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Capability of Ruthenium Isotopes in Distinguishing Spent Reactor Fuel Type and Burnup

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Abstract

A computational study was performed to determine the capability of using ruthenium deposits around a reprocessing facility to determine the burnup of the fuel reprocessed and the type of reactor that produced the fuel. The higher-mass ruthenium isotopes are produced in significant quantity via fission. It was shown that the four stable and one radioactive fissiogenic isotopes yielded a significant discrimination capability. For the four reactor types studied here, it was shown that a spread of more than 50 percent in certain isotopic ratios existed between the reactor types. This separation of the reactor types should allow for good discrimination of burnup and fuel type.

Introduction

For several years Los Alamos National Laboratory has been studying the use of noble gas isotopes for monitoring reprocessing facilities.[1-7] These studies have involved the use of sophisticated reactor physics calculations, high-precision mass spectrometry measurements, and innovative data analysis techniques. The knowledge gained in these studies may be applied to the use of other isotopes that could yield significant amounts of information about activities within a reprocessing facility.

The study presented here has centered on the use of stable and radioactive, fissiogenically produced, higher-mass ruthenium isotopes (specifically ^{100}Ru, ^{101}Ru, ^{102}Ru, ^{103}Ru, ^{104}Ru, and ^{106}Ru). These isotopes are produced in significant quantities via fission. Figures 1–3 show the fission product yields for each mass chain for thermal, fast, and high-energy ^{235}U fission and for thermal ^{239}Pu fission. Figure 4 shows the production and decay schemes for these isotopes. These plots illustrate how the quantity of each ruthenium isotope in the spent fuel is a function of the composition of the fuel and the neutron energies inducing fission. Thus, the relative concentrations of these isotopes in the spent fuel contain information that can be used to determine the burnup and reactor type for the fuel.

The radioactive fission products (Figure 4) also contain information concerning reactor power history and spent fuel age (or time since discharge). The half-lives of ^{103}Ru and ^{105}Ru (thirty-nine days and 4.4 hours, respectively) are most likely too short to be of interest in reprocessing facility monitoring (most spent fuel is cooled for at least 150 days prior to reprocessing); however, the ^{106}Ru half-life of one year is long enough to allow the isotope to still exist in significant quantities during spent fuel dissolution. For exceptionally long cooling times (which are not uncommon for spent fuel), the ^{106}Ru concentrations may decrease too much to remain measurable. Thus the reader may find that

Figure 1. Fission yield versus mass number for ^{235}U thermal and high-energy fission

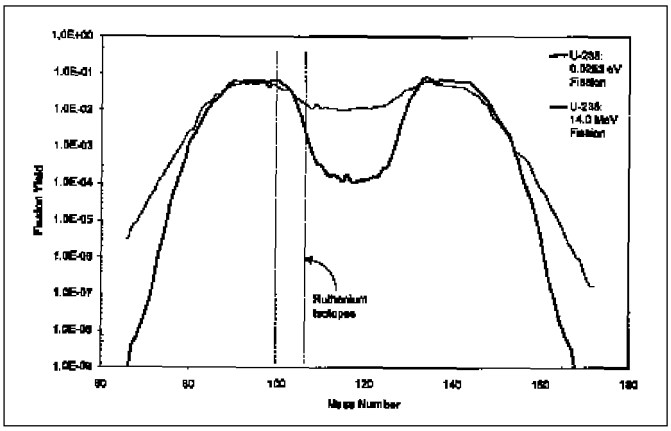


Figure 2. Fission yield versus mass number for ^{235}U thermal and ^{239}Pu thermal fission

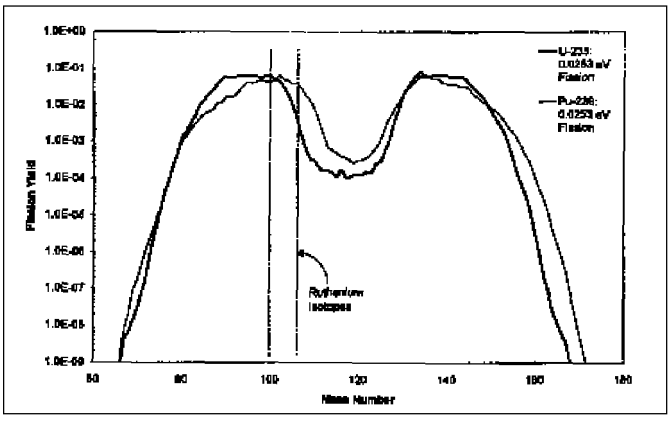
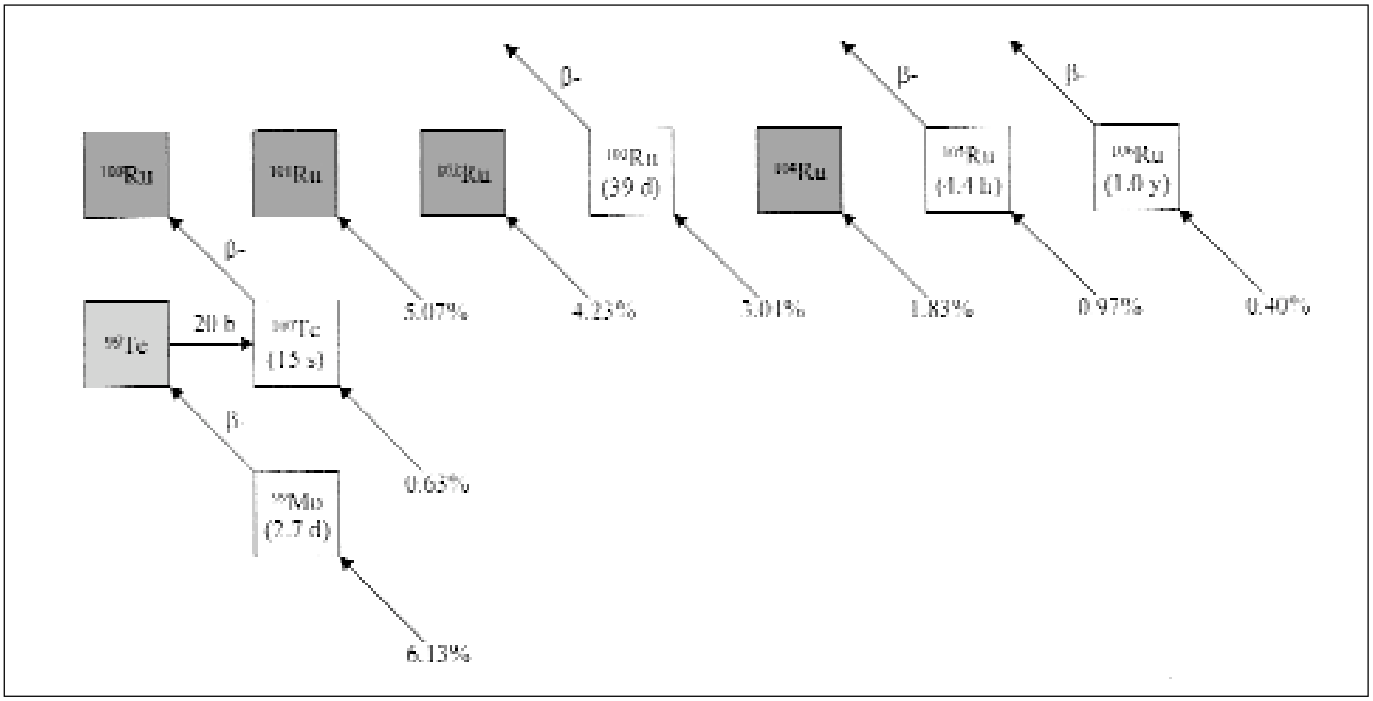


Figure 3. Production and decay schemes for stable and radioactive ruthenium isotopes (with ^{235}U thermal fission yields and thermal absorption cross-sections shown)



using this isotope is unmanageable. All of the stable isotope will exist in large quantities in the spent fuel and are not affected by changes in reactor operating histories or cooling times.

To determine the discrimination capabilities of these isotopes, several reactor fuels were modeled using a state-of-the-art reactor physics code to estimate the quantity of these ruthenium isotopes produced in the fuel. To facilitate measuring these isotopes in the field, isotopic ratios will be used. Thus, it is these quantities that will be analyzed to determine the difference between the expected signatures for various reactor types at various burnup levels.

It should be noted that little effort has been spent benchmarking existing reactor analysis codes for the production of these particular isotopes. Therefore, the numbers given in this report should be considered estimates. A significant benchmarking effort will be needed before effective implementation of this concept.

Reactor Models

Four reactor types were modeled in this study: (1) a pressurized water reactor (PWR), (2) a boiling water reactor (BWR), (3) a Canadian deuterium uranium reactor (CANDU), and (4) a Calder Hall reactor. PWRs and BWRs consist of low-enriched uranium (LEU) fuel and use a light-water moderator; however, BWRs tend to have a slightly lower moderator density due to the boiling action in the reactor. CANDUs use a natural uranium fuel and are moderated by a heavy-water coolant. Calder Hall reactors employ a natural uranium fuel and are moderated by graphite. The HELIOS-1.4 lattice physics code[8] was used to perform all calculations. Pin cell calculations were used, and the ruthenium isotopics as a function of burnup were determined. A cooling period of 150 days was used following irradiation to allow for the decay of any short-lived isotopes. The HELIOS code has been used extensively in the past for pin power, criticality, reactivity, and isotope production calculations.[9-15] HELIOS uses an ENDF/B-VI (Rev. 4) cross-section library and solves the neutron transport equation using an angularly dependent current-coupled collision probabilities method.

Predicted Mass Concentrations

The mass concentration (in g/tU) of each of the isotopes of interest was determined using HELIOS. Plots of these mass concentrations versus burnup for various reactor types can be found in figures 5–9. This information is necessary for determining the magnitude of the signature present in the fuel. Analysis concerning the dispersion of this material or the collection of samples will not be confronted here.

As can be seen from the plots, the quantity of ^{101}Ru, ^{102}Ru, and ^{104}Ru present in the fuel is extremely high, even for low burnup fuels. Also, the ^{100}Ru and ^{106}Ru concentrations are reasonably high (on the order of 100 g/tU). It is suggested that these quantities should result in a measurable signal; however, this will need experimental confirmation.

