDO. He has been to North Korea more than thirty times. From 1971-1988, Carlin was an analyst in the CIA.

End Notes

1. Likholetov, A. 2010. *Nuclear Club*, "On the Soviet Role in the DPRK Nuclear Program," (In Russian), No. 3 (4), 2010, p. 37.
2. The gas-graphite reactors were patterned after the British Calder Hall Magnox reactor, whose technical specifications were readily available because they were widely disseminated in the United Kingdom.
3. The reprocessing facility has the capacity of 110 metric tons of heavy metal/year and resembles an extension of the design of the Eurochem reprocessing plant in Mol, Belgium.
4. The Agreed Framework signed between the United States and North Korea on October 21, 1994, in Geneva agreed

to have North Korea freeze its existing nuclear program. In addition to U.S. supply of LWRs and delivery of heavy fuel oil, the two sides agreed to move toward full normalization of political and economic relations, and work together for peace and security on a nuclear-free Korean peninsula. See Joel S. Wit, Daniel B. Poneman, and Robert L. Gallucci, *Going Critical: The First North Korean Nuclear Crisis,* Brookings Institute Press, Washington, D.C. (2004) for informative discussions of the Agreed Framework and North Korean crisis in the 1990s.

5. Just how much progress Pyongyang made in developing uranium enrichment capabilities was difficult to assess until Pyongyang decided to show two of the current authors its small industrial-scale 2,000-centrifuge facility at Yongbyon on Nov. 12, 2010, as described in *Bulletin of the Atomic Scientists,* Dec. 20, 2010. http://www.thebulletin.org/web-edition/features/redefining-denuclearization-north-korea-0
6. Siegfried S. Hecker, "Lessons learned from the North Korean nuclear crises," *Daedalus*, Winter 2010, pp. 44-56. On November 12, 2010, Pyongyang chose to reveal to us the construction of a new light-water reactor (LWR) and a recently completed pilot uranium enrichment centrifuge plant.
7. Pyongyang blew up the cooling tower one day after it handed over records of its Yongbyon plutonium-producing facilities. The destruction of the cooling tower had great symbolic significance as well as financial benefits since it was reported that the United States paid Pyongyang $2.5 million for the demolition.
8. Our technical host gave the following introduction to our visit: "We have not been able to contribute to the national demand for electricity. So, we decided to make a new start. For us to survive, we decided to build our own LWR. On April 15, 2009, the Foreign Ministry stated that we will proceed with our own LWR fuel cycle. ...We are trying our best to solve our own problems. We will convert our center to an LWR and pilot enrichment facility. It is a high priority to develop uranium enrichment. We will have some difficulties with this, but we are proceeding with the LWR fuel cycle." Siegfried S. Hecker, A Return Trip to North Korea's Yongbyon Nuclear Complex, Stanford University Center for International Security and Cooperation. http://iis-db.stanford.edu/pubs/23035/HeckerYongbyon.pdf
9. The chief engineer did not want to specify the electrical power, except to say that the conversion efficiency is typically 30 percent. Hence, the electrical output may be 30 MWe, but judging from the performance of the 5-MWe gas-graphite reactor, it may be as low as 20 MWe. We also note that most modern LWR nuclear power plants generate roughly 1000 MWe power.
10. Weapons-grade plutonium is defined as plutonium with a Plutonium-239 content greater than 93 percent. LWRs operated for nuclear power typically have Plutonium-239 content closer to 50 percent. The other isotopes of plutonium that are produced in such nulcear power cycles make it very difficult to handle because of hight radiation levels and significant heat production, making reactor-grade plutonium less suitable for nuclear weapons.
11. http://www.kcna.co.jp/item/2009/200912/news17/20091217-02ee.html
12. Richard Meserve, The global nuclear safety regime, *Daedalus*, Fall 2009, pp. 100-111.
13. Siegfried S. Hecker, Redefining denuclearization in North Korea, *The Bulletin of the Atomic Scientists,* 20 December, 2010. http://thebulletin.org/web-edition/features/redefining-denuclearization-north-korea-0
14. According to various CIA and other national intelligence estimates, North Korea may have had sufficient plutonium for one or two bombs by 1993 (see Larry Niksch, "North Korea's nuclear weapons program," Oct. 9, 2002, Congressional Research Service, http://www.fas.org/nuke/guide/dprk/nuke/nk1.pdf. However, there is considerable disagreement in the technical community about these estimates and whether or not Pyongyang manufactured a nuclear weapon prior to 2003.
15. Siegfried Hecker, Sean Lee, and Chaim Braun, "North Korea's Choice: Bombs over Electricity," *The Bridge,* Summer 2010, pp. 5-12.

