Volume XXXII, Number 2

JNMM Journal of Nuclear Materials Management

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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 efficient management of nuclear materials.

SUBSCRIPTION RATES: Annual (United States, Canada, and Mexico) $100.00; annual (other countries) $135.00 (shipped via air mail printed matter); single copy regular issues (United States and other countries) $25.00; single copy of the proceedings of the Annual Meeting (United States and other countries) $175.00. Mail subscription requests to *JNMM*, 60 Revere Drive, Suite 500, Northbrook, IL 60062 U.S.A. Make checks payable to INMM.

ADVERTISING, distribution, and delivery inquiries should be directed to *JNMM*, 60 Revere Drive, Suite 500, Northbrook, IL 60062 U.S.A., or contact Jill Hronek at 847/480-9573; fax, 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

Winter 2004, Volume XXXII, No. 2

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INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

In Case You Missed This…

By John C. Matter
INMM President

47th IAEA General Conference

You may not be aware that INMM has non-governmental organization (NGO) observer status for the IAEA General Conference. This year I attended the 47th IAEA General Conference in Vienna, September 15–19, 2003, as an observer, along with Jim Tape as alternate. We were provided access to the plenary, committee of the whole (warmly referred to as the "cow"), scientific forum, exhibits and displays, briefing for NGOs, seemingly endless documents (I shipped home about fifty pounds!), and at least one reception. This was a very busy and at times contentious general conference. To get a better sense of the output of this forum, the IAEA Web page provides the fifteen resolutions and five decisions of the 47th IAEA General Conference at http://www.iaea.org/AboutPolicy/GC/GC47/Resolutions/index.html.

Another treat at the GC was a precedent-setting joint meeting of the INMM Vienna Chapter and the American Nuclear Society (ANS) Austria Section. ANS President Larry Foulke and I both attended the luncheon meeting and gave short presentations focusing on chapter and student activities.

ESARDA/INMM Joint Workshop

Another collaborative event was the European Safeguards Research and Development Association (ESARDA) and INMM joint workshop, Safeguards for a Future Nuclear Environment, held October 14–16, 2003, in Como, Italy. This was the fourth in a series of joint workshops. Congratulations for this successful workshop to organizers Jim Larrimore, INMM International Safeguards Technical Division chair, Gotthard Stein, Sergio Guardini, and Louis-Victor Bril. The workshop format was four working groups (WG) on challenges for safeguards, today and future, and future safeguards solutions and directions, technological, and institutional/political. ESARDA Chair Brian Burrows and I co-chaired one of the working groups. INMM membership was plentifully represented, including the president and three past presidents (Jim Tape, Obie Amacker, and Debbie Dickman). The report and conclusions of this workshop will be available on the ESARDA and INMM Web sites. Recommendation 8 of WG4 states, "ESARDA and INMM should intensify their efforts in the area of education and training. In addition to these efforts, ESARDA and INMM should consider how to jointly encourage broader international actions in this area."

2003 ANS/ENS International Winter Meeting

The INMM Executive Committee (EC) met last in New Orleans, November 18–19, 2003, which coincided with the 2003 ANS/European Nuclear Society (ENS) International Winter Meeting and the Embedded Topical Meeting GLOBAL 2003. One of our initiatives is in the area of students and outreach to ANS to work together in this area. I attended the ANS Student Sections Committee meeting that included participants from six American universities, gave a short introduction to INMM, and volunteered to help arrange INMM speakers at ANS student sections. I met later with Sharon Kerrick, ANS department manager for outreach and volunteer development, about INMM plans and possible opportunities to team with ANS. Then during the INMM Executive Committee meeting we were visited by ANS President Larry Foulke, Kerrick, and Ross Radel. Ross is the co-chair of the 2004 ANS Student Conference, April 1–3, 2004, at the University of Wisconsin-Madison. As part of the INMM student initiative, the EC will provide some financial support to the ANS Student Conference and has approved formation of a new Student Activities Committee. We will seek volunteers for this committee in the near future.

One of the highlights of the ANS meeting was an address at the opening plenary session by former New York City Mayor Rudy Giuliani. He gave a very motivating talk about his six rules for leadership:

- Relentless preparation
- Have strong beliefs in core principles
- Train yourself to be an optimist
- Have courage and manage fear
- Teamwork is necessary to be effective
- Communication with people is vital

45th INMM Annual Meeting Call for Papers

By now you should have submitted your abstracts for the 45th INMM Annual Meeting, July 18–22, 2004, at the Renaissance Orlando Resort at Sea World in Orlando, Florida, U.S.A. But if you haven't, it may not be too late if you immediately contact our venerable Technical Program Committee Chair Charles Pietri, cpietri@aol.com. The Technical Program Committee meets March 10, 2004, to plan all sessions of the INMM Annual Meeting. After that it will be too late to submit your abstract. We certainly expect a large, possibly record, turnout of papers and participants considering all that is happening in the world of nuclear materials management. Please contact Charles or me with your ideas for opening or closing plenary speakers, other suggestions for our annual meeting, or to get actively involved in its planning or operation.

INMM President John C. Matter may be reached by e-mail at jcmatte@sandia.gov.

Reviewing Peer Review

By Dennis L. Mangan
Technical Editor

I personally am quite pleased with the way the *JNMM's* peer-review process is being conducted, thanks to many qualified individuals. Several years ago when we started the process, Assistant Editor Steve Dupree agreed to manage and oversee it. Steve has done an excellent job! Our associate editors have also contributed significantly to this process to improve the quality of the papers we print in this *Journal*. These associate editors represent the six technical divisions of our institute and include:

- International Safeguards: *Gotthard Stein and Bernd Richter*
- Material Control and Accountability: *Dennis Wilkey*
- Nonproliferation and Arms Control: *Jim Lemley*
- Packaging and Transportation: *Scott Vance*
- Physical Protection: *Rebecca Horton*
- Waste Management: *Pierre Saverot*

When a technical paper is submitted to the *Journal*, Steve and I decide which of the technical divisions should be involved in the review process. At times, more than one division may be identified. Steve forwards an electronic package to the selected associate editor, who in turn identifies qualified people to do the review. A standard form is used in the process. The reviewer sends the completed form with appropriate comments back to the associate editor, who forwards it to Steve. Steve interfaces with authors and provides the reviewers' recommendations. The reviewer's identity is not revealed, although there have been several cases where the reviewer has offered to help the authors with paper improvements. We try to accomplish the peer review process within sixty days. Just as with any volunteer organizations, many times we succeed; however there have been times when we have failed.

An underlying theme of the peer-review process has been one of helping, and I believe it is doing just that. I want to express to all the volunteers who support the peer review process our sincere appreciation for their efforts.

It was pointed out to me that the recent fall issue of the *Journal*, which highlights the INMM Annual Meeting, did not cover those who received awards. Although this is included in the *Communicator* on the INMM Web site (www.inmm.org), the *Communicator* can be accessed only by INMM members. However, the awards article is available on the public-access area of the INMM Web site, via a link on the home page. In the next fall issue, and in subsequent fall issues, we will highlight award recipients.

In this issue of the *Journal* are three articles. In the first, scientists from Las Alamos National Laboratory (David Loaiza and Rene Sanchez) and scientists from Idaho National Engineering and Environmental Laboratory (Gregg Wachs, William Hurt, and Ronald Mizia) combined efforts to conduct a critical experiment in order to validate, improve, and benchmark a Nickel-Chromium-Molybdenum-Gadolinium alloy that would be used for nuclear criticality control of spent nuclear fuel. In this effort, they explore the effects of uncertainties of mass measurements, geometry, and impurities and how they affect the calculated multiplication factor. This experiment benchmarks the worst-case scenario for spent nuclear fuel stored in a geological repository.

The second paper is co-authored by Victoria Longmire, Christina Files, Rebecca Stevens, Morag Smith, Phyllis Russo, and Norbert Ensslin (all of Los Alamos National Laboratory), Chris Pickett and William Brosey (both of Oak Ridge's Y-12 Plant), and Joel Swanson of Lawrence Livermore National Laboratory. It discusses DOE's materials control and accountability (MC&A) modernization plan, which has as its goal, "unobtrusive surveillance with instantaneous accountability." The team effort to pursue this modernization plan involves personnel not only from the three laboratories above, but also from the Savannah River Site. They address futuristic upgrades at existing sites, and futuristic approaches for MC&A at new facilities, integrated with physical protection and safety. This concept of integrating these three functionally different elements has been around for a long time; perhaps this new study will bring focus to this needed effort.

The third article, spearheaded by Steve Mladineo, chair of our Nonproliferation and Arms Control Technical Division, summarizes an INMM hosted workshop held in Washington, D.C., "The Implications of a New Era in Arms Control on Regional Nonproliferation and Nuclear Materials Management." This workshop featured distinguished speakers and panelists. This summary paper identifies four themes that evolved from the workshop and is definitely interesting reading.

In conclusion, I want to apologize for incorrectly identifying the student who won the student paper award at the annual meeting. I identified him as Jarrod D. Williams instead of his correct name, Jarrod D. Edwards. I am truly sorry, Jarrod.

As always, should you have any comments or questions, please feel free to contact me.

Dennis L. Mangan is a consultant and can be reached at dennismangan@comcast. net.

Critical Experiment Analysis of Neutron Absorbing Nickel-Chromium-Molybdenum-Gadolinium Alloy Being Considered for the Disposal of Spent Nuclear Fuel

David Loaiza and Rene Sanchez
Los Alamos National Laboratory, Los Alamos, New Mexico U.S.A.

Gregg Wachs, William Hurt, and Ronald Mizia
Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho U.S.A.