Figure 4. Mass concentration of ^{100}Ru versus bu mup in spent fuel from various reactors

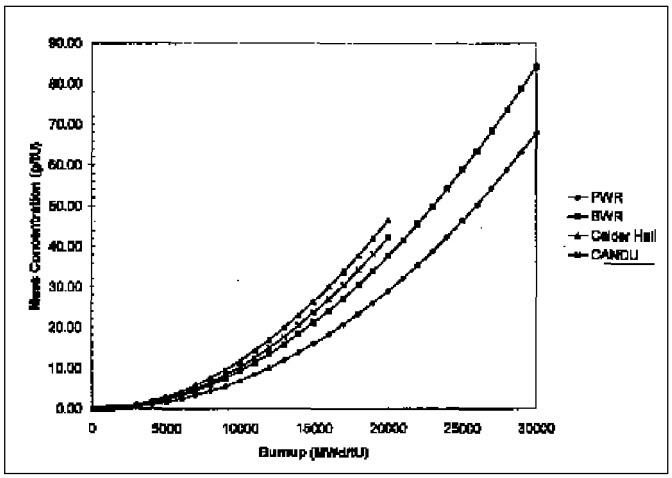


Figure 5. Mass concentration of ^{101}Ru versus bu mup in spent fuel from various reactors

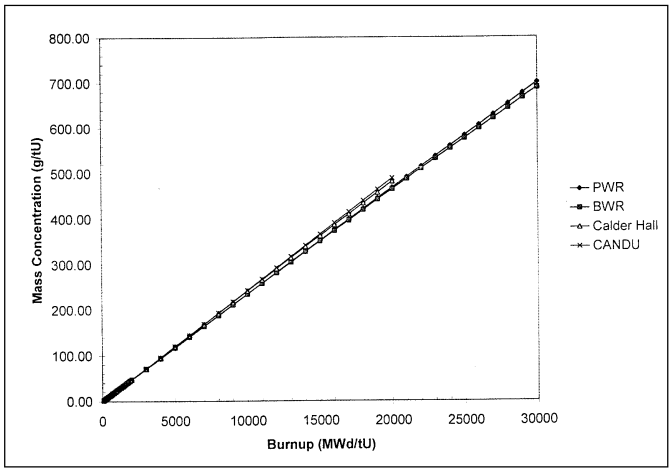


Figure 6. Mass concentration of ^{102}Ru versus bu mup in spent fuel from various reactors

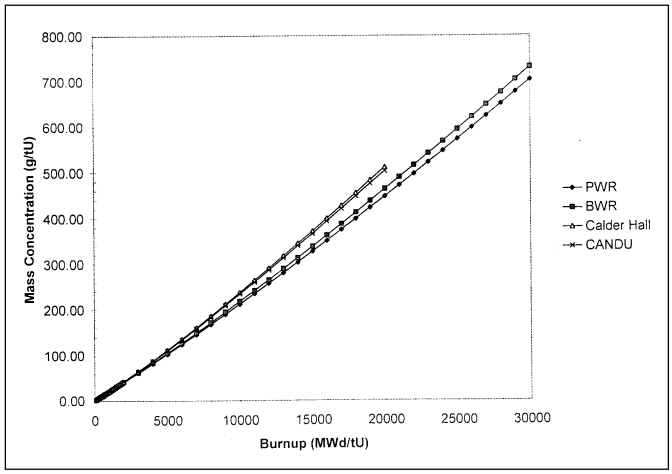


Figure 7. Mass concentration of ^{104}Ru versus bu mup in spent fuel from various reactors

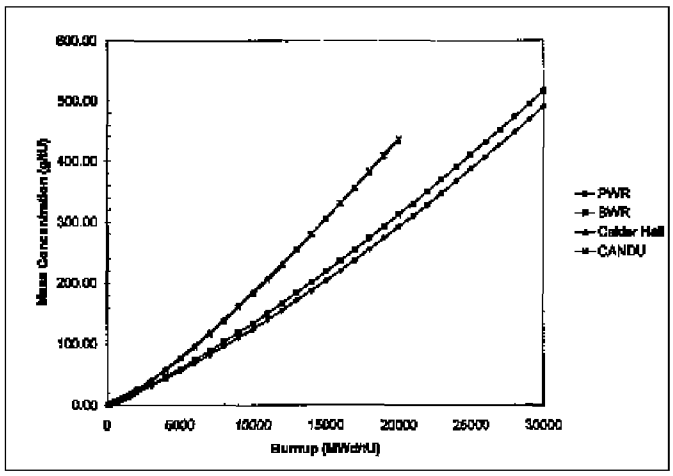
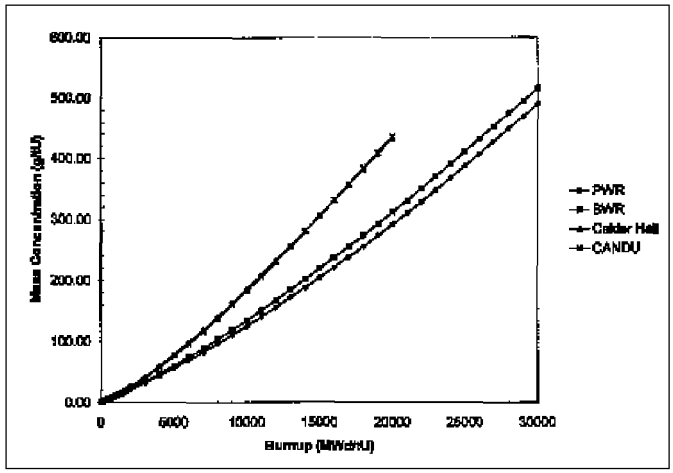


Figure 8. Mass concentration of ^{106}Ru versus bu mup in spent fuel from various reactors



Analysis of Isotopic Ratios

The number densities calculated by HELIOS were analyzed in detail to determine a set of isotopic ratio functions that yielded a significant discrimination capability. The functions chosen were the ^{100}Ru/^{101}Ru isotopic ratio, the ^{104}Ru/^{101}Ru isotopic ratio, the (^{101}Ru-^{102}Ru)/^{104}Ru isotopic ratio function, and the ^{100}Ru/^{104}Ru isotopic ratio. These isotopic ratios were chosen based on their abilities to discriminate between different reactor types (i.e., spread in the functions) and their nature with respect to burnup. Each of the functions is monotonic and all are either linear or near linear with respect to burnup. These functions, for each reactor type, are displayed in figures 10–13.

The ^{100}Ru/^{101}Ru isotopic ratio is a monotonically increasing, linear function of burnup for each reactor type. The function shows good separation characteristics with a 55 percent spread across the ratio. Its linear nature yields good burnup discrimination capabilities.

The $^{104}Ru/^{101}Ru$ isotopic ratio is a monotonically increasing, semi-linear function of burnup for each reactor type. The function tends to approach an asymptotic trend at high burnups (with each asymptote different for each reactor). The function shows good separation between reactor types with a 45 percent spread across the values. The function's burnup discrimination capabilities may be questionable due to its nonlinear nature.

The $(^{101}Ru\text{-}^{102}Ru)/^{104}Ru$ isotopic ratio function is a monotonically decreasing, semilinear function of burnup with excellent separation between the reactor types. There is a 108 percent difference between the high and low values. The fact that this function is created by subtracting two isotopic ratios may result in large uncertainties in the measured values; however, the separation characteristics are expected to compensate for this difficulty.

The $^{100}Ru/^{104}Ru$ isotopic ratio is a monotonically increasing, semilinear function with reasonable separation characteristics. A 19 percent difference is found between the high and low values. This function's greatest use is in its ability to discriminate between BWR versus PWR reactors and Calder Hall versus CANDU reactors. These reactor types tended to cluster with the other ratiofunctions.

The $^{106}Ru/^{101}Ru$ isotopic ratio (Figure 14) is a nonmonotonic function of burnup that shows excellent reactor type discrimination capabilities. This is due at least in part to the fact that it is radioactive and the ^{106}Ru concentration in the fuel eventually can reach an equilibrium concentration (Figure 9). However, since ^{106}Ru is radioactive, it is highly susceptible to changes in operating history. The half-life of ^{106}Ru is short enough that shutdowns in the reactor will alter its concentration significantly. For this reason, the $^{106}Ru/^{101}Ru$ isotopic ratio may prove difficult to use for reactor type and burnup discrimination. It may be however possible to use this ratio to yield power history information and/or the fuel cooling time. Determining the usefulness of this function is however beyond the scope of this work and will be left to future efforts.

Summary and Conclusions

The study described above was performed to determine the capability of using ruthenium deposits around a reprocessing facility to determine the burnup of the fuel reprocessed and the type of reactor that produced that fuel. The higher-mass ruthenium isotopes are produced in significant quantity via fission. It was shown that four stable and one radioactive fissiogenic isotopes yielded a significant discrimination capability. For the four reactor types studied here, it was shown that a spread of more than 50 percent in certain isotopic ratios existed between the reactor types. This separation of the reactor types should allow for good discrimination of burnup and fuel type. The radioactive isotope may also prove useful for power history and cooling time information.

This effort has shown that the ruthenium isotopes, when used in an appropriate manner, could yield significant information concerning reprocessing activities. This information could be used in

Figure 9. $^{100}Ru/^{101}Ru$ isotopic ratio versus burnup in spent fuel from various reactors

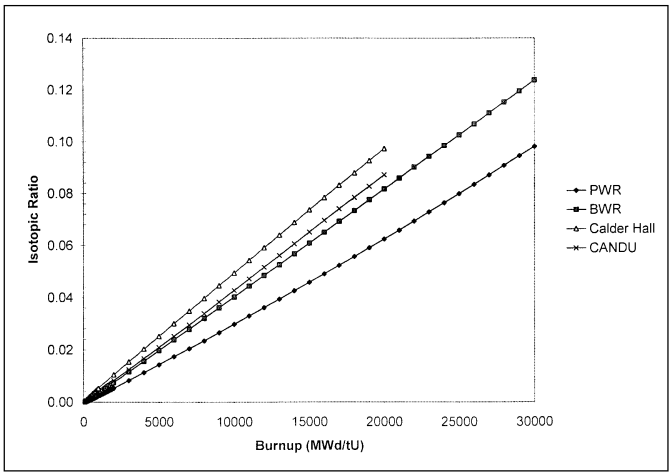


Figure 10. $^{104}Ru/^{101}Ru$ isotopic ratio versus burnup in spent fuel from various reactors

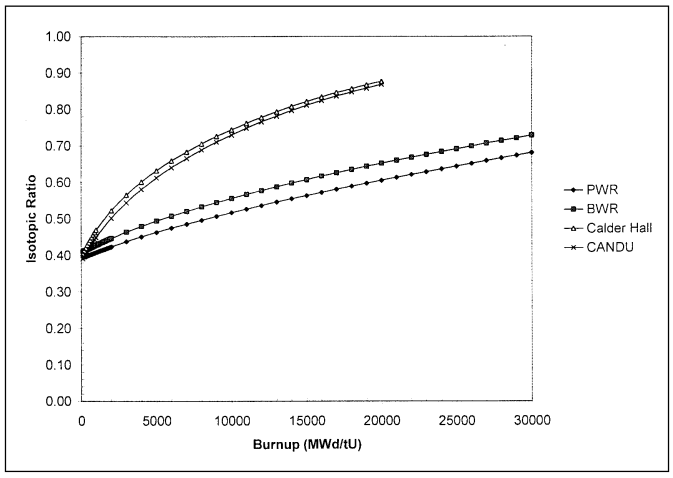


Figure 11. $(^{101}Ru\text{-}^{102}Ru)/^{104}Ru$ isotopic ratio function versus burnup in spent fuel from various reactors

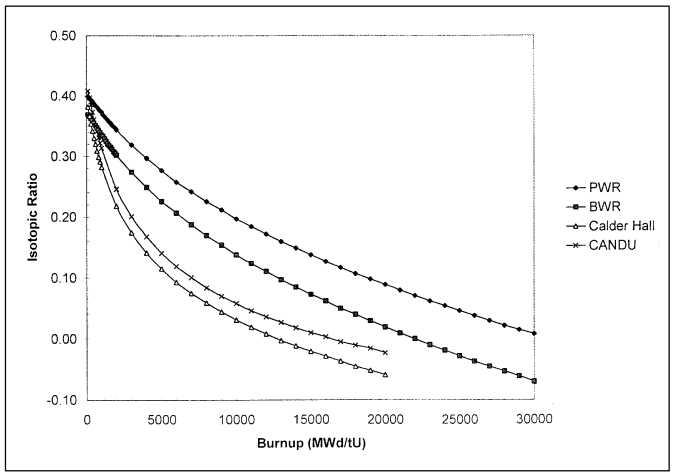


Figure 12. $^{100}Ru/^{104}Ru$ isotopic ratio versus burnup in spent fuel from various reactors