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 international safeguards, materials control and accountability, nonproliferation and arms control, packaging and transportation, physical protection, and waste management *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. All papers must include an abstract.

The *Journal of Nuclear Materials* Management is an English-language publication. We encourage all authors to have their papers reviewed by editors or professional translators for proper English usage prior to submission.

Papers should be submitted as Word or ASCII text files only. Graphic elements must be sent in TIFF, JPEG or GIF formats as separate electronic files and must be readable in black and white.

Submissions may be made via e-mail to Managing Editor Patricia Sullivan at psullivan@inmm.org. Submissions may also be made via by regular mail. Include one hardcopy and a CD with all files. These submissions should be directed to:

Patricia Sullivan
Managing Editor
Journal of Nuclear Materials Management
111 Deer Lake Road, Suite 100
Deerfield, IL 60015 USA

Papers are acknowledged upon receipt and are submitted promptly for review and evaluation. Generally, the author(s) is notified within ninety 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 number and e-mail address
- Name and address of the organization where the work was performed
- Abstract
- Camera-ready tables, figures, and photographs in TIFF, JPEG, or GIF formats. Black and white 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

JNMM is published in black and white. Authors wishing to include color graphics must pay color charges of $700 per page.

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.

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

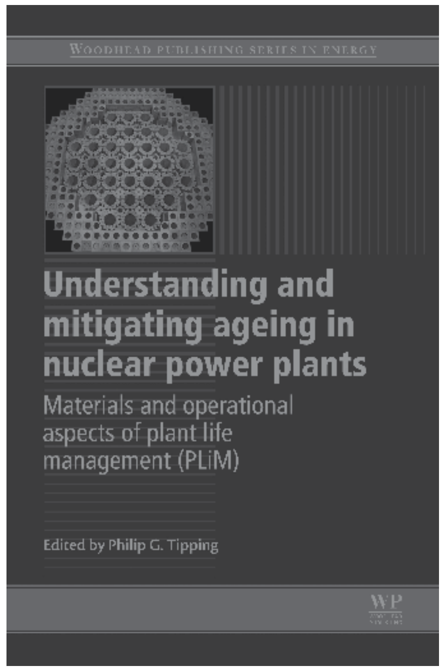
Reprints: Reprints may be ordered at the request and expense of the author. Contact Patricia Sullivan at psullivan@inmm.org or +1-847-480-9573 to request a reprint.

Book Review

by Walter Kane,
JNMM *Book Review Editor*

Understanding and Mitigating Ageing in Nuclear Power Plants

Editor: *Philip G. Tipping*
ISBN-13: 978-1845695118



As predicted, the grave consequences of global climate change are now overtaking us on a worldwide scale. This includes both extreme and extended droughts which have already turned fertile and productive areas into deserts, and torrential rains (from increased evaporation of warm ocean waters) and consequent floods. In addition, the introduction of more energy into the atmosphere via the evaporation of water produces more and more powerful storms. This has led to a major decrease in crop yields worldwide, a near-doubling of prices for many commodities, and grave consequences for the populations of many third world countries. There is no question that the principal cause of these calamities is the increase in atmospheric carbon dioxide from the use of fossil fuels.