Abstract

A critical experiment was carried out in order to validate, improve, and benchmark a Nickel-Chromium-Molybdenum-Gadolinium alloy that would be used for nuclear criticality control of spent nuclear fuel (SNF). The experiment was performed at the Los Alamos Critical Experiments Facility (LACEF). The intent of the experiment was to provide criticality safety data for spent nuclear fuel surrounded by this alloy. The experiment was fueled with highly enriched uranium (HEU), mixed with the Ni-Cr-Mo-Gd alloy, and moderated and reflected with polyethylene. The arrangement of the experiment consisted of interlacing Ni-Cr-Mo-Gd alloy/fuel/moderator in the thermal energy region. Analysis of the critical experiment consisted of systematically examining the uncertainties associated with the experiment as they affect the calculated multiplication factor (k_{eff}). The systematic analysis is separated into uncertainties due to mass measurements, uncertainties due to geometry, and uncertainties due to impurities. Each type of uncertainty is analyzed individually and a total combined uncertainty is derived. The Ni-Cr-Mo-Gd alloy-HEU experiment had an experimental k_{eff} of 1.002. The calculated k_{eff} value using Monte Carlo Neutron Partical Transport Code and ENDF/B-VI cross-section data tends to agree with the experimental values. The sensitivity analysis of the critical experiment yielded a total combined uncertainty on the measured k_{eff} of ± 0.0064.

Introduction

The disposal of spent nuclear fuel (SNF) in a deep geological repository for several years has been considered as a means to isolate the fissile material from the biosphere. Investigations are underway to characterize repository design and media characteristics.[1] One of the safety questions being addressed is preventing criticality by inserting a corrosion-resistant, weldable, structural material with the SNF. This alloy must resist the leaching of the neutron absorber if exposed to the storage environment.

The U.S. Nuclear Regulatory Commission (NRC) requires that the means to prevent and control criticality be addressed as part of the preclosure safety analyses and to evaluate hazards associated with preclosure operations at the repository surface facility.[2] The NRC also requires that the licensee demonstrate through a performance assessment that performance objectives for the geologic repository after permanent closure will need to consider only events that have at least one chance in 10,000 of occurring over 10,000 years.[3]

The U.S. Department of Energy (DOE) has been given the task of managing and disposing of the DOE-owned SNF. In turn, the DOE has created the National Spent Nuclear Fuel Program (NSNFP) at the Idaho National Engineering and Environmental Laboratory to manage the disposition of this SNF. The Ni-Cr-Mo-Gd alloy is under development by the NSNFP for use in the DOE standardized storage canisters. The standardized canisters provide management functions for packaging, storage, transport, and long-term disposal of the SNF. This alloy may then be used as a *means to control criticality* in the DOE standardized canisters during storage or transportation and in the event a moderator material is introduced into the waste package at the Yucca Mountain Repository.[3]

The program initially studied the properties of 316L stainless steel alloyed with gadolinium because of the known corrosion properties and similarities with the standardized canister material. Additionally, stainless steel has been alloyed with boron in the past. However, the stainless steel-boron alloy was ruled out due to the boron's lower than desired thermal neutron absorption cross section and high boron solubility properties. Thus, the program started to investigate the viability of alloying gadolinium with Nickel-Chromium-Molybdenum alloys.[4,5] This material has been recommended by the NSNFP due to its favorable neutronic, mechanical, corrosion resistance, and weldability properties. One of the test heats with the following chemical composition 14.71 wt. percent Mo, 14.93 wt. percent Cr, 2.38 wt. percent Gd, and 67.9 wt. percent Ni was sent to the Los Alamos Critical Experiments Facility (LACEF) for critical mass experiments. The impetus of the critical mass experiment is to provide criticality data as a basis for assessing criticality safety and for setting operating limits for SNF interspaced with a Ni-Cr-Mo-Gd alloy inserts.

The experiment performed at LACEF approximates the worst-case criticality scenario for a long-term geologic repository involving SNF (full flooding of the repository). The experiment mixed the Ni-Cr-Mo-Gd alloy inserts with HEU foils. The HEU foils were used to experimentally approximate the uniformly distributed fissile material and to simulate a homogenous solution system. A hydrogenous moderating material in the form of polyethylene slabs experimentally approximated the effect of flooding. This experiment was performed to provide validation data, which is of interest to those investigating criticality scenarios for the disposal of SNF. It should be noted that most of the DOE SNF is in the form of HEU, and as a result the choice of HEU as fuel in this experiment. This experiment sets an upper limit or provides the most conservative data for SNF. For SNF originating at commercial nuclear power reactors where the typical enrichment is 3-4 percent, the experimental data provided in this experiment is still applicable, since it will just require a greater amount of low enriched uranium to obtain a critical system. This experiment was of high quality and was documented according to International Criticality Safety Benchmark Evaluation Project (ICSBEP) guidelines.[6] Similar experiments have been performed at LACEF with various waste matrix materials.[7, 8] Earlier experiments consisted of mixing HEU with SiO_2, Al, MgO, Fe and Gd.[7] Later experiments reduced the thickness of moderation, increased the amount of HEU, and the doubled the amount of the waste material being analyzed (SiO_2, Al, and Fe).[8] These experiments, thus, provide different ratios of HEU to waste materials.

Two factors are important in the analysis of the Ni-Cr-Mo-Gd alloy: the ability of the alloy to either absorb neutrons (Gd) or scatter neutrons (Ni, Cr, and Mo). Because cross sections vary as a function of the neutron energy, criticality analyses in the postulated flooding scenarios required data for thermal systems. Thus, this experiment was performed in the thermal energy region for the postulated wet condition scenario. Because no experiments have been performed with this unique alloy, the ability of the computer codes and data libraries to predict the correct k_{eff} for systems that contain this alloy is not entirely known. The lack of experimental data leaves nuclear criticality analysts to rely almost solely on the results provided by neutronic codes.

The purpose of deriving computer models for this system is to allow calculations of critical parameters that can be used as a basis for assessing criticality safety and for setting operating limits. Criticality analysts use neutronic codes such as Monte Carlo Neutron Particle Transport Code (MCNP) to calculate whether a given material mixture in a given shape is subcritical. If it is shown that the material mixture is sufficiently subcritical, then the ratio or composition of the materials of interest can be employed to set operational limits such as mass storage limits. Therefore, to demonstrate the safety of SNF surrounded with the Gd alloy, experimental results must be compared with results predicted by the neutronic codes and cross-section libraries. These experiments must be performed using strict guidelines to identify uncertainties or biases in the experiment in order to set conservative safety margins.

Understanding these uncertainties provides data needed to expose limitations in computational methods or weaknesses in neutron cross-section libraries. This process affords reliable data so that appropriate criticality safety margins can be set. Thus, sensitivity analyses must provide realistic uncertainties so that no biases are hidden or biases appear where none exist. In order to combine and compare the uncertainties of each component, all the components are evaluated at the same confidence level. The confidence level in this evaluation is $\pm 1\sigma$ (one standard deviation). The advantages of this process are that the sensitivity analyses help identify factors that lead to, or contribute to, the overall uncertainty and shows the limitation of some of the cross sections and methods.

Description of the Experiment

The experiment was performed using the Planet critical assembly at the LACEF. The Planet critical assembly is a vertical lift machine residing in the Critical Assembly and Storage Area (CASA) I. The Planet critical assembly consists of a movable platform powered by a hydraulic lift and jackscrews. The vertical displacement of the movable platform can be measured and controlled within 0.00254 cm (1/1,000 inch). The maximum speed of the movable platform is adjustable for each experiment to limit the insertion rate of reactivity to less than 0.05 $/s. To disassemble the configuration, the movable platform is dropped to its initial out position. There are no other control or safety rods inside the assembly.[9]

Figure 1 shows a picture of the Planet critical assembly and the experimental setup. The experiment consisted of placing HEU foils interspersed with the Ni-Cr-Mo-Gd alloy plate in a short and fat column stack. The uranium foils were moderated and reflected by square polyethylene plates. A unit consisted of one polyethylene plate with a central recess in its top side that contained the Ni-Cr-Mo-Gd alloy being examined and four HEU foils on top of the neutron absorber plate and a polyethylene insert.

The approach to critical was performed by, first, hand-stacking the units following the *half-way rule* and the *3/4 rule*. The 3/4 critical-mass rule states that the hand-stacking of multiplying systems shall never exceed three-fourths of the extrapolated (or predicted) critical mass. The half-way rule states that the size of each step shall not exceed one-half the increment to predicted delayed critical or double the multiplication of the system. In this experiment, the more conservative rule was followed when adding an additional unit. Once the hand-stacking limit was reached, typically seven units, the operators split the stack. The bottom part of the stack, which contained approximately half of the critical mass, was placed on the movable platform of the Planet critical assembly. The top part of the stack was placed on the top platform and typically contained two or three units. The lower portion of