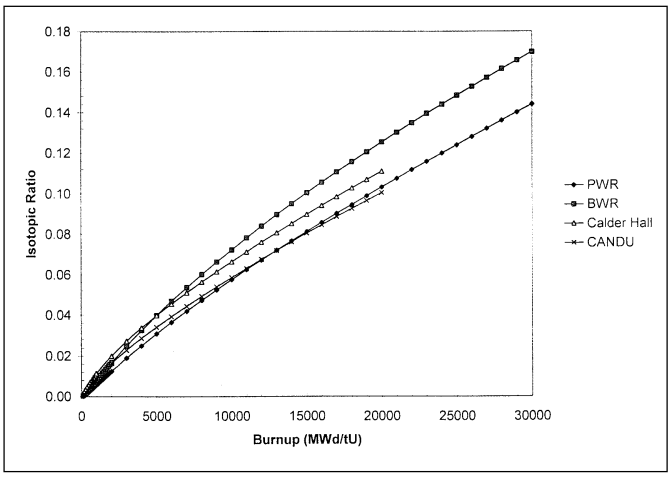


Figure 12. $^{100}Ru/^{104}Ru$ isotopic ratio versus burnup in spent fuel from various reactors

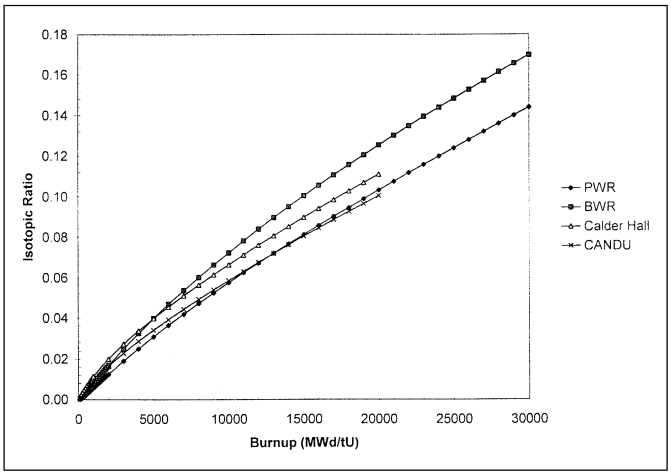
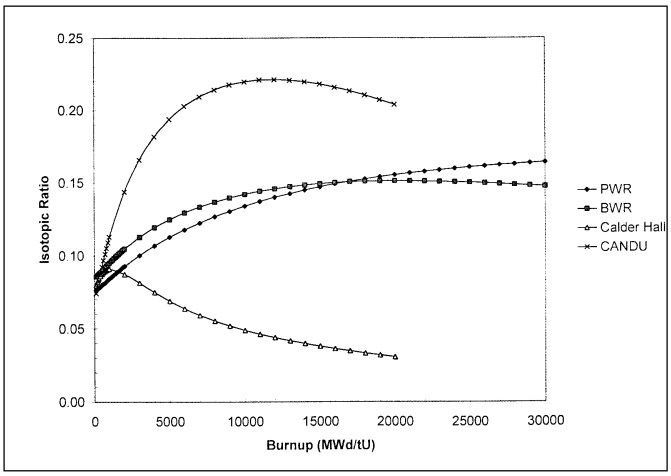


Figure 13. $^{106}Ru/^{101}Ru$ isotopic ratio versus burnup in spent fuel from various reactors



various verification regimes. Significant effort however still remains to demonstrate the ability to measure this signature in the field and determine its deposition from a particular facility. Future efforts will be made to study the environmental deposition and transport of ruthenium. Also, efforts will be made to pursue performing measurements in the field to verify the viability of this signature.

William S. Charlton earned a Ph.D. in nuclear engineering from Texas A&M University and is an assistant professor in the Nuclear and Radiation Engineering Program of the Mechanical Engineering Department at the University of Texas at Austin. His research interests include fuel-cycle analysis, nuclear-data measurement and experimentation, reactor physics and shielding code development, and advances in innovative safeguards techniques and international nuclear security.

Jane Poths has a Ph.D. in chemistry from the University of Chicago and was a staff scientist with Chemical Science and Technology Division at Los Alamos for the last fifteen years. She is currently a scientist in the ESA Tritium Science and Engineering Group at Los Alamos National Laboratory. Her areas of research include developing ultrasensitive technologies for mass spectrometry and applying them to nuclear science and isotope geochemistry.

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Application of Radioactive Markers for Nuclear Materials Control

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Abstract

This paper addresses the possibility of increasing the sensitivity of gamma-spectrometric assays of nuclear materials by introducing radioactive markers into nuclear material composition. The radionuclides ^{60}Co, ^{152}Eu, and ^{154}Eu can be applied as the markers. For detection of the *marked* nuclear material, a scintillation gamma-spectrometer is suggested, and for the follow-up detailed analysis of the detected item, a germanium spectrometer. An evaluation is presented for ^{60}Co concentration required to detect 10 g ^{235}U or ^{239}Pu shielded by lead with the time of a control measurement equal to 10 seconds. Introduction of the radioactive markers does not change the physical and chemical nuclear material properties, and does not worsen radiation safety of personnel involved in nuclear materials management. At the same time, introduction of the radioactive markers makes it possible to reduce the time of nuclear material control measurements and to apply simpler and less-expensive equipment.

Introduction

The objective of this paper is to consider the possibility of increasing the sensitivity of nuclear materials gamma-spectrometric measurements for assays by introducing into nuclear materials composition special radioactive impurities—markers, emitting high-energy gamma-radiation. The sensitivity of gamma-spectrometric assays is of great importance especially for fast measurements at transport chokepoints that are intended to detect unauthorized nuclear materials transportation. Increasing the sensitivity gives an opportunity to apply simple and relatively cheap equipment for control measurements, to detect small quantities of nuclear materials, and to conduct measurements outside of nuclear facilities including at railroad stations and airports using both stationary and portable devices.

Several conditions define the selection of a control method:

- Minimal detectable activity of nuclear materials (nuclear materials quantity);
- Time and cost of assay;
- Complexity of the equipment used, required level of personnel training;
- Minimal health threat for both monitored people and staff.

Gamma-spectrometric devices or neutron detection systems are usually applied in controlled, nondestructive nuclear materials measurements. The possibilities of such measurements are limited by the nuclear materials properties: energy and intensity of radiation, half-life of radionuclides, cross-sections of neutron reactions, etc.

A passive gamma-spectrometric assay implies detection of intrinsic nuclear materials gamma-radiation. Some properties of nuclear materials are presented in Table 1.

It can be seen from Table 1 that the isotopes contained in nuclear materials have long half-lives and, as a consequence, low specific activities. The branching ratios for gamma-quanta (quantum yield) are generally very small. Moreover, the largest intensities are produced by lines below 200 keV. (We do not consider gamma-radiation of ^{208}Tl and other daughter products of ^{236}Pu and ^{232}U decay. These nuclides may be present in reprocessed uranium fuel or in plutonium with a high burnup; however, in spectra of weapon grade materials their radiation is almost absent.) Such radiation is strongly absorbed in the source materials as well as in the walls of metal containers and shields. A lead layer of 5 mm is thick enough for complete shielding of this radiation.

There is an opportunity to use active and passive neutron measurements of nuclear materials. However, the neutron method of nuclear materials control has a number of disadvantages, including:

- High cost of equipment, especially for active measurements
- Necessity to attract high-skilled personnel for conducting measurements
- Application of active neutron coincidence counting creates a radiation field around the measuring installation
- If thermal neutrons are used for irradiation, illegally transported nuclear material can be easily protected by use of an absorbing shield.

The disadvantages inherent in modern methods of nondestructive control measurements are maximized in measurements of small nuclear materials quantities; for example, at a luggage checkpoint. The proposed method of introducing radioactive markers into nuclear materials composition can offer maximum gain just for such applications. The method used should satisfy the following requirements:

- Short control measurement time (no longer than 10 seconds)
- Rather small quantity of nuclear materials required for detection (10 g of ^{235}U or ^{239}Pu)

Table 1. Characterization of nuclear materials as gamma emitters1

Isotope	E_g, keV	Branching ratio, γ-quanta per decay	Intensity, γ-quanta/(g>s)	Half thickness of lead, mm
^{235}U $T_{1/2}=7.03*10^8$ years	185.7	0.57	$4.3 \ddagger 10^4$	0.5
	205.3	0.05	$4.0\ddagger 10^3$	0.6
^{238}U $T_{1/2}=4.47*10^9$ years	766.3	$3.2\ddagger 10^{-3}$	26	6.8
	1,001.0	$8.4\ddagger 10^{-3}$	75	9.1
^{238}Pu $T_{1/2}=87.7$ years	152.7	$9.4\ddagger 10^{-6}$	$6.0\ddagger 10^6$	0.3
	742.8	$5.0\ddagger 10^{-8}$	$3.2\ddagger 10^4$	6.6
	851.7	$1.3\ddagger 10^{-8}$	$8.2\ddagger 10^3$	7.7
^{239}Pu $T_{1/2}=2.41*10^4$ years	375.0	$1.5\ddagger 10^{-5}$	$3.6\ddagger 10^4$	2.4
	413.7	$1.5\ddagger 10^{-5}$	$3.6\ddagger 10^4$	2.8
	769.2	$1.2\ddagger 10^{-7}$	$2.7\ddagger 10^2$	7.0
^{240}Pu $T_{1/2}=6.56*10^3$ years	104.2	$7.1\ddagger 10^{-5}$	$5.9\ddagger 10^5$	0.1
	642.4	$1.4\ddagger 10^{-7}$	$1.0\ddagger 10^3$	5.7
^{241}Pu $T_{1/2}=14.4$ years	103.7	$1.0\ddagger 10^{-6}$	$3.9\ddagger 10^6$	0.1
	148.6	$1.9\ddagger 10^{-6}$	$7.2\ddagger 10^6$	0.3

Selection of Radioactive Marker

The material used for the radioactive marker must possess the following characteristics:

- The radionuclide must be an emitter of high-energy gamma-radiation with low absorption inside the nuclear material, container, or shielding
- Half-life of the radionuclide must be on the order of a few years in order to provide sufficiently high specific activity to allow a small amount of admixture to be introduced into nuclear materials and still provide a rather long period in which it is possible to conduct control measurements with the *marked* nuclear material.

Comparison of the radionuclide properties allows us to conclude that the radionuclides ^{60}Co, ^{152}Eu, and ^{154}Eu are suitable for application as the radioactive markers. Properties of these radionuclides as gamma emitters are presented in Table 2.

These isotopes are characterized by suitable values of half-life (five-thirteen years), and they emit high-energy gamma-radiation with energies of 1,000-1,500 keV with rather high penetrating ability. The dependence of the mass absorption factor in lead, UO_2 and PuO_2 on gamma-radiation energy has been studied, and the following conclusion can be made: penetrating abilities of the proposed markers' radiation are higher by a factor of about twenty to twenty-five than that of 185.7 keV radiation of ^{235}U, and by a factor of about five than those for the radiation from plutonium isotopes in the energy range of about 400 keV. The latter are used in assays of shielded plutonium samples with application of the FRAM code.[2] Using different radionuclides as a radioactive marker, it is possible not only to detect nuclear materials, but also to identify its type. For example, ^{60}Co may be used as a uranium marker, ^{152}Eu as a plutonium marker. A high-energy gamma-radiation will be a sign of nuclear materials presence, and, based on a marker radionuclide, one can determine the type of nuclear material. Nuclear materials segmentation may be more detailed (segmentation based on enrichment or chemical form, for example.) if one were to use more markers and/or to use a combination of radionuclides as a marker by varying their relative concentrations.