Evidently, the answer to this continually worsening situation is to reduce our consumption of fossil fuels as fast as possible. Our options include, most importantly, energy conservation, and then our "green options," wind and solar, and nuclear power. While wind and solar are very popular, they have a number of disadvantages—high cost (a kilowatt hour from a solar cell costs six times as much as one from a nuclear plant), intermittency and distance from the consumer. This has led to proposals for a completely new power grid and costly energy storage systems that have not yet been invented and put into use. These considerations have led to proposals for a "nuclear renaissance," the construction of a large number of new nuclear plants worldwide. This has not occurred, due largely to the high initial cost of the plant and uncertainties in its profitability.

Another solution to this problem exists—to extend the useful life of our existing reactors. Typically, they have 30-year operating licenses, but their useful life, with appropriate measures, may be double this extent. "Understanding and Mitigating Ageing in Nuclear Power Plants" addresses this problem in detail. It is a compilation of twenty-four articles by experts world-wide who have worked to understand and remedy the ageing of reactor components. These articles range from the monitoring of the *health* of reactor components, and their replacement where necessary, and the metallurgy of the alloys used and, for example, stress corrosion cracking and radiation-induced embrittlement, to the managerial and regulatory aspects of these programs. The body of work already carried out to address this issue is impressive, and the technology has more than passing interest.

For INMM members who are concerned with the future of nuclear energy, this work is a useful asset. Clearly prolonging the safe and useful life of our existing reactors is the least cost solution to our energy needs.

Taking the Long View in a Time of Great Uncertainty
Preparing for Social Chain Reactions

By Jack Jekowski
Industry News Editor

"What should the INMM's role be in a world defined by the new 'international order' and how should we be preparing today to fill that role in the future?"

Introduction

In the last two issues of the *JNMM*, we traced the remarkable journey by the Obama Administration in its efforts to pursue the seemingly impossible goal that many have had since the dawn of the atomic age: the elimination of nuclear weapons and the creation of a new international order. We also explored the complexities of the nuclear fuel cycle with guest columnist, INMM Vice President Ken Sorenson, in the context of world events and the recent reorganization of the Institute's technical divisions. Those first two columns have sparked some e-mail exchanges with members, including Jim Larrimore, the chair of the International Safeguards Division, that indicate a genuine interest exists in creating a forum to discuss current and future events and what more the INMM can do to better prepare for very different futures.

Since the first two columns were published, President Obama has achieved his first major goal on a timeline toward the objectives set forth in his April 5, 2009, Prague speech: the ratification of the New Start Treaty.[1] With the exchange of the ratification instruments with Russia at a ceremony in Munich, Germany, on February 5, 2011, the stage is now set to pursue more difficult objectives: Senate ratification of the Comprehensive Test Ban Treaty (CTBT); the negotiation and ratification of a Fissile Material Cutoff Treaty (FMCT); and the negotiation of a follow-on treaty to New START that addresses tactical weapons and even further reductions in stockpiles. At the same time, the objective of sharing nuclear technology for peaceful purposes continues to be advanced as the United Arab Emirates (UAE) works toward building the first of four large nuclear power plants. This success by the UAE has encouraged other nations in the Middle East to pursue nuclear power to solve their future energy needs, as the United States demonstrates an extraordinary willingness to remain flexible in negotiating agreements with those countries.

But, as with any path toward an uncertain future, there are detours that may occur, driven by critical uncertainties that could suddenly take us in a very different direction. Such is the news coming out of the Middle East in January: political and social upheavals in Tunisia, Egypt, Yeman, Algeria, and even Iran. Facilitated by twenty-first century technology, including the proliferation of handheld communication devices and social networks such as Facebook and Twitter, these historic uprisings and potential regime changes alert the scenario planner that serious potential discontinuities are in the offing that will change the path to the future.