Figure 1. Experimental setup for the 2 x 2 waste matrix experiments

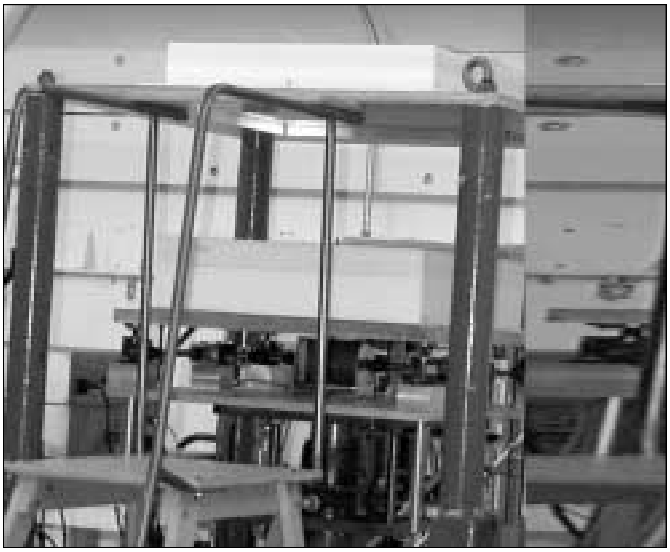
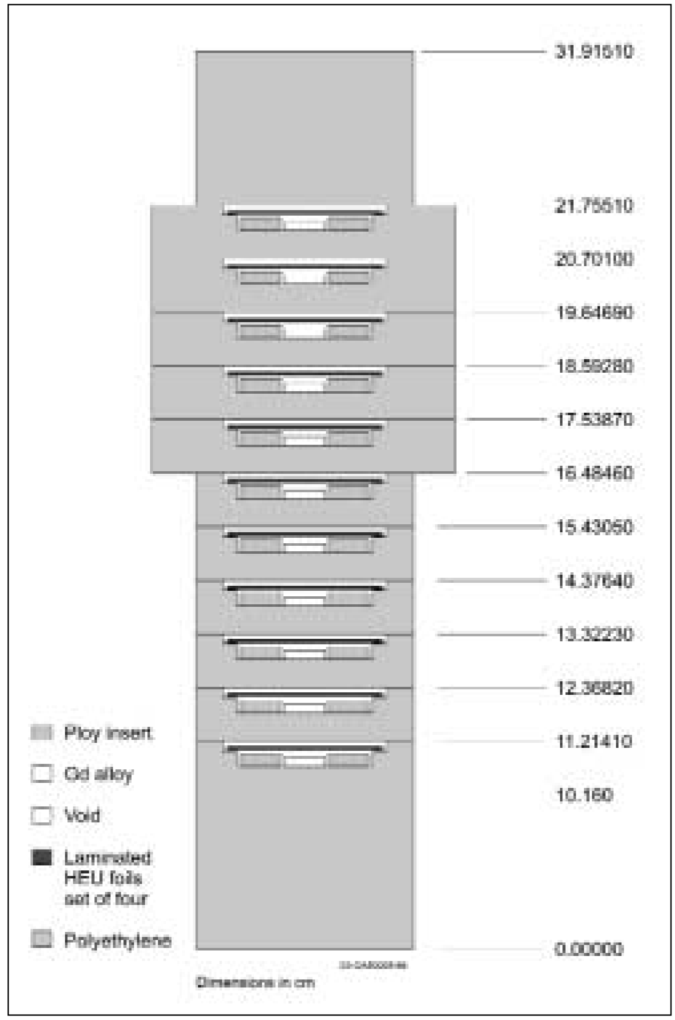


Figure 2. Schematic of the experimental arrangement with the gadolinide allow plates



the stack, which contained a Pu-Be source, was then raised remotely.

The experimental arrangement is depicted in Figure 1. As Figure 1 illustrates, the stack is divided into two parts. The bottom half of the stack rests on an aluminum support plate that is 2.54-cm thick. The approach to critical is achieved by decreasing the gap between the top and bottom portions of the stack until the bottom stack lifts the upper stack. The neutron leakage from the stack was measured with four BF_3 detectors, and the inverse count rate (1/M) as a function of the number of units was plotted. By extrapolating the last two points of the (1/M) values to zero, the number of units necessary to reach criticality was determined.

The number of units necessary to reach criticality (no gap between bottom and top stack) was eleven plates of Ni-Cr-Mo-Gd alloy and 11¾ units of HEU foils. A unit consisted of one plate of polyethylene, four HEU foils, and one plate of the alloy. A schematic of the experimental arrangement is shown in Figure 2. The dimensions in Figure 2 correspond to the location of the top of each moderating plate from the bottom of the assembly. The total critical mass consisted of 3,207 g of HEU and 10,211 g of the Ni-Cr-Mo-Gd alloy. Taking into account that the Gd content is 2.38 wt. percent, then the total amount of gadolinium present is That translates to approximately 243 grams.

As Figure 2 illustrates, the experiment is a homogeneous or a semi-homogeneous arrangement. The actual disposal of SNF with the Gd alloy will be in a heterogeneous arrangement. The intent of the experiment is to evaluate the critical mass of HEU mixed with a Ni-Cr-Mo-Gd alloy, since no experimental data exists on this alloy. The neutronic properties of the Ni-Cr-Mo-Gd alloy will be the same in a homogeneous or a heterogeneous system provided both systems are on the thermal energy range which is the worst-postulated scenario for the disposal of SNF.

Description of Material and Data

The experiment was fueled with HEU foils. The nominal dimensions of the bare HEU foils were 22.86-cm by 22.86-cm square and 0.00762-cm thick. These foils were laminated with plastic (polyethylene) to minimize the amount of oxidation and airborne contamination. The final laminated foils had dimensions of approximately 25.4 by 25.4 cm and were 0.02286-cm thick. A schematic of these foils is presented in Figure 3. The average mass and density and their standard uncertainties for HEU foils in the Ni-Cr-Mo-Gd alloy experiment were 68.23 ± 2.23 g and 17.14 ± 0.56 g/cm^3, respectively. The isotopic composition for the foils is presented in Table 1 as weight percent and atom percent. The weight percent values were directly measured and the atom percent values were derived from that measurement. The reported error in the analysis is ± 0.02 weight percent.

Figure 3. Schematic of the HEU foils

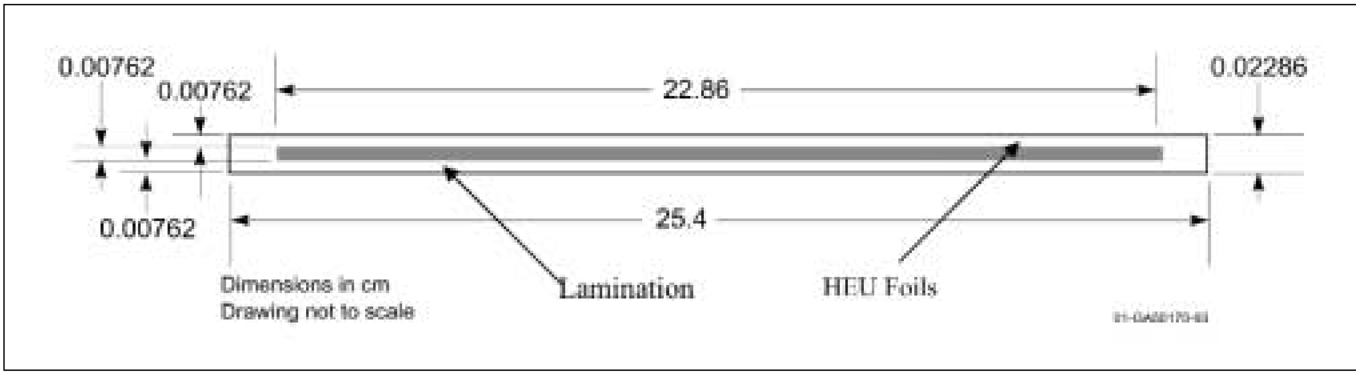
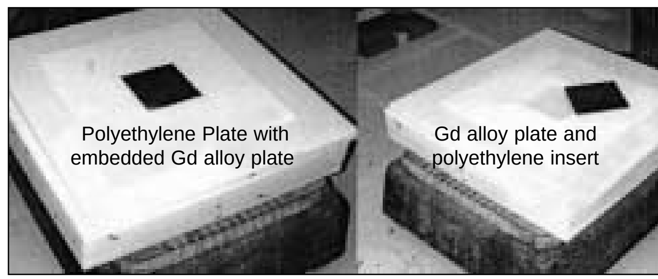


Table 1. Composition of HEU Foils

Isotope	Weight Percent	Atom Percent
^{233}U	0.0000	0.0000
^{234}U	1.1339	1.1395
^{235}U	93.2321	93.2919
^{236}U	0.2581	0.2572
^{238}U	5.759	5.3114

Figure 4. Ni-Cr-Mo-Gd alloy with moderating polyethylene plates



The Ni-Cr-Mo-Gd alloy plates were 14.76756-cm by 14.76756-cm square with a tolerance of ± 0.00508 cm. The thickness of the plates was 0.48489 ± 0.00508 cm. The average mass and density of these plates were 928.35 ± 10.65 g and 8.78 ± 0.10 g/cm^3, respectevely. The typical content of Gd in the plates was 2.38 ± 0.02 wt. percent. This uncertainty was assessed from the two chemical analysis reported, and it is considered to be an upper limit in the content of the Gd in the alloy plates. The chemical analysis was performed by NSL Analytical Services, Inc. It should be noted that the dimensions of the Ni-Cr-Mo-Gd plate are too small to fill the recess in the polyethylene plate. Therefore, a polyethylene plate insert was used to fill the remaining space of the recess. This polyethylene plate insert was 45.7073-cm by 45.7073-cm square and 0.67056 cm thick with a central recess. Figure 4 shows a picture of the Ni-Cr-Mo-Gd plate with the polyethylene moderating plate and the polyethylene insert.

The moderator and reflector for this experiment were constructed from high-density polyethylene. The average density of these plates was 0.962 g/cm^3. Two different sizes of moderating plates were used in this experiment (see Figure 5). The dimensions for the bottom moderating and reflector plates were 66.04-cm by 66.04-cm square with a tolerance of ± 0.254 cm. The thickness of the moderating plates was 1.0541 ± 0.0127 cm, and the thickness of the reflector plate was 2.54 cm. The bottom moderating plates that compose the bottom stack rest on the movable platform of the Planet critical assembly. The second set of moderating plates that constitutes the upper part of the stack rests on the on the top platform of the assembly. These plates are larger than the bottom ones because they hold the entire weight of the top stack. The dimensions of the top moderating plates were 75.184-cm by 75.184-cm square with a tolerance of ± 0.254 cm. The thickness of the second set of moderating plates was also 1.0541 ± 0.0127 cm. The impurities in the polyethylene plates were reported to be less than 200 ppm. No uncertainty in the impurities of the polyethylene plates were reported, since most of the impurities were close to the detection limit and therefore are unquantifiable. Figure 5 shows a schematic of the moderating plates. The top reflector plates had the same dimensions as the ones that form the bottom reflector.