It should be noted that there is a theoretical possibility of chemically processing nuclear materials to remove the radioactive markers before transportation. Appropriate procedures have been tested and described including those applicable outside of specialized laboratories. However, if the possibility of chemical treatment of nuclear materials before transportation is assumed, then not only the method proposed, but the majority of the control methods usually applied, should be considered unsuitable. For example, ^{234m}Pa and ^{231}Th can be removed from uranium samples, and gamma spectrometric assays would become difficult to perform. As for plutonium, manual chemical operations with plutonium-containing nuclear materials are extremely dangerous. So, purification of such nuclear materials before transportation is hardly probable.

Evaluation of ^{60}Co Quantity Needed for Introduction into Nuclear Materials as a Marker

Semiconductor or scintillation detectors can be used for the detection of ^{60}Co, ^{152}Eu, and ^{154}Eu gamma radiation. The efficiency

Table 2. Characteristics of 60Co, 152Eu, and 154Eu as emitters of gamma radiation

Isotope	E0, keV	Branching ratio, γ-quanta per decay	Half thickness of lead, mm
^{60}Co $T_{1/2}$=5.27 years	1,173	1.00	11
	1,332	0.99	12.5
^{152}Eu $T_{1/2}$=13.2 years	778.9	0.13	7
	964.1	0.15	8.5
	1,086	0.10	10
	1,112	0.14	10
	1,408	0.21	13
^{154}Eu $T_{1/2}$=8.6 years	873.2	0.115	8
	996.3	0.103	9
	1,004.8	0.174	9
	1,274.5	0.355	12

of the scintillation detectors is significantly higher than that of the semiconductor detectors, but the energy resolution is several tens of times worse. Therefore, the scintillation detectors are better for nuclear materials detection while the semiconductor detectors are better for the follow-up, more detailed nuclear materials assay.

In the measurements described in this paper, the scintillation NaI-detector (15 cm in diameter and 10 cm thick) was used. However, smaller detectors may be used. The measurements demonstrate that detector shielding should be applied to reduce natural radiation background within the working energy range of 1,100-1,500 keV. The level of the radiation background in the 1,100-1,500 keV energy range, as measured by the NaI-detector used here, was about ten pulses per second.

Let's determine required concentration of cobalt in the nuclear materials. The following conditions were chosen for control measurements:

- The measurements are conducted within the 1,100-1,500 keV energy range using a NaI scintillation detector
- After ten years, the intensity of the radiation emitted by the radioactive marker must exceed the level of the radiation background within the working energy range by a factor of five
- Nuclear materials, during their transportation, may be masked by lead shielding 5 cm thick (mass of such a shield will reach 20–30 kg)
- During the control measurement the nuclear material is placed 15 cm from the detector

Proceeding from the conditions listed above, required activity A of the marker can be calculated using the following formula:

$$A = \frac{5 \cdot I_{bckg}}{2 \cdot \varepsilon \cdot I/I_0}$$

where I_{bckg} = intensity of the background radiation; ε = detection efficiency of the ^{60}Co radiation source that was placed 15 cm from the scintillation detector (according to experiment results, ε=0.01); I/I_0 =attenuation factor of ^{60}Co radiation by lead layer 5 cm thick. The factor of 2 in the formula's denominator allows for the fact that the total activity of ^{60}Co includes two gamma lines within the 1,100-1,500 keV energy range (1,173 keV and 1,332 keV, for each of which the yield is close to 100 percent).

The value of the ratio I/I_0 is equal to 0.0358. Under the given conditions, taking into account the requirement for obtaining information about the nuclear materials for ten years, the initial activity of the marker introduced in nuclear materials sample should be equal to 260 kBq. Because the minimal controllable amount of ^{235}U is equal to 10 g, the concentration of ^{60}Co is required to be 26 kBq per gram of ^{235}U, or the mass of ^{60}Co is required to be $6.1 \cdot 10^{-10}$ gram per gram of ^{235}U. The radiation spectra of *marked* uranium samples are presented in Figure 1.

The amount of ^{60}Co that would be required to mark all the fuel produced annually in Russia for use in nuclear power reactors can be determined. Table 3 presents the estimated value of nuclear fuel annually loaded into Russian nuclear reactors[3] and the amount of the radioactive marker material required.

Table 3. Amount of fuel annually loaded in nuclear power plants and activity of ^{60}Co required

	Reactor Type		
	VVER-440	VVER-1000	RBMK-1000
Nuclear fuel mass, t	87	190	550
Enrichment, percent	3.6	4.4	2.6
^{60}Co activity, Cm	1.47	3.84	6.10

Thus, the total amount of radioactive isotope ^{60}Co required for admixing into nuclear fuel is equal to about $1.6 \cdot 10^{-2}$ g, which would have a total activity about 17 Ci. (The cost of ^{60}Co in April 2000 was equal to $180 per Ci.)

Obviously, the mass of cobalt introduced into uranium will be substantially larger than the mass of the ^{60}Co isotope because not all cobalt isotopes are radionuclides. If the relative ^{60}Co content in a cobalt marker is 0.1 percent, then the cobalt concentration in VVER-1000 fuel will not exceed $2.7 \cdot 10^{-2}$ gram of ^{60}Co per gram of fuel.

Radiation Safety in Operations with Nuclear Materials Marked with ^{60}Co

Introduction of the radioactive markers into nuclear materials composition can change the radiation conditions in nuclear fuel management.

Two operations are considered here:

- Fabrication of fuel elements for VVER-1000 reactor
- Handling an unirradiated fuel assembly of VVER-1000 reactor

In the first case, pellets of sintered UO_2 with enrichment of 4.4 percent are located at the working place, i.e. the operator works with the open radioactive source.

According to the regulations on radiation safety in Russian Federation,[4] ^{60}Co and uranium are attributed to the same group of radionuclides. At the same time, the value of the natural activity of uranium fuel assembly with ^{235}U enrichment of 4.4 percent is approximately thirteen times higher than that of the marker (^{60}Co) introduced. According to the regulations,[5] the conditions required for operations with open radioactive sources and, consequently, a category of laboratory are determined by the activity of the sources. Hence, the presence of ^{60}Co in uranium fuel will not affect the category of the laboratory.

For the assessment of probable influence of ^{60}Co in fuel on handling with an unirradiated VVER-1000 fuel assembly, the absorbed dose rate has been calculated at a distance of one meter from the fuel assembly.

The VVER-1000 fuel assembly consists of a hexahedron with a *wrench* size of 238 mm. Every assembly consists of 317 fuel pins in a Zr sheath and of fourteen Zr tubes for absorbing rods, detection of heat generation, etc. The mass of UO_2 fuel in the fuel assembly is about 500 kg. The fuel length is 353 cm. For the calculations, a fuel assembly was considered as an equivalent cylinder with a diameter of 246 mm filled with a homogenous mixture of UO_2 and Zr. Calculation of the dose rate was carried out using the method described in *Protection from Ionising Radiation*.[6] The value of the absorbed dose rate obtained was about 150 mGy/hr that, based on maximum permissible dose, equaled 20 mSv/yr.[4] This allows the staff to handle such a source daily for thirty to forty minutes without shielding.

Conclusions

The following conclusions may be drawn from analysis of the current results:

1. The introduction of radioactive markers into nuclear materials allows the expansion of possible control measurements: to improve detection sensitivity, to reduce the time of measurements, to apply simpler and less-expensive equipment. For example, the portal with detector similar to that described in Reference 7 may be used for nuclear materials control.
2. The radionuclides ^{60}Co, ^{152}Eu, and ^{154}Eu are the most promising candidates for application as radioactive markers.

Figure 1. Spectrum of uranium, marked uranium, and background, measured using a NaI scintillation detector (15 cm in diameter and 10 cm thick). Uranium enrichment is 6.5 percent, mass of ^{235}U-10 g, relative concentration $^{60}Co = 4.1 \cdot 10^{-10}$ g/g ^{235}U.

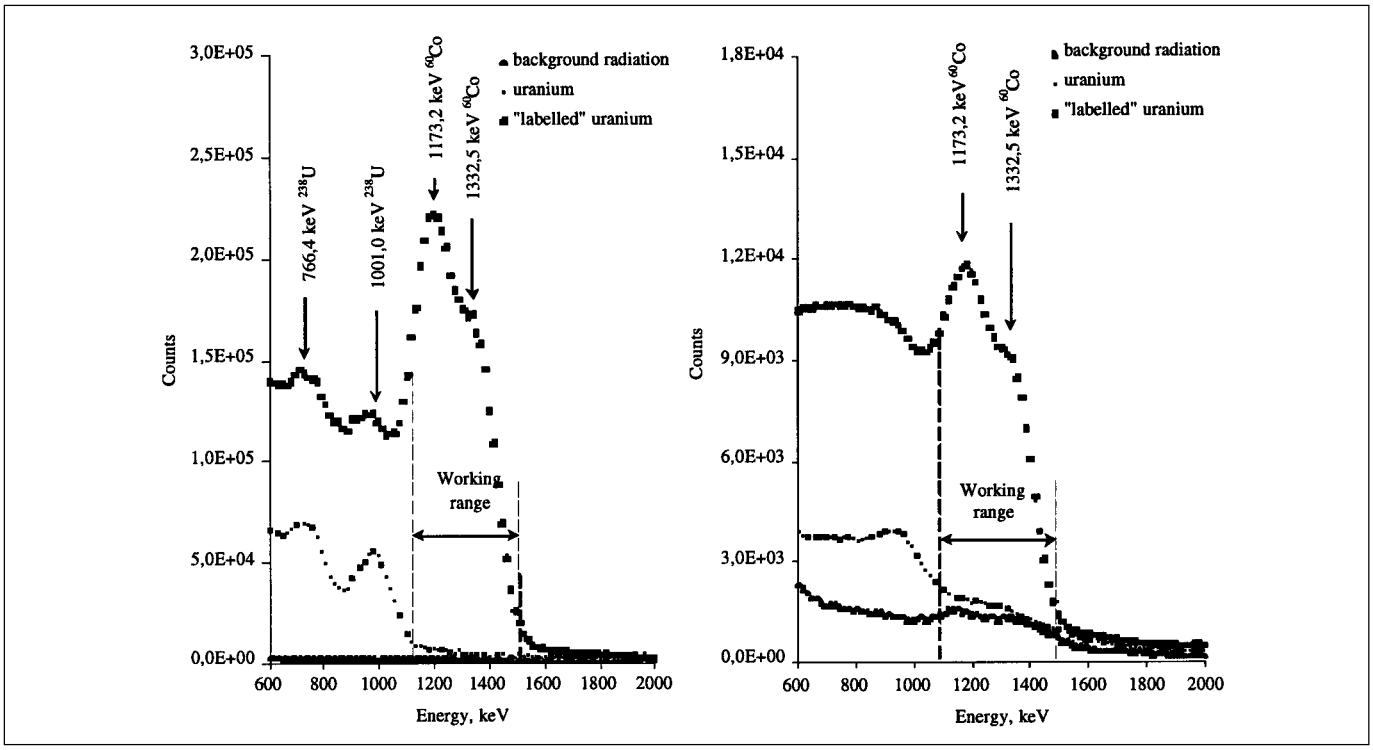

Figure 1a. Measured spectrum

Figure 1b. Spectrum of uranium sample surrounded by lead 5 mm thick

Their separate or combined applications will allow the unique marking of different nuclear material categories. The marker becomes a kind of bar code for nuclear materials control.