Connecting the Dots — The Impact of Social Chain Reactions

In scenario planning it is not unusual for critical uncertainty-driven events on very different future paths to occur in the same time frame. One of the powerful benefits of scenario planning is the expansion of the imagination to visualize the impact of seemingly disconnected events and how they will influence the future, enabling preparation for dramatic change. Thus, on one path toward the future, today we have the ratification of New START and the encouraging cooperation with several nation states in the development of their nuclear energy programs. On a simultaneous-occurring darker path to the future, we have the continuing clandestine pursuit of nuclear programs by Iran and North Korea, and their defiant attitudes in the face of overwhelming international pressure. These are known critical uncertainties that we can monitor, and as events unfold aligned with them we can "connect the dots" to project their impact to create possible futures enabling us to make more informed decisions.

Occasionally, however, wildcards occur that change the game.[2] Such were the events that occurred in Tunisia and Egypt in January and February. How these events will unfold and impact the global security landscape is the subject of much speculation, particularly in light of the decision by the Mubarak government last year to begin construction of their first nuclear power plant with Russian assistance. Of particular note is the role that twenty-first century technology has played in facilitating the events in Egypt and the failed attempt by the government to intercede by temporarily shutting down the Internet. We have indeed entered a new age of technology, where political and social change can be directly influenced by these new instantaneous modes of communications. In fact, what we witnessed in Egypt could be characterized as a "social chain reaction" unleashed upon the body politic. A new set of critical uncertainties has been established:

- What new regime will emerge?
- How will that regime view its international obligations with respect to their nuclear program?
- What other dominoes will fall in the

Table 1.

Original Question	Reshaped to Stimulate Direct INMM Engagement
How will the world deal with the untenable situations in Iran and DPRK?	How could the nuclear situations in Iran and DPRK be resolved in a win-win manner?
What happens if other nation states similarly pursue nuclear weapons?	How could the nonproliferation system be improved to encourage NPT states to fully meet their obligations and stay in the system, and to better deal with cases where a lack of confidence develops that a nation is meeting its obligations?
Can nuclear forensics provide the deterrence needed to prevent terrorist attacks?	How could nuclear forensics become more effective in the nuclear nonproliferation and nuclear security toolbox and in deterring nuclear terrorism?

Middle East and elsewhere, encouraged by the events in Egypt?
- How will these events be shared with the rest of world through socially connected networks?

Suddenly, our world has become even more complicated.

Creating a Dialogue Within the INMM

In the first column of this series I posed eight questions for the membership to consider as we travel the path to the future. Intended to be thought-provoking in their design, and painted in caricature, these questions can be refined by discussions to provide more specific and manageable challenges for the Institute:

- How will the world deal with the untenable situations in Iran and DPRK?
- What happens if other nation-states similarly pursue nuclear weapons?
- How are other nations responding to President Obama's global nuclear initiatives and what impact will those responses have on the INMM?
- What will be the worldwide response to the first terrorist nuclear event (either nuclear or dispersal)?
- Can nuclear forensics provide the deterrence needed to prevent terrorist attacks?
- Will unilateral reductions in the U.S. stockpile influence the decision of other nuclear weapons states to further reduce their own stockpiles?
- What is the evolving role of the United Nations and IAEA in the new "international order" proposed by President Barack Obama?
- What scientific, technological, and policy innovations can INMM promote to make the world a safer place?

In e-mail exchanges with Jim Larrimore, mentioned earlier, the suggestion was made that we should recast these questions into meaningful challenges the Institute could pursue. An example of transforming the initial set of questions to inquiries that might use the Institute's range of competencies is shown in the table above for three of the original eight questions.

Larrimore has suggested that these types of challenges to the Institute would enrich the Sunday afternoon Technical Division discussions at the INMM Annual Meeting and better engage the membership. We will explore the logistics of that suggestion as more input is received on this column from the membership.

The global social networking phenomenon that we have watched emerge in its various forms also presents an opportunity to facilitate strategic discussions within the INMM family. Such a change brings with it a re-learning of concepts of personal interaction, something that is not comfortable for many of us from the "older generation." However, never has there been as dramatic an example of "a sign of the times" as this technological phenomenon, perhaps since the launch of the Internet itself. Nor has there been a more urgent need to provide a dynamic social environment for those discussions, particularly for the growing number of younger generation members in the Institute. An early entrée into using these communications technologies by the Institute is the *INMM Communicator* (http://www.inmm.org/INMM_Communicator_Newsletter/1695.htm), designed to provide a more immediate and informal mechanism to communicate to the membership on issues and happenings in the INMM.