Method of Analysis

The experiment described was reported with enough detail to permit the development of a very comprehensive model. The calculations analyzed in this study were performed using the MCNP code. MCNP was used because of its historic and recognized success in the performance of benchmark evaluations and applications analyses for licensing activities. Additionally, MCNP can calculate several critical parameters such as the effective neutron multiplication factor, neutron lifetime and generation time, and energy-dependent fluxes for complex geometries and material compositions. Of these parameters, k_{eff} is the most important parameter for assessing criticality safety. Therefore, the reactivity effect of the uncertainties can be quantified using an MCNP

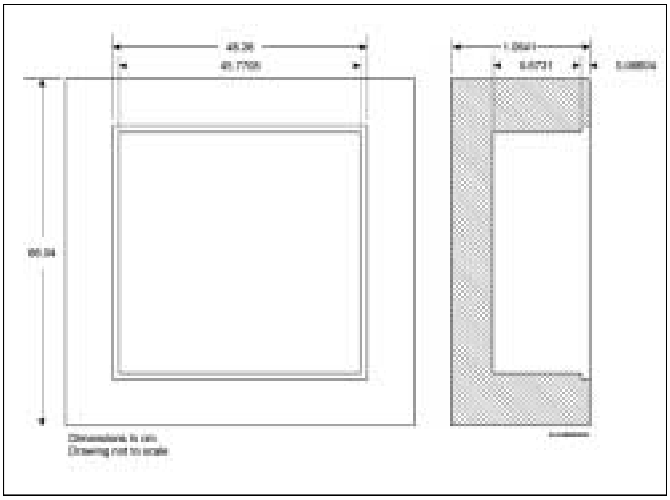


Figure 5. Schematic of the moderating plates

model. The goal in the development of the benchmark model is to simplify the input deck file as much as possible without significantly changing the calculated k_{eff}. A second detailed model was also created. This second model contains very few simplifications and it is the best attempt to model the exact arrangement of the experiment. From this model, effects, as measured by changes in k_{eff}, can be evaluated for simplifications and verification of assumptions.

The MCNP analysis was performed by employing a detailed three-dimensional model with continuous-energy cross sections from ENDF/B-VI neutron data. The MCNP calculations had 6 million active histories. A total of 5,000 histories per generation were used and 1,250 generations of neutrons. The first fifty generations were skipped to obtain a well-distributed neutron source.

The individual effect of the parameter being analyzed on the k_{eff} of the system was calculated by varying one parameter at a time. First a reference k was obtained, $k_{eff}(r)$, using the reference values of the experiment. Then a parameter, r_i, is perturbed while all other parameters are kept at their reference value, and a new k is calculated based on the perturbation. The change in k (Δk_{eff}) is then calculated for ± the standard uncertainty (S.U.). Thus, the change in k_{eff} is defined as

$$(1) \quad \Delta k_{eff} = \frac{\left[\left|k_{eff}(r) - k_{eff}(r+S.U.)\right| + \left|k_{eff}(r - S.U.) - k_{eff}(r)\right|\right]}{2}$$

where $k_{eff}(r)$ is the reference case, k_{eff} (r + S.U.) is the perturbed case in the positive direction of the standard uncertainty, and k_{eff} (r – S.U.) is the perturbed case in the negative direction.

The combined standard uncertainty, σ_{keff}, is defined as the square root of the quadratic sum of the effects of the individual standard uncertainties on the experimental parameters. As stated above, each individual change in k_{eff} is the effect from the variation of a parameter (i.e., mass of fuel, geometric effect, or impurity) that is equal to the standard uncertainty of that parameter. All these individual changes were taken into account when calculating the total or combined standard uncertainty. Thus, the combined standard uncertainty is defined as[8]

$$(2) \quad \sigma^2_{k_{eff}} = \sum_{i=I}^{N} \frac{S.U.^2_{Pi}}{\delta^2_{Pi}} \left[(k^i_{eff} - k^r_{eff})^2 + 2\sigma^2_{MC}\right]$$

where ($k^i_{eff} - k^r_{eff}$) represents a change in k_{eff} induced by change in δ_{pi} on parameter pi, $S.U._i$ is the standard uncertainty of the parameter p_i, and N is the number of parameters being included in the analyses. The parameter σ^i_{MC} is the statistical uncertainty on the k_{eff} calculated by the Monte Carlo code. If this value is sufficiently small, then the effect of the σ_{MC} will be negligible. The parameter variation, δ_{pi}, was kept small enough to maintain the linear-dependence assumption of k_{eff} on the parameter.

Analyses and Results

The above delayed-critical state (k_{eff} >1) for the experimental configuration was attained by closing the gap between upper and lower stack (see Figure 1). The Ni-Cr-Mo-Gd alloy experiment was slightly supercritical. To determine the k_{eff} in this experiment, several reactor periods were measured and converted into reactivity through the Inhour equation. The Inhour equation simply relates a reactor period to reactivity in the system. This reactivity, in turn, was converted to k_{eff} and is presented in Table 2. Table 2 shows the experimental and the calculated k_{eff} with the benchmark and the detailed models. As shown in Table 2, the reported experimental k_{eff} agrees quite well with the calculated keff for the detailed model. The benchmark model was composed of average densities and nominal dimensions for all the materials. While the detailed model is composed of individual densities and individual dimensions, it includes all the impurities of the materials. Table 2 also presents worth calculations for the Gd alloy. The Ni-Cr-Mo-Gd alloy plates were replaced by void in the calculations to show the importance of these materials in the experiment.

The Gd alloy experiment was carefully performed and measurements of all significant parameters were recorded. Thus, the uncertainty analyses can be performed on all the components of the experiment. The uncertainties affecting the experiment have been divided into three broad categories. They are: 1) mass measurement, 2) geometry, and 3) material composition. Each category is considered in turn and then the combined experimental uncertainty is presented. Each uncertainty estimate is one standard deviation.

The first category includes the material mass uncertainty, which is calculated by changes in density. The uncertainties in the mass of the fuel, in the mass of the Gd alloy plates, in the mass of the polyethylene moderator plates, and in the mass of the fuel

Table 2. Material Data for the Waste Matrix Materials

Material	Experimental k_{eff}	Benchmark k_{eff}	Detailed k_{eff}	Worth Calculations for Material in ($)[a]
Gd alloy	1.0017	1.01317± 0.00034	1.00102± 0.00034	$8.89

[a] Waste material replaced by void in calculation.

lamination were considered. The uncertainty in the ^{235}U enrichment was also investigated under this category.

The second category includes the fabrication or geometry uncertainties of the different components. The geometry uncertainties examined include the change in volume of the Gd alloy plates, the moderator plates, the fuel, and the lamination.

The third category examined was the uncertainty in the material composition and impurities. Additionally, other uncertainties analyzed under this category were the effect of room-return neutrons and the effect of the supporting structure.

Analysis of Mass Uncertainties

The reactivity effect in the HEU mass was studied by varying the density of the HEU foils. This variation in the mass was manifested in the MCNP input file through a change in the atom density of the fuel while keeping the dimensions constant. The uncertainty in the fuel comes from weighing the fuel. To characterize this uncertainty, the standard uncertainty of the average density was varied to represent the mass uncertainty. The results of the uncertainty in the HEU mass are presented in Table 3. The uncertainty in the fuel enrichment was also analyzed.

The effect of mass uncertainty in the polyethylene moderating plates was also evaluated. The masses of the polyethylene plates and lamination were obtained by using a balance that had an accuracy of 0.2 grams. The uncertainty in the mass of the polyethylene material is represented by adjusting the atom density and maintaining the dimensions of the polyethylene plates and lamination constant. The uncertainty in k_{eff} due to the uncertainty in the mass of the polyethylene plates, and the effect in k_{eff} due to the uncertainty in the mass of the polyethylene laminations are summarized in Table 3.

The effects of uncertainty in the mass of the Gd alloy were also analyzed by varying the density of the material. The uncertainty in the mass of the Gd alloy is summarized in Table 3.

Table 3. Summary of Mass Uncertainty

Mass Uncertainty	Δk_{eff} for *Gd alloy*	S.U. [a] in k_{eff} *Gd alloy*
HEU	±0.0059	±0.0059
Enrichment in ^{235}U (wt.%)	±0.0003	±0.0003
Polyethylene Plate	±0.0009	±0.0009
Polyethylene Lamination	±0.0008	±0.0008
Polyethylene Insert	±0.0002	±0.0002
Gd Alloy	±0.0003	±0.0003

Analysis of Geometry Uncertainty

This uncertainty includes tolerances in the engineering drawings and their effect on the as-built component. Tolerances are typically given to machinist in the form of $p \pm \Delta p$ to achieve a desired precision. The Δp refers to the upper and lower bound; therefore, the nominal dimension of a component is bound by the tolerance. Since each nominal dimension is known within the interval, an uncertainty analysis can be performed to observe the effect of taking the lower and upper bound of the dimension. Then the change in the parameter can be divided by the square root of $3(\Delta p/\sqrt{3})$ to obtained the standard uncertainty, because the value is equally probable everywhere within the interval. The material dimensions were obtained from the original engineering drawings, from conversations with the experimenters, and from bounding assumptions in cases where no data existed. The computations for uncertainty in the dimensions were applied by adjusting the material density while keeping the material mass constant. In addition, only one dimension (i.e., x-direction) was varied at a time, and then the results were combined quadratically, i.e., $\sqrt{(x^2+y^2+z^2)}$.