3. Nuclear materials marking can be performed in different ways, including:
   - Under production of highly-enriched uranium dioxide at precipitation stage from aqueous solution
   - Injection of cobalt-containing aqueous solution under low-enriched uranium dioxide production in flame reactor
   - If mixed uranium-plutonium oxide fuel (MOX fuel) is used, the markers may be introduced in co-precipitation process of UO_2 and PuO_2 powders from aqueous solutions
   - The markers may be introduced with plasticizer at the stage of fuel granulation before pressing of pellets
   - If metal is used, the markers may be introduced at the stage of refining melting
4. The amount of the marker introduced is small enough to produce no changes in physical and chemical properties of the nuclear materials.
5. The radiation emitted by the markers does not impede nuclear materials management including procedures of fabrication and transportation.
6. For measurements of marked nuclear materials, NaI gamma-radiation spectrometers can be used for the detection of small quantities of nuclear materials, and Ge-spectrometers for decoding nuclear materials categories in case small quantities of nuclear materials are encountered, and for control of large amounts of nuclear materials.
7. ^{60}Co content in fuel needed for assays was conservatively evaluated. Possibilities of nuclear materials control with the application of the radioactive labels may be even more promising than it is presented in this paper.

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New Brunswick Laboratory Measurement Evaluation Programs

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Abstract

New Brunswick Laboratory (NBL) is owned and operated by the U.S. Department of Energy (DOE). NBL serves as the U.S. government's central authority for nuclear materials measurements and measurement evaluation. It is also the U.S. government's certifying authority for nuclear reference materials.

New Brunswick Laboratory has been assigned by the U.S. Department of Energy, Office of Security, to assess and evaluate the adequacy of measurement technology as applied to materials accounting in DOE nuclear facilities. NBL manages two measurement evaluation programs. The Safeguards Measurement Evaluation Program is a means to monitor and evaluate the quality and effectiveness of nuclear materials accounting destructive measurements, while the Calorimetry Exchange Program evaluates nondestructive measurements. This paper presents an overview of the programs with representative results from 2001.

Overview of the Programs

Participants in the programs include both domestic and foreign laboratories. With the approval of the DOE Office of Security, non-DOE laboratories may participate on a cost-recovery basis. Table 1 shows the laboratories participating in the uranium portion of the Safeguards Measurement Evaluation Program for the fiscal year 2001 reporting period, while Table 2 shows the laboratories participating in the plutonium isotopic portion of the Safeguards Measurement Evaluation Program. Table 3 lists CalorimetryExchange Program participants for calendar year 2001.

Table 1. Uranium Sample Exchange Participating Facilities

Uranium Sample Exchange Participating Facilities
Argonne National Laboratory–West
BWX Naval Nuclear Fuels
Global Nuclear Fuel – Americas, LLC.
Los Alamos National Laboratory
New Brunswick Laboratory
Nuclear Fuel Services
Paducah Gaseous Diffusion Plant
Portsmouth Gaseous Diffusion Plant
Savannah River Site
Framatome ANP
Tokai Safeguards Analytical Laboratory
Westinghouse Electric Commercial Nuclear Fuels
Y-12 National Security Complex

Table 2. Plutonium Isotopic Exchange Participating Facilities

Plutonium Isotopic Exchange Participating Facilities
Argonne National Laboratory–West
Los Alamos National Laboratory
New Brunswick Laboratory
Savannah River Site

Table 3. Calorimetry Exchange Participating Facilities

Calorimetry Exchange Participating Facilities
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Rocky Flats Environmental Technology Site
Savannah River Site

The Safeguards Measurement Evaluation Program

Measurement Methods and Laboratory Participation

During fiscal year 2001, Safeguards Measurement Evaluation Program participants used six different methods to perform uranium concentration measurements on four different materials, and two different measurement methods to perform isotopic measurements on both low- and high-enriched uranium materials. Additionally, plutonium samples were analyzed for elemental amount by isotope dilution mass spectrometry and isotopic abundances by thermal ionization mass spectrometry. Table 4 illustrates the various materials analyzed and measurement methods used by participating laboratories (identified by laboratory code only). Table entries are laboratory codes followed by the number of data sets submitted by each participant in fiscal year 2001.

Characterization of Test Materials

Characterization measurements were performed at NBL on each of the test materials as packaged for use in the program. For each material, a plan was developed that specified the number of randomly selected samples to be analyzed to provide the characterized value, and the measurement method to be used. A requirement for concurrent validation of measurements with Certified Reference Materials was incorporated into every characterization protocol. This requirement also provided traceability to the national measurement base. As a participant in the program, NBL

Table 4. Laboratory Participation for Fiscal Year 2001 By Material and Measurement Method

Method	U Solutions	UO_2 Pellets	UO_3 Powder	UF_6	Pu Sulfate
Dichromate Titration	B3 C2 F1 S2 U2	F1 T2	F1		
Ceric Titration	G2				
Gravimetry		M2 P2 R2		C2 E2	
High Precision Titration		F1		F1	
U IDMS	A5 B1 J4		A1		
X-Ray Fluorescence	A5	A2			
Pu IDMS					B1 F1 G1
Mass Spectrometry LEU	A2 B1	M2 T2		C2 E2 F1	
HEU	A5 B2 F1 J5 P2 U2				
Pu					B2 F1 G1 J1 T3
ICP-MS LEU		R2			
ICP-MS HEU	S2				

Upper Portion of this Table Shows Methods and Materials for Assay Measurements
Lower Portion of this Table Shows Methods and Materials for Isotopic Measurements
Table entries are laboratory codes with the number of times each participated in fiscal year 2001.

periodically reanalyzes all the materials distributed for analysis, both for the evaluation of its own performance and as a check on the integrity of the materials.

Distribution of Materials and Analysis Requirements

The characterized materials were distributed to the participating facilities with instructions on handling and analysis. For uranium measurements, whenever possible, participants were asked to analyze each of the two samples specified for the measurement period in duplicate on each of two days, producing a total of eight results. This maximized the information available for statistical evaluation while minimizing analytical effort. For plutonium isotopic measurements, only duplicate analyses were requested on each of the samples.

Reports Back to Participants

All data were reviewed for handling, analysis, and reporting problems before statistical analysis. If necessary, the submitting laboratory was contacted for any necessary clarifications or corrections. For each set of data submitted, individual data evaluation reports were prepared and distributed to the reporting facility. These reports were distributed within three weeks of receipt of raw data, whenever possible, to provide rapid feedback to the participant. In order for this feedback to be most meaningful, timely submission of data to the program is very important.

In order to normalize the data for evaluation, the percent relative difference (% RD), from the reference value, defined as % RD = [(observed value - reference value)/reference value](100 percent), was calculated for each reported measurement value. For a set of data, the mean of the % RD values was calculated and compared to target values for systematic error. The standard deviation of the % RD values was also calculated and compared to target values for random error.

Calorimetry Exchange Program

A one-watt plutonium oxide standard is measured routinely for both heat output (by calorimetry) and isotopic composition (by gamma spectroscopy). These measurements are combined to derive plutonium mass. Measurement and mass data are compiled and summarized in an annual report. The report for calendar year 2001, NBL-369, is the last Calorimetry Exchange Program annual report that will be issued as hard copy. Future reports will be issued electronically in Adobe® Portable Document Format, also known as a PDF, and available on the NBL Web site.

Table 5. Performance Summary: Uranyl Nitrate Solution - Percent U

Method	Lab Code	Mean	Standard Deviation	N
Ceric Titration	G	-0.016	0.035	16
Davies-Gray Titration	B	-0.271	0.117	23
	C	0.158	0.397	16
	F	-0.028	0.032	16
	S	–0.025	0.042	15
	U	0.099	0.147	12
IDMS	A*	0.003	0.144	40
	B*	-0.897	1.162	8
	J*	-0.021	0.084	56
X-Ray Fluorescence	A**	0.223	0.242	40

Representative Results for 2001—Safeguards Measurement Evaluation Program

Results for one of the Safeguards Measurement Evaluation Program analyses, uranium concentration in uranyl nitrate solution, are presented to illustrate the evaluation and presentation of data. The analysis of pure uranyl nitrate solutions represents the most direct test of measurement systems for uranium elemental concentration. Three uranyl nitrate solutions of normal enrichment are analyzed by most participants. These three normal solutions differ from one another in elemental concentration by

approximately 0.2 percent; the ability to differentiate among them demonstrates good analytical capabilities. Data are graphically presented in figures 1 and 2. Results for other materials and methods may be found in NBL-370.1

Figure 1. Data summary plot emphasizing bias

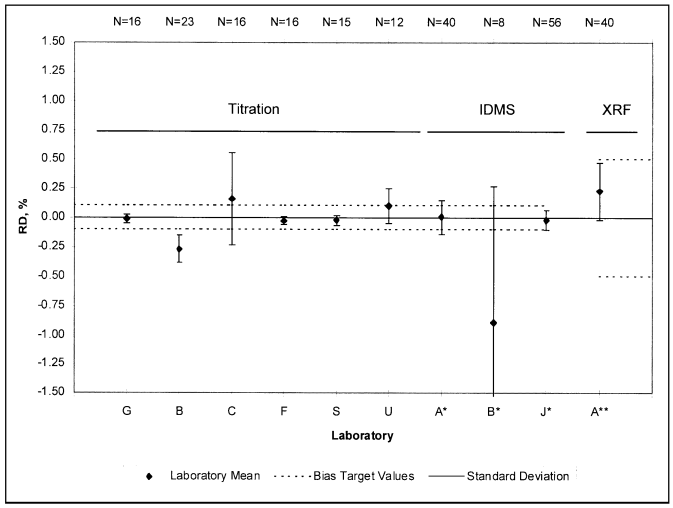
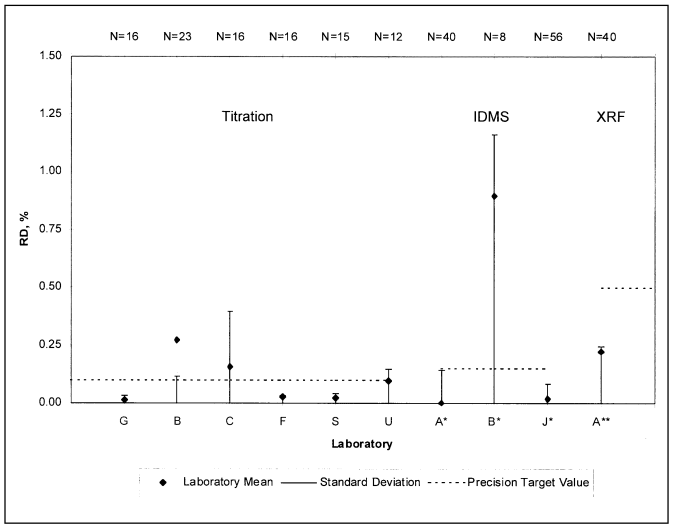


Figure 2. Data summary plot emphasizing precision



For figures 1 and 2, the data are arranged by methods and their target values. Laboratories G, B, C, F, S, and U measure uranium concentration by titration. Facilities A,* B,* and J* measure uranium concentration by IDMS. Facility A** uses X-ray fluorescence (XRF). International Target Values are used for titration and IDMS. There are no specific 2000 International Target Values for XRF, so DOE target values[2] from 1993 are used. Target values for bias are 0.1 percent for titration and IDMS, and 0.5 percent for XRF. Target values for precision are 0.1 percent for titration, 0.15 percent for IDMS, and 0.5 percent for XRF. Target values for bias are plotted in Figure 1. Target values for precision are plotted in Figure 2.

As seen in Figure 1, laboratories B and C (titration) and B* (IDMS) did not meet the target limits for bias in fiscal year 2001. As seen in Figure 2, laboratories B, C, and B* did not meet the target limits for precision. The results from laboratories A*, A**, F, G, J*, and S demonstrate very good accuracy and precision in the measurement of uranyl nitrate solutions. Table 5 presents the numerical values of the plotted data.