Perhaps the time has come for the INMM to consider its own "social chain reaction," by launching an interactive Web presence.

We encourage *JNMM* readers to actively participate in these strategic discussions, and to provide your thoughts and ideas to the Institute's leadership. With your feedback we hope to explore these and other questions in future columns, addressing the critical uncertainties that lie ahead for the world and the possible paths to the future based on those uncertainties.

Jack Jekowski is a principal partner with Innovative Technology Partnerships, LLC (ITP), a national security consulting and services company that provides support to the U. S. Department of Energy, the U.S.National Nuclear Security Administration, the national laboratories and other federal and commercial customers. He can be contacted at jpjekowski@aol.com.

End Notes

1. For timelines of the Obama Administration's efforts to implement the Prague goals see: http://itpnm.com/whats-new-archives/criticaluncertaintytimelinegeneric2010.pdf and http://itpnm.com/whats-new-archives/criticaluncertaintytimelinegeneric2011.pdf.
2. See *Ahead of the Curve: Anticipating Strategic Surprise,* by Peter Schwartz and Doug Randall, for a discussion of how to anticipate forcing events and wild cards in global politics. http://www.gbn.com/articles/pdfs/Monitor.GBN_%20strategic%20surprises_SchwartzRandall.pdf

Calendar

May 16–20, 2011
33rd ESARDA Annual Meeting
Helia Conference Hotel
Budapest, Hungary
http://esarda2.jrc.it/events/esarda_meetings/2011-Budapest/01-index.html

June 26–30, 2011
2011 ANS Annual Meeting
Seizing the Opportunity: Nuclear's Bright Future
The Westin Diplomat
Hollywood, Florida USA
http://www.new.ans.org/meetings/m_75

July 17–21, 2011
52nd INMM Annual Meeting
Desert Springs JW Marriott Resort & Spa in Palm Desert, California USA
Sponsor: Institute of Nuclear Materials Management
Contact: INMM
+1-847-480-9573
Fax: +1-847-480-9282
E-mail: inmm@inmm.org
www.inmm.org

October 16–20, 2011
INMM/ESARDA Workshop
Future Directions for Nuclear Safeguards and Verification
Aix en Provence, France
Co-Chairs: Jim Larrimore, INMM
Michel Richard, ESARDA

Oct. 30–Nov. 3, 2011
2011 ANS Winter Meeting and Nuclear Technology Expo
The Status of Global Nuclear Deployment
Omni Shoreham Hotel
Washington, DC USA
http://www.ans.org

July 15–19, 2012
53rd INMM Annual Meeting
Renaissance Orlando
Resort at SeaWorld
Orlando, Florida USA
Sponsor: Institute of Nuclear Materials Management
Contact: INMM
+1-847-480-9573
Fax: +1-847-480-9282
E-mail: inmm@inmm.org
www.inmm.org

Decommissioning?

The new AURAS-3000 Box Counter from ORTEC will make short work of those bulky free release construction waste containers!

www.ortec-online.com/solutions/waste-assay.aspx

- Free Release Assay of large waste containers up to 3 m^3: B25 ISO Box, smaller boxes with demonstrated regulatory compliance.[1]
- Container Weights up to 6000 kg, with on-line weighing to 3000 kg and 1 kg resolution.
- Full Quantitative Assay of all detectable gamma emitters, with non-gamma emitter estimates by correlated scaling factors.
- FAST: High sensitivity, large area integrated HPGe detectors (85 mm diameter) achieve rapid release levels.
- Individual and averaged activity AND MDA reporting.
- Highly automated.
- Extensive Safety Protection.
- Tested to EMC, Electrical and Safety standards.

[1]http://www.ortec-online.com/download.asbx?AttributeFileId=0b1f5761-c46b-4901-91ac-e0b810655b6a