The uranium foils were cut by the experimenters; therefore, no specified tolerances exist. However, the foils were measured to be 22.86-cm square after being cut. This dimension is a representative measurement of the foil rather than a maximum and minimum measurement. The horizontal dimensions were increased and then decreased by this amount. The HEU foils were rolled to obtain the desired thickness. For this analysis, an uncertainty of ±0.5 percent was assumed in the dimension of the HEU foils, which is considered a best estimate.The thickness of the foil was cut by a laser. For this analysis, based on a discussion with a machinist who has experienced cutting HEU foils, an uncertainty of ± 0.05 percent was assumed which is considered to be a maximum uncertainty in the thickness. The horizontal dimensions were increased and then decreased by this amount. The HEU foils were rolled to obtain the desired thickness. For this analysis, an uncertainty of ± 0.05 percent was assumed for the thickness of the foil. The effect, Δk_{eff}, and standard uncertainty in the dimension of the foils are presented in Table 4.

Table 4. Summary of geometry uncertainty

Geometry Uncertainty	Δk_{eff} for *Gd alloy*	S.U. in k_{eff} *Gd alloy*
HEU	±0.0002	±0.0001
Polyethylene Plate	±0.0011	±0.0006
Polyethylene Lamination	±0.0001	>0.0001
Gd Alloy	±0.00013	±0.0007
Polyethylene Insert	±0.0004	±0.0002

Effects due to the uncertainty in the polyethylene plate dimensions were assessed by adjusting the dimensions by the tolerance provided on the original engineering drawings. The engineering drawings show that the tolerance for the width and length of the plates was ± 0.254 cm and the tolerance of the thickness was ± 0.0254 cm. This uncertainty was represented by varying the dimensions in the ± x-plane and ± z-plane and maintaining the masses of the plates. The variation was performed one dimension at a time. The effects of the dimensional uncertainty in each of the three directions (tolerance divided by the square root of 3) were calculated (keeping mass constant) and combined quadratically. These results are presented in Table 4.

The uncertainty in the dimensions of the Gd alloy was analyzed by varying the dimensions of the plates by the specified uncertainty (tolerance). The dimensions were varied one at a time. The effects of the dimensional uncertainty in each of the three directions were calculated (keeping mass constant). The results are summarized in Table 4.

From the schematic drawings of the moderating plates (Figure 4), one can see that air gaps exist in two locations: 1) a gap between the Gd alloy plates and the foils and 2) a gap between the top of HEU foils and the polyethylene plate on top of them. The first gap is a result of the material recess. The material recess is 0.6731-cm thick and the thickness of Gd alloy is 0.48489 cm, which yields a total air gap of 0.18821 cm. The foil recess is 0.06604-cm thick and the thickness of the laminated HEU foil is 0.02286-cm thick, which yields a total air gap of 0.04318 cm. The effect of the uncertainty in these air gaps is presented in the summary table of the geometry uncertainties.

All the uncertainties in Table 4 are judged to be equally probable everywhere within the interval.

Analysis of Composition Analysis

The uncertain reactivity due to impurities of the materials, the reactivity uncertainty on the room-return neutrons and the reactivity uncertainty on the structural support material were analyzed under this category. Calculations were also performed to evaluate the effect of the impurities in the polyethylene plates and laminations, and more importantly, to evaluate the importance of the impurities on the Gd alloy.

The effects of material impurities were treated as uncertainties rather than biases because the polyethylene impurities were only representative of one sample and the manufacturer gave the impurities in the Gd alloy as *typical* values. The effects of the impurities are presented in Table 5.

Table 5. Summary table of additional calculations

Geometry Uncertainty	S.U. in k_{eff} *Gd alloy*
Impurity in Lamination	-0.0001
Impurity in Polyethylene Plates	-0.0006
Impurity of Gd Alloy	0.0001
Support Plates/Room Return	<0.0007[a]
Polyethylene Insert	±0.0002

[a] The standard uncertainty from support plates and room return is estimated as 0.0010

Table 6. Summary of total uncertainties

Geometry Uncertainty	Total for Gd Alloy
Total Uncertainty: Quadratic Total	±0.0064

Total Combined Uncertainty

The total or combined experimental uncertainty for the experiment is ± 0.0064. The total experimental uncertainties were derived from the individual effects provided in tables 3, 4, and 5, and statistically combining the independent uncertainties as presented in the Method of Analysis section of this paper. Of the uncertainties due to variations in mass in the experiment, the HEU mass uncertainty is important. In addition, the uncertainty of the polyethylene lamination has approximately the same magnitude as the uncertainty in the polyethylene plate. Two of the uncertainties in the geometry category are important: uncertainties in the polyethylene plates and the uncertainty in the Gd alloy. Of the composition uncertainties, only the uncertainty of the Gd alloy is significant. As mentioned earlier, the effect of room return and the aluminum in the structural support of the assembly were deemed negligible.

Conclusion

The goal of the experiment was to test the effectiveness of the newly developed Ni-Cr-Mo-Gd alloy neutron absorber. The experiment was performed at LACEF in order to provide criticality data for a neutron absorber that is being considered for criticality control with SNF. The Ni-Cr-Mo-Gd alloy has approximately 2.38 wt. percent Gd content. Increasing the Gd content in the alloy decreases the metallurgical properties of the alloy. Therefore, a maximum of 2 wt. percent Gd content is expected in the Ni-Cr-Mo-Gd alloy.

The HEU foils experimentally approximate the uniformly distributed fissile material, and the polyethylene plates experimentally approximate the effect of interstitial water or flooding. The Gd alloy is used to increase the criticality safety margin in the waste. Both detailed and benchmark models were prepared for the experiment in order to assess the effect of the known uncertainties in the keff of the system.

The sensitivity analysis addresses the question of which parameters contribute the most to the total combined uncertainty. All sensitivity calculations were performed using MCNP with ENDF/B-VI cross-section libraries. The uncertainties in the expected value of k_{eff} arise from neutron return from surroundings, uncertainties in material measurements (primarily HEU, waste material, and polyethylene density, mass, and composition), machining tolerances of components, and others. Individually, the effects are small, and taken together, they may be compensating. One of the benefits of preparing a sensitivity analysis is to provide data to help qualify codes and cross sections used in criticality assessments. These calculations and models have realistic uncertainties and the associated biases reflect the true accuracy of the criticality calculations.

This critical experiment provides data to those investigating criticality scenarios for geological repositories, and it is considered to be acceptable as a criticality benchmark experiment.

Acknowledgments

The authors wish to acknowledge the samples provided by Gregg Wachs and Ronald Mizia of the National Spent Nuclear Fuel Program. We also like to acknowledge the support by Steve Clement of Los Alamos National Laboratory and the operating staff of the Los Alamos Critical Experiments Facility as well as Blair Briggs, chair of the International Criticality Safety Benchmark Evaluation Project (ICSBEP). This paper evolved from the benchmark evaluation prepared in support of the ICSBEP.

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The SO-13 MC&A Modernization Plan: a Status Report

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Abstract

During the past quarter century, at U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA) sites tremendous progress has been made through DOE Office of Security Policy-sponsored research and development (R&D) programs in improving materials control and accountability (MC&A) measurements and accountancy of special nuclear materials (SNM). However, during this same period of time, site labor costs and compliance costs have increased exponentially, while the performance of the MC&A function at each site has remained virtually the same. This means that performing the MC&A function still requires shutting down all operational activities and sending in teams of well-trained personnel to make measurements, cleanout processes, and inspect seals to ensure that no SNM is missing. This function and process continues to be very labor intensive and time-consuming, and risks being compromised if costs continue to grow.

New technology and R&D is needed to ensure that SNM inventories at DOE/NNSA sites will remain safe and secure, and be reconciled in a relatively fast and cost-effective manner. This report describes the short-term and long-term issues, needs, and opportunities that currently exist at DOE/NNSA sites. We also emphasize reasons why MC&A systems at DOE/NNSA sites must be modernized to thwart emerging threats and rising operational costs, if we want to achieve our MC&A modernization goal of *unobtrusive surveillance with instantaneous accountability.*

Introduction

MC&A provides assurance to the nation that nuclear materials are controlled in accordance with their strategic and economic importance, and that the misuse, theft, or diversion of these materials will be detected. MC&A plays an important part in security at nuclear facilities, especially in addressing threats such as theft of materials, environmental contamination, and nuclear safety incidents associated with nuclear materials. For this reason, it is important that MC&A takes advantage of new technologies and methods in order to provide information on a site's nuclear materials in the most timely and useful manner possible.

Within the U. S. Department of Energy (DOE), the Office of Security Policy, the Policy Integration and Technical Support Program (SO-13) is responsible for the development of safeguards and security technology that enables DOE and NNSA facilities to safeguard their SNM. The SO-13 Program has tasked safeguards personnel at Los Alamos National Laboratory, the Y-12 Plant, Lawrence Livermore National Laboratory, and the Savannah River Site to prepare an MC&A modernization plan that provides recommendations for development of innovative new technologies and methodologies for MC&A in both new and existing DOE facilities. The near-term objective is to identify MC&A problems or inefficiencies in existing DOE facilities and provide recommendations for technology development to improve them. It is very important to take into account new concerns about the protection of nuclear material following the attacks of September 11, 2001. The long-term objective is to identify opportunities for new MC&A approaches that can provide increased freedom of operation and increased security for new DOE facilities that are just entering the planning and design stage. The objectives of this project integrate with DOE's twenty-five-year planning process by identifying opportunities to implement more effective and efficient MC&A programs at future nuclear facilities that will be built over the next two decades.