Representative Results for 2001—Calorimetry Exchange Program

A sample of PuO_2 powder is available at each participating site for NDA measurement, including either or both calorimetry and high-resolution gamma-ray spectroscopy. These elements are combined typically to provide a calorimetric assay of plutonium mass. The facilities measure the sample as frequently and to the level of precision that they desire, and then submit the data to NBL for analysis. The data report includes summary tables for each measurement and charts showing the performance of each laboratory. Comparisons are made to the accepted values for the exchange sample and to data previously reported by that laboratory. This information is displayed to show quarterly variation over each calendar year, and overall performance for that year, in an annual report intended for use by exchange participants in measurement control programs, or to indicate when bias corrections may be appropriate.

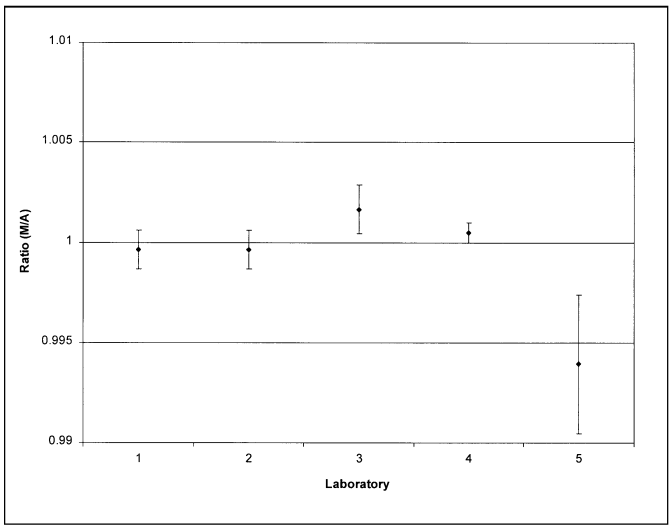
A typical summary plot of data is shown in Figure 3. The mean and standard deviation of the ratio (measured/accepted) for power measurements by each laboratory are displayed. Most laboratories are quite close to the accepted value, but one site can be seen to be biased low and have significantly larger random errors in comparison to other participants. Similar data plots are developed for other measurements and presented in the annual report (for CY2001, NBL-369[3]).

2002 MEP Annual Meeting

The NBL Measurement Evaluation Program annual meeting was held on June 23, 2002, in conjunction with the INMM Annual Meeting. The presentations included:

- Summaries of the 2001 results for the SME and Calorimetry Exchange programs
- A description of new and ongoing programs and initiatives of the Department of Energy Office of Plutonium, Uranium, and Special Materials Inventory
- An overview of the Uranium by Davies-Gray Analysis at the Savannah River Site
- A description of the Interlaboratory Comparison Program at the Japan Nuclear Cycle Development Institute

Figure 3. Calorimetry power perfo mance summary



- An update on measurement evaluation programs conducted by the Institute for Reference Materials and Measurements
- A description of current and planned reference materials produced by NBL
- A description of a measurement program that expands the use of the Calorimetry Exchange Program standards, and
- An overview of the Transportable Calorimetry Laboratory

Minutes of the meeting (NBL-371[4]) may be found at the NBL Web site.[5] The next meeting is planned for July 13, 2003, in conjunction with the INMM Annual Meeting in Phoenix, Arizona, U.S.A.

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Megawatts and Megatons: A Turning Point in the Nuclear Age?

Richard L. Garwin and Georges Charpak
Alfred A. Knopf. 2001. 412 pp., 54 illustrations
ISBN 0-375-40394-9

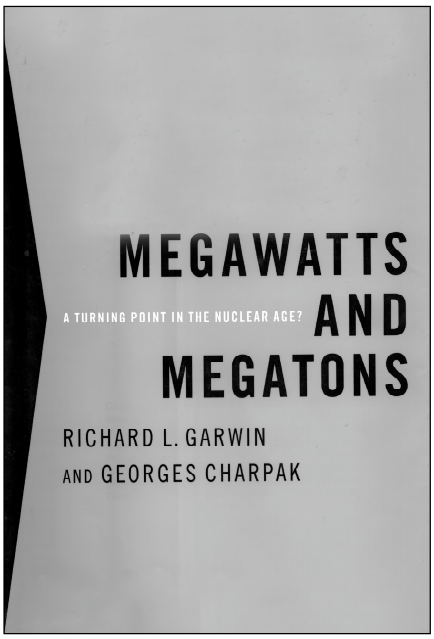
By Walter R. Kane

Megawatts and Megatons is a timely and important work that should find wide acceptance in the nuclear materials management community. It deals clearly and rationally with the most compelling concerns of our time—nuclear weapons and nuclear energy, the biological effects of radiation, nuclear waste, the hazards of reactor accidents and other industrial hazards, and, most importantly, arms control and nonproliferation issues.

Richard Garwin's experience in these areas goes back to 1950 when, at Los Alamos National Laboratory, he played a key role in the development of the theoretical basis for U.S. thermonuclear weapons program. Since then he has served on many committees and advisory groups providing advice and guidance to the U.S. government on matters of national defense. He is now Philip D. Reed Senior Fellow in Science and Technology at the Council on Foreign Relations and adjunct professor of physics at Columbia University. Georges Charpak works at the European Center for Particle Physics (CERN) in Geneva. In 1992 he received the Nobel Prize for physics for his invention of electronic detectors for ionizing particles, now widely used in physics, industry, and biology.

The first three chapters of *Megawatts and Megatons* consist of a simple, lucid, but thorough discussion of the fundamentals of nuclear physics, an interesting history of the discovery of nuclear fission, and the physics of fission and nuclear weapons. Much of this material will be familiar to the specialist; for the nonspecialist these chapters provide a knowledge base for the remaining chapters.

The fourth chapter, "Nuclear Radiation and Living Things," is an equally thorough discussion of the biological



effects of nuclear radiation, based both on our current knowledge of cellular biology and epidemiological evidence. The bottom line of this chapter is the conclusion, from all available evidence, that the judgment of the International Commission on Radiation Protection that the dose-response curve for radiation effects is probably linear with a zero threshold, and that an additional dose of 1 sievert (100 rem) will lead to an increased probability of a fatal cancer of 4 percent, is the best guide for public policy. The careful analysis and honest science in this chapter are particularly refreshing and useful in view of the misinformation and contention that have characterized this area for decades.

The fifth and sixth chapters treat, respectively, existing technology in the civilian nuclear power industry, including the disposal of spent fuel, and new reactor concepts that offer substantial advantages in safety, proliferation resistance, and the quantity of nuclear waste generated. Considerable attention is given to various means for dealing with spent fuel that will minimize its eventual radiotoxicity. Particularly interesting in this area is the concept of the subcritical *energy amplifier* originated and developed by Hiroshi Takahashi, Carlo Rubbia, and others, which is a thorium-232-uranium-233 breeder that will utilize a spallation source to provide the neutrons necessary for the chain reaction in the uranium-233 fuel. This concept has a number of advantages: Since it is subcritical, a Chernobyl-type criticality accident cannot occur. Thorium is a more abundant element than uranium and it is found in much richer ores, so that while 100,000 tons of uranium ore must be mined to supply a light-water reactor for one year, 70 tons of thorium ore will suffice—a major environmental advantage. The concept has further advantages in the areas of proliferation resistance, reprocessing, and the eventual radiotoxicity of the spent fuel.

The remaining chapters deal with important questions of arms control and nonproliferation. They include a detailed history of our nuclear deterrent from 1945 to the present, the cooperative program of the United States and Russia to provide improved safeguards at Russian nuclear facilities and to dispose of excess weapons materials, and a critique of the proposed missile defense. In this area the authors make a strong case for a defense based on the destruction of hostile missiles in the initial boost phase rather than at mid-course where the defense can be defeated by decoys and other readily available means. Although the manuscript for *Megawatts and Megatons* was evidently completed before the events of September 11, 2001, the authors, prophetically, discuss in

considerable detail the possibility of terrorist acts utilizing nuclear explosives, dispersal of radioactivity, biological warfare utilizing either anthrax or smallpox, chemical agents, and the hijacking of airliners. In this connection they quote a significant statistic—a one-gigawatt light-water reactor produces in one week of operation sufficient plutonium for an explosive device with a one- or two-kiloton yield. This statistic is a defining boundary condition for both international safeguards and counterterrorism programs.

Finally, the authors put forth compelling arguments for drastic reductions in national nuclear weapons stockpiles—in the case of Russia and the United States, from current levels to 2,000 weapons each, and eventually, to the vicinity of 200 each, with comparable reductions for the other nuclear powers.

Megawatts and Megatons treats the major and most dangerous problems of our time with common sense, factual material, and detailed analysis where it is required. It is a valuable resource for anyone concerned with these problems.

Walter Kane is Book Review Editor for the Journal of Nuclear Materials Management.

NRC OKs NNSA Tritium Production at TVA's Watts Bar Nuclear Station

The U.S. Nuclear RegulatoryCommission (NRC) approved a license Amendment for the Tennessee Valley Authority's (TVA) Watts Bar Nuclear (WBN) station to irradiate tritium producing burnable absorber rods (TPBARs) in the power reactor during normal operation.

The National Nuclear Security Administration's (NNSA) Commercial Light Water Reactor Program, selected as the primary means of tritium production in 1998, has developed, tested, and irradiated a lead test assembly of thirty-two TPBARs (in the WBN reactor previously) and validated the design and operation of those TPBARs in earlier program development.

The TVA, partnering with NNSA and owner/operator of the WBN station, received the license amendment that permits production quantity irradiation of TPBARs in the WBN reactor in September 2002.

NNSA's Acting Administrator Linton Brooks said this new production capability is important to U.S. national security strategy.

METI Plans New Entity to Inspect Nuclear Plants

Japan's Nuclear and Industrial Safety Agency (NISA) has moved up plans to establish an independent body to be responsible for inspecting nuclear power plants. The agency had planned to set up the body in April 2004 but has decided to create it in 2003 instead.

The agency, a unit of Japan's Ministry of Economy, Trade and Industry (METI), submitted a bill for the creation of the organization to the Diet during the extraordinary session in October 2002, NISA officials said.

The agency wants to implement the plan for the inspection body following a series of scandals involving cover-ups of defects by the Japanese nuclear plant operators. In 2002, nuclear plant operators—including Tokyo Electric Power Co., Japan's largest power supplier—came under fire for covering up damage at nuclear plant facilities over several decades.

METI wants the new organization to be entirely responsible for checks on facilities and to examine the results of regular internal checks by nuclear plant operators, with the final evaluation of results conducted by the agency, officials said.

The organization will include several hundred experts from the nuclear industry and related fields.

The agency also asked the Diet to tighten existing laws on the electric and nuclear industries in an effort to prevent future cover-ups. Penalties would include fines of around 100 million yen on nuclear plant operators found violating the law.

USEC and DOE Ink CRADA

The U.S. Department of Energy announced that it has signed a five-year, $121 million cooperative research and development agreement (CRADA) with USEC Inc. that will allow the department's Oak Ridge National Laboratory (ORNL) and USEC to develop and deploy a highly efficient gas centrifuge uranium technology.

The agreement is part of U.S. President George W. Bush's National Energy Plan, which includes support for the expansion and research of nuclear power.

Over the next few years, ORNL will receive $28.5 million from USEC Inc. for specific design, testing, and analysis work to improve DOE's centrifuge technologies for the production of enriched uranium for nuclear power purposes. Technical personnel from ORNL and USEC will design and test equipment that will be deployed in USEC's "lead cascade" uranium enrichment test facility. Operation of this full-scale centrifuge test facility will provide the cost, schedule, and performance data necessary to plan the future construction of a $1 billion to $1.5 billion commercial centrifuge uranium enrichment plant. The gas centrifuge process produces a uranium stream concentrated in uranium-235, a radioisotope suitable for making fuel for nuclear power plants.