MC&A Modernization Plan Mandate

The past decade has witnessed the immense growth of technology and tools for improving the way businesses account for and control the movement of goods and personnel. While this technology has altered the way commercial inventories (goods such as razors and clothing) are managed and tracked, very little of this technology has been implemented in the world of nuclear MC&A at DOE/NNSA facilities. In some cases, in fact, operations are taking place in the original facilities built during the Manhattan Project and one of the few modernizations that has taken place since that time is the implementation of a computerized accounting system. In many cases, rising workforce costs are making it compulsory to find automated ways to reduce the time and effort involved in labor-intensive MC&A activities. The mandate of the

MC&A modernization team is to find ways to leverage new technology and to identify new areas where technology should be developed in order to improve effectiveness and reduce costs associated with safeguards at nuclear material facilities. Some of the technologies and tools have the potential to reduce costs not only for MC&A functions but also for overall physical security. The new technology thrust areas identified by the team to improve the efficiency and effectiveness of MC&A at DOE/ NNSA sites include an integrated safeguards, security, and safety approach for new and existing facilities; modern safeguards and security systems that are increasingly automated; continuous, real-time asset management, process monitoring, and storage facility monitoring; and greater use of in-process nuclear material measurements.

The result of this effort will include recommendations for new measurement technology development in areas where new types or better methods of measurements are needed, new MC&A approaches for accounting and control that incorporate new tools and technologies into the current process of MC&A, and recommendations on the design of the MC&A systems, especially in new facilities that will enter the planning and design stage in the next decade.

The modernization plan will provide both short-term and longer-term recommendations. In the near term, the plan should identify areas where improvements can be made in MC&A that reduce inefficiencies in the MC&A process in existing DOE facilities. Longer-term technology development, facility design considerations, and MC&A system design should enable MC&A practitioners to operate facilities with reduced risk, lower costs, and increased efficiency. These recommendations should address the issues of decaying infrastructure and high maintenance costs. They should also help to avoid unscheduled shutdowns due to safety or security incidents, provide faster reconciliation of anomalies, reduced reliance on two-person rule and personnel assurance programs, and enable safety benefits such as reduced radiation exposure.

It should be noted that this effort is not intended to point out deficiencies in current MC&A practice in the complex. Rather it seeks to find processes, areas, or technologies that can be improved in order to enhance efficiency, reduce risks, costs, or radiation exposure rates, and provide more accurate and timely information for the security of DOE facilities.

Status

The MC&A modernization plan is a work in progress representing the collaboration between MC&A specialists from within the complex and facility advisors from Lawrence Livermore National Laboratory, Los Alamos National Laboratory, the Savannah River Site, Y-12, New Brunswick Laboratory, and the DOE. The following sections of this report summarize the methodology used by this team in identifying areas for modernization and technology development. Subsequent sections will address the information collected by the team during visits made in the past year, and will highlight the team's vision for modernized MC&A processes. The examples shown in tables 1-4 are drawn from a comprehensive list of measurement and other technology needs that we are gradually refining through site visits and with input from the DOE. This process of validating potential needs through discussion and comparison should conclude at the beginning of 2004, and the report highlighting the recommendations and conclusions of the team should be issued in the spring. We hope to present the conclusions of this effort at the INMM Annual Meeting in July 2004. However, we see the report of this team as a living document—one that will continue to grow over time as new technologies become available for existing facilities, and new facilities are designed and constructed—and we will continue to seek input on proposed technology solutions for the complex.

Methodology

The team's objective has been to look at the entire scope of the MC&A program and identify current capabilities and new technologies that support or enhance the modernization vision in the basic functional areas of the MC&A system. For the team's purposes, these areas were delineated as nuclear material measurements, material accounting, material control and MC&A system design.

Nuclear Material Measurements

The area of nuclear material measurements is being handled separately from material accounting, material control, and system design. For this area, we have prepared a very large table of roughly ninety nuclear material categories for plutonium, uranium, mixed plutonium/uranium, alternative nuclear materials, and irradiated fuel. Table 1 illustrates some of the columns in this table for one nuclear material category, HEU metal scrap. The goal of this table is to identify nuclear materials for which current measurement capability is sufficient, and others where additional technology development is needed. To prepare this table, we used the DOE database of nuclear material quantities, and then compiled a vast amount of existing data on nondestructive assay options, current measurement capabilities, and current measurement uncertainties.

Potential needs for measurement improvements to meet DOE requirements for accountability, verification, or confirmation quality measurements are called out in the fourth column of Table I. The technical capability and operational capability needs columns refer to the current complex-wide capability to make the measurements required by DOE MC&A orders. Descriptions for the symbols in these columns are given in Table 2.

The MC&A modernization team is now in the process of visiting senior MC&A and safeguards measurement staff at the major DOE facilities to work through the list of potential needs in Table I and validate those that are relevant at each site. For validated measurement needs, team members and site personnel will document the impact on security or the cost of not meeting these

Table 1. Sample measurement needs analysis

Nuclear Material Category	Quantity	NDA Technique	Potential Need Description	Tech. Need	Oper. Need	Need No.	Impact on security of not addressing need	Impact on cost of not addressing need
37. HEU metal scrap	High	Active Neutron Coincidence	Accountability measurements of HEU metal scrap	●	○	37a	Lack of timely accountability	More expensive assay systems needed
		Active Neutron Multiplicity	Accountability measurements of HEU metal scrap	◐	◐	37a	Lack of timely accountability	More expensive assay systems needed
		Delayed Neutron Shuffler	Accountability measurements of HEU metal scrap	◐	◐	37a	Lack of timely accountability	More calibration effort needed
			Calibration for HEU metal scrap via standards or calculations	◐	◐	37b	Potential for inventory differences	Higher costs for sampling and DA

Table 2. Description of technical and operational capability needs

Technical Capability Need		Operational Capability Need	
Accountability and verification requirements cannot be met by this technique.	●	Current technique is too slow or costly for most facility operations.	●
Only verification requirements can be met by this technique.	◐	Current technique is not available for many facilities or material containers.	◐
Both accountability and verification requirements can be met by this technique.	○	Current technique is available for most materials at most facilities.	○

Table 3. Sample Modernization need for nuclear material accounting

MC&A Topics	Opportunities for Improvement	Impact of Current Capability	Technical Need Status	Operational Need Status
Enhanced timeliness of MC&A information	Automated inventory system for continuous inventory capability	Current inventory procedures result in high personnel exposure, are time intensive, and involve many manual tasks that can result in administrative errors.	◐	○

measurement needs. Team members and site personnel will also list potential measurement technology development opportunities to meet these needs, and categorize them as near-term, mid-term, or long-term. This will help SO-13 identify areas where investments in new measurement technology development would be most beneficial.

Nuclear Material Accounting, Control, and MC&A Design

The approach taken by the team to target modernization needs for accounting, control, and system design was based on assessing the impact of current processes on the facility in terms of manpower, exposure, time, and risk. This approach generated a list of *opportunities for improvement*, which, if implemented, would

Table 4. Technical and operational capability summary for accounting and control

Technical Capability		Operational Capability	
Specific technology does not exist to meet strategic goal	●	Operational impact of current capability is too great	●
Technology exists, but would require adaptation to meet strategic goal	◐	Operational impact of current capability is significant	◐
Technology exists to meet strategic goal and can be implemented	○	Operational impact of current capability is acceptable	○

allow a facility to enhance the efficiency with which it conducted MC&A functions. This list has been the subject of discussion among some of the sites with large nuclear material holdings over the past months. The objective has been to cull a list of opportunities that would provide the most benefit across the complex, either in terms of total reduction of cost and risk, or in terms of the number of facilities that would benefit from the technology. An example of the structure of the opportunities is shown in Table 3.

A similar summary of technical and operational capabilities is used for this table, and is presented in Table 4.

Throughout the process of identifying and analyzing potential modernization areas, the team has narrowed its recommendations by ensuring that the proposed solutions provide significant improvements based on at least one of the following criteria:

- Security risk
- Operating costs
- Contribution of measurement uncertainty to limit of error on inventory difference (LEID)
- Time required to carry out safeguards functions
- Operator radiation dose incurred

The modernization team is currently validating these opportunities and needs across the complex through visits to sites with large amounts of nuclear materials. At the time of this writing, the modernization team has looked at these issues with Lawrence Livermore National Laboratory and Y-12 National Security Center. Additional site visits are planned for the Savannah River Site and Los Alamos National Laboratory.

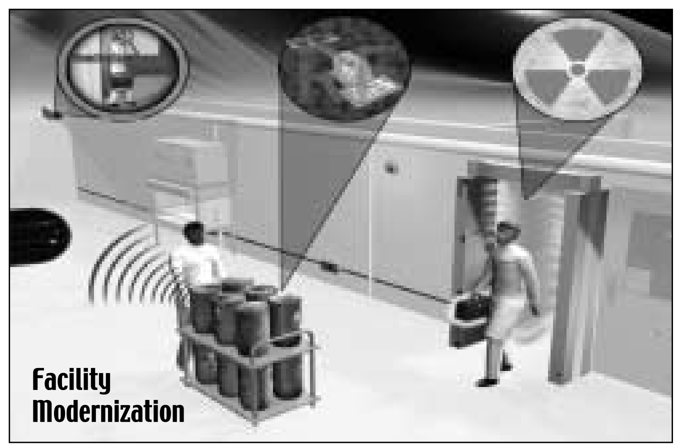
Preliminary Results

For the purposes of this report, the preliminary results of the modernization team shall be discussed for both existing facilities and future facilities. In both cases, these results are expressed as a vision for what a fully modernized MC&A system might look like.