GIF Nations Agree to Six Technologies

For the last year, more than 100 experts from ten countries, as well as the Organization of Economic Cooperation Development Nuclear Energy Agency, the European Commission, and the International Atomic Energy Agency have participated in the development of a Generation IV technology roadmap. The result is an agreement on the development of six "next generation" nuclear energy systems.

The Generation IV International Forum (GIF), which is composed of ten leading nuclear nations, reached the agreement in September 2002. The advanced nuclear reactor and fuel-cycle technologies will be available after this decade but before 2030 and represent significant advances in economics, safety, reliability, proliferation resistance, and waste minimization.

The six technologies are:

- Gas-cooled fast reactor systems
- Lead alloy liquid metal-cooled reactor systems
- Molten salt reactor system
- Sodium liquid metal-cooled reactor systems
- Supercritical water-cooled reactor systems
- Very-high-temperature gas reactor systems

The GIF was formally chartered in July 2001 and is an international collective represented by the governments of leading nuclear nations that agree that nuclear energy is important to the future of world energy security and economic prosperity. They are dedicated to joint development of the next generation of nuclear energy systems.

The GIF nations are Argentina, Brazil, Canada, France, Japan, the Republic of Korea, South Africa, Switzerland, the United Kingdom, and the United States.

U.S.-Russian Expert Group Identifies Means of Reducing HEU

An expert group established by U.S. and Russian officials to work out proposals on

near- and long-term, bilateral, and multilateral means to reduce inventories of highly enriched uranium (HEU) and plutonium forwarded its initial report to the presidents of the two nations three months earlier than its deadline.

The expert group identified several areas where joint cooperation could lead to reduction of HEU over-and-above commitments already in place under existing agreements. These include:

- The creation of a strategic reserve in the United States from Russian HEU down blended into low-enriched uranium (LEU)
- Increase in the rate and quantity of HEU converted to LEU under the Nuclear Material Consolidation and Conversion Project
- Use of LEU down blended from Russian HEU to fuel reactors in Western countries
- Use of Russian HEU to fuel selected U.S. research reactors, until cores are converted to LEU
- In parallel, work on accelerated development of LKEU fuel for both Soviet-designed and U.S.-designed research reactors.

The expert group also identified potential new areas of near-term cooperation for weapon plutonium disposition. These include:

- Fabrication of additional mixed oxide fuel for use in Russian reactors, using additional weapons grade plutonium under the 2000 agreement
- A variation of this scenario that would provide for the possible use of some MOX fuel in Russia and for leasing or exporting the remainder to other countries

The expert group will continue to study additional options that could be relevant in the future.

UN Assesses Depleted Uranium in Bosnia-Herzegovina

At the request of the government of Bosnia-Herzegovina, a team of experts from the United Nations Environment Program is investigating twelve sites that may have been targeted by ordnance containing depleted uranium (DU) during the Bosnian conflict in 1994 and 1995.

The seventeen-member team UNEP Depleted Uranium Assessment Team conducted its research in October 2002. Its conclusions will be presented in a report scheduled for publication in March.

The team took soil, water, air, and plant samples at six sites identified by the North Atlantic Treaty Organization as having been struck by DU weapons. They examined six other sites that local residents believe may have also been targeted.

At the request of the local authorities, a medical sub-team, led by an expert from the World Health Organization, examined data on cancer rates in the main urban centers of Sarajevo and Banja Luka. The team met with the local medics and with patients in Bratunac who may have been exposed to DU during the conflict.

The governments of Italy and Switzerland funded the mission.

The assessment team includes experts from UNEP, the Swedish Radiation Protection Authority, Spiez Laboratory of Switzerland, Italy's National Environmental Protection Agency, the International Atomic Energy Agency, the Greek Atomic Energy Commission, the U.S. Army Center for Health Promotion and Preventative Medicine, the Nuclear Safety Institute of the Russian Academy of Sciences, and the University of Bristol, UK.

In Brief

Ice Blast Technology Test Successful

Universal Ice Blast Inc. (UIBI) announced that its Ice Blast technology has been successfully tested and proven for nuclear decontamination. Both Oak Ridge National Laboratory and the Idaho National Engineering and Environmental Laboratory have achieved "superior decon" results with Ice Blast, UIBI said in a written statement.

UIBI has a patented process known as Ice Blast technology that it has positioned into three billion-dollar markets: precision cleaning (automated production cleaning and deburning), industrial cleaning (fixed systems parts cleaning, petrochemical, pulp and paper), and environmental cleaning (lead paint and asbestos abatement). Since 1995, the company has actively engaged in developing its technology for these markets.

Havana Ratifies Treaty of Tlatelolco

Cuba ratified the Treaty of Tlatelolco, which establishes a nuclear weapon-free zone in the Caribbean and Latin America, in October 2002. Cuba signed the treaty in 1995 but was the last of thirty-three eligible states to ratify the treaty. In early October, Cuba announced its intention to ratify the treaty.

"The ratification of the Tlatelolco Treaty reaffirms Cuba's commitment to and respect for the principle of nuclear nonproliferation in a global context," the Cuban Foreign Ministry said in a statement at the time the island country ratified the treaty.

Five Central Asian Nations Agree to Nuclear-Weapon-Free-Zone

Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan reached agreement in September 2002 on a nuclear-weapon-free-zone (NWFZ) treaty.

The NWFZ agreement follows criteria outlined in a 1975 UN General Assembly resolution that defines a nuclear-weapon-free-zone treaty as "the statute of a total absence of nuclear weapons to which the zone shall be subject" and calls for "an international system of verification and control…to guarantee compliance."

Study Finds No Increase in Cancers from TMI

A twenty-year follow up study of mortality data on residents living within five miles of Three Mile Island found no significant increase overall in deaths from cancer.

The findings are published on the Web site of *Environmental Health Perspectives*, http://ehis.niehs.nih.gov, a journal of the National Institutes of Health's National Institute of Environmental Health Sciences. The paper will appear in the March 2003 issue of the journal.

INMM Membership Application

All information should be printed or typewritten

Name _____ Date _____

Date of Birth _____ Citizenship (Country) _____

Preferred Mailing Address (If different from employment address below)

Address _____

City _____ State/Province _____ Country _____ ZIP _____

Telephone _____ Fax _____ E-mail _____

Membership Level Desired

- ❑ **Student $20**
- ❑ **Regular $50**

Sustaining Members

- ❑ **0–19 employees $250**
- ❑ **20–49 employees $500**
- ❑ **50 or more employees $750**

Areas of Desired INMM Technical Division Involvement

International Safeguards	Materials Control and Accountability	Nonproliferation and Arms Control
Packaging and Transportation	Physical Protection	Waste Management

From the categories listed above, please rank your interest area by importance:

1st _____ 2nd _____ 3rd _____

Present Experience

Total number of years work experience in nuclear materials management field(s) _____

Field(s)/Subject(s) of expertise _____

Present title _____ Telephone _____ Fax _____

Employer _____

Address _____

City _____ State/Province _____ Country _____ ZIP _____

E-mail _____

Duties (in brief) _____

Type of organization:

❑ Commercial Utility	❑ Government Contractor	❑ Nuclear Material Processing
❑ Equipment Manufacturer	❑ Government or International Agency	❑ Research or Consulting

Other Experience or Training (Attach additional sheet if necessary)

_____

_____

Education

College or University	Major/Degree	Dates Attended
1		
2		
3		

Other Scientific and Technical Societies

Names and Membership Grades _____

Honors/Honorary Societies _____

Signature of Applicant

PAID BY: ❑ Check ❑ MasterCard ❑ VISA ❑ American Express ❑ Diners Club

Card No. _____ Exp. Date _____

Please copy this form, complete the application and mail or fax it, with membership dues, to:

INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT
60 Revere Drive, Suite 500 • Northbrook, Illinois 60062 USA
847/480-9573, Fax: 847/480-9282
E-mail: inmm@inmm.org • Website: www.inmm.org

INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Membership Has Its Benefits

By Scott Vance
INMM Membership Committee Chair

Welcome to 2003! How quickly the three years have passed since the subject of every article seemed to be Y2K. Now, it seems that almost as many articles are focused on nuclear security and how to enhance it. What an opportunity for INMM members, who include most of the world's experts on this very subject.

Online News

As membership continues to increase and the amount of news of interest to the membership has expanded, the *Journal* has attempted to keep up by adding features that keep the membership informed. Over the past few years, we have seen the average issue of the *Journal* expand from roughly forty pages to more than seventy. While the desire of the Executive Committee is to keep members informed, it has become unclear if we are informing the membership in the best way possible. Often, because of the normal delays in printing, the news that has appeared in the *Journal* was already old news by the time it appeared. In light of this limitation, and a desire to contain printing costs while continuing to improve the *Journal,* the INMM Executive Committee has agreed to the creation of an online member newsletter, effective early this year.

The newsletter will contain many of the features that INMM members have come to expect, including this column. Other features that will appear only in the online newsletter include the Reports to the Executive Committee, Inside Insight, New Members, and the Meet the Member profiles. Because this newsletter can be published in a much shorter period, the information will be more up-to-date and timely. The hardcopy version of the *JNMM* will continue to present the high-quality technical and policy papers our members have come to expect, book reviews, the President's Message, Technical Editor's Note, and the events calendar. Other features will appear from time to time as deemed appropriate.

Four times a year, INMM members will receive an e-mail announcement that the newest issue of the online newsletter is posted on the INMM Web site (http://www.inmm.org). A downloadable PDF version of the newsletter will be available for those who prefer it. Other delivery options will be available for those who do not have Web access. Patricia Sullivan, managing editor of *JNMM,* will be the managing editor of this new newsletter, and she will work with a volunteer editor to develop the newsletter each issue.

So watch your e-mail for an announcement about this exciting INMM member benefit.

Annual Meeting Notes

Less than a month now remains for you to submit a paper for presentation at the 44th Annual Meeting. (The deadline for submitting an abstract for the INMM Annual Meeting is February 1, 2003. See page 24 for more information.) This year's meeting in Phoenix, Arizona, will present itself as your best opportunity as a member to take advantage of the corporate knowledge represented by our diverse membership.

While you are encouraged to attend the meeting and learn what is new in your field, you are especially encouraged to present your work to others who will be attending. And remember, if you have not yet become a member of INMM, you must do so by April 13, 2003, in order to take advantage of the discounted registration fee available only to members. You will find a membership application on page XX of this issue or on the INMM Web site at www.inmm.org.

New Members

I am happy to report that many individuals continue to recognize the advantages of INMM membership. Since the fall 2002 issue of *JNMM* was published, eighteen new members have joined the INMM. A list of these new members will be included in the online newsletter shortly. Their contact information-and contact information for the entire membership-is available in the online INMM Membership Directory, available only to members at www.inmm.org.

To Print or Not to Print

The online membership directory provides many advantages, not the least of which is the ability to add new members as soon as they join the INMM instead of when the directory is printed the next year. On the other hand, the print directory, while expensive to produce, provides its own advantages-including portability-but unfortunately it's out-of-date before it's mailed. How do *you* use the directory? As decisions are made regarding future publications of the hardcopy version, your input is welcomed. Let me know your opinions and preferences to me via e-mail at scott.vance@shawpittman.com.

Sustaining Benefits

Not only are individuals welcome to join our membership, but we also encourage organizations that are related to the field of nuclear material management to become sustaining members. If you are unfamiliar with he benefits of a sustaining membership, please contact me or anyone on the Membership or Executive Committees, and we will quickly get some information to you.

Chapters, Divisions, Committees Leadership Changes

Since the last issue of the *Journal,* the Technical Divisions, Regional Chapters, and Standing Committees have all elected new officers, and I encourage you to read their respective reports in the upcoming

INMM newsletter. Although the elections are over for this year, opportunities for your participation in any of the divisions, chapters or committees abound.

If you have an interest in one of these areas, contact the chair and find out how you can be more involved. As a volunteer organization, INMM always has room for more involvement by all of the members, and I encourage you to participate. A complete listing of INMM technical division, committee, and chapter chairs—and their contact information—is available on the INMM Web site at www.inmm.org.

As always, if you have any news about an INMM member, including yourself, be sure to keep your colleagues informed by contacting either me at scott.vance@shawpittman.com or our *JNMM* Managing Editor Patricia Sullivan at psullivan@inmm.org. Please include photographs when possible.

INMM Leadership

Executive Committee

President
John Matter
E-mail: jcmatte@sandia.gov

Vice President
Cathy Key
E-mail: cathykey@chartertn.net

Secretary
Vince DeVito
E-mail: vdevito@aol.com

Treasurer
Bob Curl
E-mail: ruc@inel.gov

Members-at-Large
Chris Hodge
E-mail: chris.hodge@srs.gov

Bruce Moran
E-mail:bwm@nrc.gov

Nancy Jo Nicholas
E-mail: njnicholas@lanl.gov

David W. Swindle
E-mail: dswindle@egginc.com

Immediate Past President
James D. Williams
E-mail: jim.williams@hq.doe.gov

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Annual Meeting
Charles E. Pietri
E-mail: cpietri@aol.com

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Constitution and Bylaws
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Amy B. Whitworth, *Vice Chair*
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International Safeguards Division Chair
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Materials Control and Accountability Division Chair
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Packaging and Transportation Division Chair
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Physical Protection Division Chair
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Waste Management Division Chair
Ed Johnson
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Urals Chapter
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Ukraine Chapter
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E-mail: scherb@mpca.kiev.ua

Vienna Chapter
Shirley Johnson
E-mail: s.johnson@iaea.org

John Wells Wachter

1924–2002

John Wells Wachter, who was honored with a special letter of commendation at the 43rd INMM Annual Meeting in June 2002, died Wednesday, October 9, 2002, at the University of Tennessee Medical Center at Knoxville. He was 78.

Dr. Wachter was a retired Oak Ridge National Laboratory physicist and had a long and distinguished career in a number of Oak Ridge area nuclear research facilities. He worked on behalf of numerous regional and national professional societies, including the Institute of Nuclear Materials Management. He served as treasurer of INMM's Central Chapter from its inception in 1981 until 2000. The INMM recognized Dr. Wachter's long and devoted service to the INMM with the special letter of commendation. Central Chapter President Chris Pickett delivered the letter to Dr. Wachter after the meeting.

Dr. Wachter earned a bachelor's degree in nuclear engineering from Lafayette College, a master's degree in physics from Cal Tech in 1949 and a doctorate in nuclear physics from the University of Tennessee in 1961.

Dr. Wachter worked at the Naval Research Laboratory in Washington, D.C., and on several military assignments from 1944 to 1946 while in the U.S. Army.

In 1951 he joined the Union Carbide Nuclear Division at the Y-12 Plant, where he developed handling procedures for nuclear materials. In 1961 he joined Oak Ridge National Laboratory to work on linear acceleration research in the Neutron Physics Division. He later worked on criticality safety projects as a member of the Chem Tech Division and the Full Recycle Division. In 1990, he retired from Oak Ridge National Laboratory.

Throughout his life, Dr. Wachter served on several boards of directors, including the Institute of Nuclear Materials Management, the National Kidney Foundation of East Tennessee and the Oak Ridge League of Women Voters and Oak Ridge Civic Music Association.

Dr. Wachter is survived by his wife, Peggy; his son, Stephen Wells Wachter of Knoxville; two stepsons, Brian Emmett and wife, Sarah, of Raleigh, N.C., and Greg Emmett of Knoxville; and by two step-grandchildren.

INMM Awards Program Honors Students and Professionals in Nuclear Materials Management

At the INMM Annual Meeting in Orlando, Florida, in June 2002, several student papers were presented and all were considered for an INMM Student Award. The award is given a full-time college or university student for the best paper presented at the meeting. Last summer, first place was awarded to Peter Jansson of Uppsala University for his paper, Measurable Implications of Partial Defect Due to Replacement of Fuel Rods in an 8x8 BWR-Assembly by Dummy Rods: A Preliminary Study.

INMM Past President J. D. Williams, far left, and INMM President John C. Matter, far right, flank two students honored at the INMM Annual Meeting in 2002. Peter Jansson, left, received the top prize, while Phillip Hypes, right, was awarded second place.

"It's important for us to recognize the hard work being done by college and university students and to encourage them to continue," said INMM Awards Committee Chair Yvonne Ferris.

Student papers are submitted to a review committee that selects the best paper and recommends it for the award. The first place winner receives $1,000 and recognition at the INMM Awards Banquet along with the recipients of INMM's other awards.

Bestowing awards for excellence, at the student and professional levels, is central to the work of the INMM. Honoring those people who meet or exceed high standards of professional ethics, education, and attainments in nuclear materials management is one of the core missions of the Institute.

The INMM's Distinguished Service Award is given to individuals who attain a distinguished level of accomplishment in and service to nuclear materials management. This award focuses on long-term noteworthy service to the nuclear materials safeguards and management profession. Recipients are not required to be INMM members.

The Meritorious Service Award is given to an INMM member for outstanding service to nuclear materials management and the Institute. This award focuses on long-term outstanding contributions to the INMM as well as the individual's noteworthy professional accomplishments.

Distinguished Service and Meritorious Service award recipients must be nominated to the INMM Awards Committee by March 15, 2003. Nominations may be made by any INMM member. Send the following information to INMM Headquarters:

- The name of the award
- The name and title of the nominee (Use the former title if the individual is retired.)
- Name, address, and phone number of nominee's company or employer
- Nominee's recent resume
- Supporting information—nominations should summarize the individual's accomplishments and contributions
- Letters of support from peers
- The name, company, address, telephone, and fax number of the nominator—the Awards Committee may need to contact you to obtain additional information

It has been the custom of the INMM to withhold the names of the Distinguished Service and Meritorious Service award recipients until the awards are presented the night of the Awards Banquet at the Annual Meeting. Ferris asks that the number of people informed about your nomination be limited and that you not inform the nominee unless absolutely necessary.

Address your nominations to:
INMM Headquarters
Awards Committee
60 Revere Drive, Suite 500
Northbrook, Illinois 60062 U.S.A.

For more information and a list of past award recipients, see the INMM Awards page on the INMM Web site at http://www.inmm.org/topics/contents/awards.htm.

Beautiful Setting, Topnotch Program Highlight the 44th INMM Annual Meeting

The 44th Annual Meeting is a superb professional forum for the exchange of the latest technical information in nuclear materials management. Each year the INMM Annual Meeting addresses all aspects of nuclear materials management with papers and posters organized by INMM's Technical Program Committee that relate to international safeguards; materials control and accountability; nonproliferation and arms control; packaging and transportation; physical protection; and waste management. In 2003, we are especially attempting to address issues relating to weapons inspection in Iraq and nuclear nonproliferation in North Korea.

INMM 44th Annual Meeting

The Setting

This year's meeting will be held at the first-class JW Marriott Desert Ridge Resort & Spa, an outstanding resort and convention facility with dazzling amenities, superior comfort, and deluxe accommodations. JW Marriott Desert Ridge Resort & Spa is woven into the Sonoran Desert where northeast Phoenix converges with Scottsdale. The resort offers majestic views of the McDowell Mountains, and is just twenty minutes north of the Phoenix Sky Harbor International Airport. The resort is the centerpiece of the Valley's burgeoning northeastern corridor, surrounded by the pristine Sonoran Desert.

The JW Marriott Desert Ridge Resort features two eighteen-hole championship golf courses; a full service spa salon; a state-of-the-art fitness center; an eight-court tennis pavilion; swimming pools; waterfalls; and a lazy river.

The Institute of Nuclear Materials Management has negotiated with the JW Marriott Desert Ridge Resort & Spa to offer the rate of $99 (exclusive of 11.07 percent tax). This rate will be available to INMM Annual Meeting attendees three days before and three days after the official meeting dates of Sunday, July 13, through Thursday, July 17, 2003.

To reserve a room, call the JW Marriott Desert Ridge Resort & Spa at 480/609-3646 or 800/228-9290 and mention that you are with the INMM to receive the discounted rate. Reservations must be made at the JW Marriott Desert Ridge Resort **before June 12, 2003**. Make your reservations early to ensure your accommodations.

Reduced Fees for INMM Members

Members of INMM pay a discounted registration fee to attend the INMM Annual Meeting. To be eligible for the member registration rate, you must be a member of INMM for a minimum of one fiscal quarter (three months) before the Annual Meeting. **To qualify for the member rate in 2003, you must be a member by April 13, 2003**. All speakers must register by June 30, 2003.

Call for Papers

The deadline to submit an abstract for consideration by the Technical Program Committee is **February 1, 2003**. The call for papers and abstract submission information are available on the INMM Web site at http://www.inmm.org. Click on Annual Meeting for more information.

Up-to-date information on the 44th INMM Annual Meeting is available on the INMM Web site at http://www.inmm.org. Or call INMM HQ at 847/480-9573.

Calendar

March 30–April 2, 2003
10th International
High-Level Radioactive Waste
Management Conference
Texas Station Hotel, Las Vegas, Nevada, U.S.A.
Sponsors: American Nuclear Society, University of Nevada, Las Vegas, and the U.S. Department of Energy
Contact:
American Nuclear Society
E-mail: registrar@ans.org
Web site: www.ans.org/meetings/ihlrwm

May 13–15, 2003
ESARDA 25th Annual Meeting
Symposium on Safeguards and
Nuclear Material Management
City Conference Centre, Stockholm, Sweden
Contact:
European Safeguards Research and Development Association (ESARDA)
Web site: www.jrc.cec.eu.int/esarda/

May 18–22, 2003
ESTECH 2003, the 49th Annual
Technical Meeting of the IEST
Phoenix Civic Plaza and Hyatt Regency Hotel, Phoenix, Arizona, U.S.A.
Sponsor: The Institute of Environmental Sciences and Technology
Contact:
IEST, 940 East Northwest Highway, Mount Prospect, IL 60056
Phone: 847/255-1561
Fax: 847/255-1699
E-mail: iest@iest.org

June 1–5, 2003
American Nuclear Society
Annual Meeting 2003
Town and Country Convention Center, San Diego, California, U.S.A.
Sponsor: American Nuclear Society
E-mail: registrar@ans.org
Web site: www.ans.org

June 2–6, 2003
International Conference on Storage
of Spent Fuel from Power Reactors
Vienna, Austria
Organized by the International Atomic Energy Agency in cooperation with the OECD Nuclear Energy Agency
Contact:
International Atomic Energy Agency
IAEA-CN-108
Vienna International Centre
P.O. Box 100
Wagramer Strasse 5
A-1400 Vienna, Austria

July 13–17, 2003
44th INMM Annual Meeting
JW Marriott Desert Ridge Resort, Phoenix, Arizona, U.S.A.
Sponsor: Institute of Nuclear Materials Management
Contact:
INMM, 60 Revere Drive, Suite 500, Northbrook, IL 60062
Phone: 847/480-9573
Fax: 847/480-9282
E-mail: inmm@inmm.org
Web site: www.inmm.org