Vision for Existing Facilities

The modernization vision for existing facilities relies on incorporating emerging technologies that reduce the labor associated with performing the MC&A function and do not require major process changes. These technologies should be selected based on their ability to improve process efficiency and overall system effectiveness. Some of the emerging technologies are illustrated in Figure 1 and include:

Figure 1. Modernization technologies



- Technologies for continuous inventory such as radiofrequency identification devices (RFID) and infrared (IR) tagging, and technologies for more efficient inventory taking such as advanced bar code and smart buttons
- Portable interfaces for inventory taking such as personal data systems (PDAs), portable terminals, and capability to download data into accounting system from remote sites
- Real-time asset management technologies including surveillance, RFID, and bar coding
- Integrated systems (surveillance plus radiation actuated portals)
- Improved response capabilities through providing real-time information on assets
- Automated tools to reduce reliance on administrative controls
- Integrating measurements into the process to reduce material moves

Figure 1 illustrates how some of these emerging technologies might be incorporated into existing facilities to provide better tracking and automated functions for accounting and control functions. In the illustration, three specific technologies are called out in the circles at the top of the picture. The first circle shows how integrated surveillance systems may provide monitoring that is triggered by radiation detectors or other monitoring systems to provide smarter surveillance. The second circle illustrates how technologies such as RFID tags may be used to track movements of nuclear materials, providing opportunities for real-time monitoring. The third circle shows how the use of radiation monitors at entrances/exits to material balance areas might be integrated with personnel identification cards (smart badges or proximity badges) to track the movement of people with nuclear materials.

Vision for MC&A in future new DOE facilities

Due to the World War II legacy at many of DOE's major nuclear material storage and processing sites, the MC&A program is a retrofit effort. Processes were designed and implemented before any consideration of MC&A. It was only after World War II that significant emphasis was placed on implementing appropriate MC&A functions. With the potential of several new SNM processing and storage facilities to be built within DOE/NNSA in the next decade, we now have the opportunity to ensure that these new facilities and processes are designed with MC&A in mind.

New facilities should be designed to incorporate cost-effective safeguards that enable facility workers to have more information available when needed, more accurately and more quickly. To achieve this, new facilities should be able to integrate safeguards, security, and safety functions. For example, a facility could leverage the systems used to monitor for criticality safety for monitoring against possible radiation sabotage incidents. New facility designs should make it more feasible to provide protection capabilities as well, such as ensuring that no single insider could shut down a facility; providing the timely ability to determine if material was taken during an attack on a facility and if so, how much; and providing the information needed by protective forces on material at risk in a timely manner. One option would be to have *hard-shelled* facilities that allow considerable freedom of movement within the protective shell. Greater freedom of movement could be achieved by moving toward a *real-time asset management* philosophy of operations. This approach stipulates that assets to be protected—SNM, radioactive sources that could be dispersed, classified information, classified parts that require monitoring and tracking, high explosives, and facility workers—must be tracked within a building by means of integrated entrance/exit monitoring systems, surveillance, and other engineered controls. Another great benefit would be fuller automation for MC&A processes such as accounting data entry, inventory verification, inventory difference validation, measurements and measurement control, shipper-receiver validation, and automated storage facilities.

This type of facility layout should provide more freedom of operation within the facility, including a reduction in two-person

Figure 2. MC&A in a modernized facility

rule operations, a reduction in manpower use for high-radiation tasks such as inventory taking, and less obtrusive safeguards systems that do not hinder operations.

Figure 2 is a depiction of the types of MC&A systems that are envisioned for a modernized facility. This figure illustrates a facility where all SNM materials and personnel are continuously tracked and monitored. All materials are kept in either monitored storage arrays or in enclosures or containers that prevent direct access and the accounting is done in real-time as the materials move through the process and facility.

Conclusion

The SO-13 MC&A modernization plan is intended to identify those areas where technology development and investment would bring the most benefits. This has required looking at the impact that current MC&A practices have on costs, safety, health, and manpower in order to determine where possible benefits may be found. This effort has concentrated on identifying measurement needs and how to address them. The project has also addressed what other improvement—in terms of accounting, control, and overall design— could be made to reduce manpower, timeliness, exposure, risk, and other costs. The final modernization plan, when completed, will provide a road map for the next twenty-five years of retrofitting, new design, and ongoing work in MC&A across the DOE complex.

Acknowledgement

This work was supported by the DOE Office of Security Policy, Policy Integration and Technical Support Program (SO-13). We are also receiving valuable technical support and input from members of the Office of Safeguards and Security Policy (SO-11) and

the Office of Plutonium, Uranium, and Special Materials Inventory (SO-62). In addition, we would like to thank the many senior MC&A personnel at Los Alamos, Livermore, Y-12, Savannah River, and New Brunswick National Laboratory who are serving as advisors on the development of this modernization plan.

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The Implications of a New Era in Arms Control—Perspectives and Analysis

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Introduction

The signing of the Strategic Offensive Reduction Treaty (SORT), also called the Treaty of Moscow, by the United States and the Russian Federation marked a new era in arms control. Signed on May 24, 2002, the treaty effectively codified a sea change in the relationship between the United States and Russia. In contrast to the elaborate bilateral arms control agreements of the past, this treaty is short, only about one and a half pages. Although it continues the Strategic Arms Reduction Treaty (START) verification mechanisms, there is no new verification regime, and no mutually restrictive milestones. According to media reports at the time, the Bush administration would have been content to dispense with an agreement entirely, and had proposed mutual unilateral cuts. Thus the treaty implies a significant change in future arms control and nonproliferation. These changes may also affect the objectives and procedures of nuclear materials management. Consequently, the INMM Nonproliferation and Arms Control Technical Division and the INMM Northeast Chapter initiated a workshop of topical experts to assess the trends and identify challenges and opportunities for the nuclear materials management community.

Summary

On November 13, 2003, the INMM hosted a workshop in Washington, D.C., The Implications of a New Era in Arms Control on Regional Nonproliferation and Nuclear Materials Management. In this paper we summarize the workshop's highlights and provide our analysis of the dominant themes.

Ambassador Linton Brooks, administrator of the National Nuclear Security Agency (NNSA), delivered the keynote address and focused on four points that are key to understanding the new era:

- The demise of traditional East/West arms control
- The new strategic relationship between Russia and the United States
- The blurring of the distinction between nonproliferation and counter-terrorism
- The growing recognition that the nonproliferation regime is no longer adequate and needs to be strengthened

Brooks issued a set of challenges to the workshop participants: if his premises were right, what should replace the lexicon of arms control? He described a four-part strategy for nuclear materials protection in Russia,[1] and asked if that model should be replicated globally—potentially by leveraging the new relationship with Russia. Should it be through the International Atomic Energy Agency (IAEA), bilaterally, or through some other mechanism? Asserting that the old Nonproliferation Treaty (NPT) regime was inadequate, he asked what should replace it, and how do we bring it about?

Three panel discussions were presented:

- Implications of a New Era in U.S./Russia Arms Control Agreements
- Implications of a New Era in Arms Control Upon Regional Nuclear Nonproliferation: South Asia/East Asia/Middle East
- Nuclear Materials Management in a New Era of Arms Control

In the first panel, Daryl Kimball, executive director of the Arms Control Association, argued that arms control agreements provided predictability in the reduction of arms, and had been successful in advancing the methods of verification. Lucas Fischer, the deputy assistant secretary for arms control at the U.S. State Department acknowledged that INF and START provide a basis for verification and transparency. He defended the Treaty of Moscow, arguing that a related U.S.-Russian joint declaration established working groups to focus on introducing transparency in offensive weapons and missile defense.

Michael Levi of the Brookings Institution contended that the arms control consensus has evaporated and a new consensus is needed. Nuclear weapons proliferation is now the most important security topic with risk stemming from the inventories present in former Soviet states and elsewhere. New focus areas for policy should be a new *cooperative threat reduction* and strengthened export controls. Gael Tarleton, a consultant, agreed that traditional arms control has been replaced by a new U.S.-Russia relationship. She described a new security risk management dialogue, where mutual security interests have led both countries to conclude that it is in their interests to develop a strategic partnership. Her concept of proliferation risk management includes the setting of priorities regarding agreed upon common threats and continued dialogue to resolve differences in approach.

Robert Gallucci, dean of the Walsh School of Foreign Service at Georgetown University, began the second panel, focusing on South Asia, Iran, and North Korea. He argued that the India and Pakistan confrontation is the most dangerous of the three because the common border, disputed territory, and the inequality of conventional forces leads to instability. He was not optimistic about future prospects but noted that the Fissile Materials Control Treaty (FMCT) would have great benefit if applied to India and Pakistan. Moving to Iran, he asserted that Iran's deeply rooted nuclear ambitions make it the most difficult to resolve. Neither the United States nor Iran have been motivated to engage directly on Iran's activities and concerns. North Korea, in contrast, seeks to engage the United States but its threatening rhetoric makes it the most frustrating regional security situation.

Susan Burk, acting director of the U.S. State Department's Nonproliferation Bureau, contended that there is a need to strengthen the NPT because three signatories (Iraq, North Korea, and Iran) have cheated. She also saw a need to keep sensitive nuclear technologies from countries that would misuse them. Michael Yaffe of the National Defense University argued that U.S. policy traditionally emphasizes the supply side of the nuclear weapons proliferation problem. He stated that more emphasis should be placed on the demand side, such as addressing the security concerns of countries that motivate their nuclear weapon programs.

The third panel addressed nuclear materials management. David Albright, president of the Institute for Science and International Security, argued that Iran had clearly violated its safeguards agreement, and verifiable dismantlement of their enrichment program is required. With respect to North Korea, he argued that intrusive verification is now the norm; that the NPT Additional Protocol is necessary, but not sufficient when there is noncompliance; that constraints on reprocessing and enrichment are needed; that fissile material stocks should be minimized; and that verification should focus on dismantlement of nuclear weapons.

Charles Ferguson of the Monterey Institute of International Studies argued that the highest priority threat is nuclear terrorism, specifically the danger that terrorists could obtain weapons-usable highly enriched uranium (HEU). The highest priority should be to consolidate and down-blend weapons-usable HEU in the former Soviet Union and in research reactors worldwide. Steve Fetter of the University of Maryland argued that the protection of nuclear materials is an international responsibility. He advocated an expanded convention for physical protection, peer review of physical protection standards, worldwide material protection, control, and accounting (MPC&A), support for the Reduced Enrichment of Research and Test Reactors (RERTR) Program, and he reinforced Ferguson's point about HEU blend-down.

Analysis

The combined challenges provided by the agenda session titles and by the charges from the keynote speaker highlighted the themes that emerged from the discussion.

The first theme is the significance of the new relationship, similar to a partnership, between the United States and Russia that has fundamentally altered the nature of traditional arms control. Because of this new relationship, the two nations see no need to invoke the rigor and formality of adversarial verification and transparency regimes opting for more informal cooperative activities. Viewed through the lens of political science realism, it seems likely that the two nations have each simply arrived at a national security calculus that it is in each of their national interests to cooperate in the area of nonproliferation and disarmament. Both countries appear to recognize that their most immediate threat is that of international terrorism—including nuclear terrorism. Consequently, along with the financial and security benefits of reducing nuclear weapons stocks, there is motivation to work together to address nonproliferation issues that could adversely impact both countries.

The second theme is the acknowledgment of the importance nuclear weapons on regional security. The nuclear dilemmas in North Korea, Pakistan/India, and Iran, all reinforce this theme. As the international community seeks to prevent the spread of nuclear weapons through a cooperative nonproliferation regime, it simultaneously needs to help reduce the regional tensions that motivate countries to pursue nuclear weapons. Iran appears to have nuclear weapons ambitions that are deeply rooted in historical notions of Iran's national security needs. The existence of an Israeli nuclear capability evidently weighs heavily on Iranian thinking, and has led to nearly two decades of subterfuge. North Korea's conclusion from the recent war in Iraq seems to have been that the ownership of nuclear weapons is a serious deterrent to attack. In the South Asian cases, first India concluded that it needed a nuclear deterrent to China, and Pakistan reacted, judging that it needed a nuclear deterrent to India. While Iran and North Korea are the most pressing concerns, there is an ongoing need to address the security concerns of other potentially proliferant states, such as Syria or Libya. Regional nonproliferation could be enhanced by nuclear states' pledging not to provide weapons technology, expertise, or equipment to non-nuclear states. By focusing on the suppliers in addition to consumers, the tools of export control can evolve to limit the ability of proliferators to produce the materials needed for nuclear weapons.

The third theme that emerged was the need to strengthen the NPT. Many argued that the NPT, while important, is not sufficient to maintain the nonproliferation regime. The IAEA and other international institutions are not well equipped to deal with cheating. The Iraq case alerted the international community that the IAEA's inspection regime was weak, especially in regard to undeclared facilities and material, leading to the development of the Additional Protocol. Although it cannot be determined whether the Additional Protocol would have discovered cheating in Iran, where cheating has been confirmed, a more robust inspection regime may be necessary. The dimensions of such a regime should be discussed, and, once defined, authority sought from the United Nations. The alternative seems to be the threat of the use of force to prevent the covert development of nuclear weapons.

The final theme was the importance of the programs for protecting nuclear materials from terrorists. There is a clear need to continue the multiple U.S./Russian programs for protecting the materials since Russia will continue to be the largest potential source for terrorists seeking nuclear materials for the foreseeable future. Programs that support protection of materials in other former Soviet states need to continue until the materials can safely be disposed of or moved to secure locations. The risk of nuclear materials in countries outside the former Soviet Union demands that similar attention be paid to the programs for dealing with that risk such as the RERTR Program. Programs that reduce the total quantity of HEU, such as the Megatons to Megawatts Program, are important in reducing the risk that nuclear material will fall into terrorists' hands. The use of commercial entities to manage this program using market incentives may offer a model for future programs.

Conclusion

The transformation of East-West relations with the end of the Cold War and the growth of international terrorism (including the emergence of catastrophic terrorist events) were the main catalysts that have led to the new era of arms control. It is noteworthy that all of the themes that emerged from the workshop depend in some way upon the notion that the distinction between nonproliferation and counterterrorism is no longer clear. The threat of nuclear terrorism has captured high priority in international relations. As scholars and experts continue to search for solutions to nuclear problems in this new era, the tools of traditional arms control either will evolve to counter the new threats posed by nuclear proliferation and terrorism, or they will play a smaller role than in the past.

Notes

1. The four steps are: 1) stop making nuclear material, 2) consolidate the nuclear material that exists, 3) protect that nuclear material, and 4) eliminate nuclear weapons usable material through blend-down or use in mixed oxide fuel for nuclear reactors.

DOE Seeks Public-Private Partnerships to Demonstrate One-Step Licensing

The U.S. Department of Energy (DOE) is moving ahead with the next major phase of the *Nuclear Power 2010* program, seeking formal applications from nuclear generating companies to partner with the department on licensing activities that would enable a new nuclear plant to be ordered and licensed for deployment early in the decade. The activities include preparation and submittal of combined construction and operating (or one-step) license application to the Nuclear Regulatory Commission (NRC) and certification of advanced, Generation III+ nuclear plant designs.

The expansion of nuclear power in the United States is a key recommendation of the *National Energy Policy.* Under the *Nuclear Power 2010* initiative, DOE will match industry investments over the next several years to demonstrate the key regulatory processes designed to make new plants more efficient, effective, and predictable. The program is currently working with three U.S. utilities to obtain permits for sites at which new plants could be built. For this latest phase of the initiative, DOE is seeking proposals from teams led by U.S. power generating companies to develop and implement plans to license and build new plants. Proposals will be evaluated on a first-come, first-serve basis.

Copies of the solicitation number DE-PS07-04ID14435, can be obtained from the DOE's Interactive Procurement Web site, http://e-center.doe.gov.

U.S. Presents Atoms for Peace Sculpture to IAEA

In commemoration of the fiftieth anniversary of Atoms for Peace and in celebration of President Eisenhower's vision, International Atomic Energy Agency Director General Mohammed ElBaradei accepted, on behalf of the IAEA, a bronze bust of U.S. President Dwight D. Eisenhower presented by U.S. Ambassador Kenneth Brill as a gift of the people of the United States. Jim Brothers, a sculptor who has commemorated many monumental figures in bronze, carved Eisenhower's likeness.

Brill, in his opening comments at the ceremony, said "President Eisenhower proposed not only a radical new direction for the use of nuclear technology, but also a critical role for a new international organization committed to the goal of nuclear nonproliferation... President Eisenhower, a man who came to the presidency as a war hero, posited a future where the unbridled pursuit of military power was transplanted by dreams of peace."

Martin to Head DOE's Nuclear Energy Research Advisory Committee

William F. Martin has been appointed to head the U.S. Department of Energy's (DOE) Nuclear Energy Research Advisory Committee (NERAC), an independent panel that provides advice on the direction of the department's nuclear program. Martin, a leading U.S. energy economist, is the founder and chair of Washington Policy and Analysis. He served as deputy secretary of energy and executive secretary of the National Security Council under former U.S. President Ronald Reagan.

Martin succeeds James Duderstadt, former president of the University of Michigan, who served as the panel's first chair.

Since its formation in 1998, NERAC has met about three times a year to review the DOE's nuclear energy program and provide advice and recommendations on long-range plans, priorities, and strategies. The committee also provides advice on national policy and scientific aspects of nuclear energy research issues. NERAC is currently composed of twenty-seven representatives of academia, the federal and state governments, national laboratories, an environmental advocacy organization, and the private sector.

Information on the NERAC, including its charter, may be found at http://www.nuclear.gov.

Contract Awarded for Nuclear Submarine Conversion

In December 2003, the U.S. Defense Department awarded a $222 million contract to General Dynamics Electric Boat for the conversion of nuclear weapons submarines to Tomahawk missile and special operations platforms. The contract covers the conversion of the first Trident ballistic missile submarine, the USS Ohio. The converted submarines will be known as SSGN submarines.

After the conversion, a submarine will be able to carry up to 154 Tomahawk cruise missiles and sixty-six special operations personnel, according to the Defense Department.

General Dynamics will also prepare the conversion of two other Trident submarines, the USS Michigan and USS Georgia. In 2004 the Pentagon has the option of adding the Ohio-class USS Florida to the project.

DOE Establishes Office of Security and Safety Performance Assurance

The U.S. Department of Energy (DOE) has established the new Office of Security and Safety Performance Assurance.

The new office will be responsible for the development and implementation of the department's safeguards and security policies and will report directly to the secretary of energy. This follows a comprehensive review that identified the need to reform and better coordinate the roles of independent oversight and the security policy organizations within the DOE.

The Office of Security and Safety Performance Assurance will work closely with the National Nuclear Security Administration, through the Office of Security Policy, to ensure that NNSA security policies emulate the intent of departmental security policies; and through the Office of Independent Oversight and Performance Assurance to continue the independent oversight of NNSA's safeguards and security, cyber-security, environment, safety and health, and emergency management programs.

The two major branches of the new office, the Office of Security Policy and the Office of Independent Oversight and Performance Assurance will remain independent of each other, ensuring the integrity of the independent oversight functions. Both offices will report to the director of the Office of Security and Safety Performance Assurance to promote the resolution of safeguard and security policy issues identified through the independent functions of each office.

Soviet-Era HEU Returned to Russia from Bulgaria

Seventeen kilograms of Russian-origin highly enriched uranium (HEU) were returned from Bulgaria to the Russian Federation in December 2003, according to the U.S. Department of Energy (DOE). It was part of the DOE-funded Russian Research Reactor Fuel Return Initiative. The fresh HEU was airlifted from Bulgaria to Dmitrovgrad, Russia, where it will be down-blended.

The highly enriched nuclear fuel assemblies were originally supplied to Bulgaria by the former Soviet Union for the Russian-designed two-megawatt research reactor, located in Sofia. The reactor was shutdown in 1989, and is going to be reconstructed. The nuclear fuel was loaded into four fresh fuel transportation canisters provided by the Russian Federation. International Atomic Energy Agency (IAEA) safeguards inspectors and DOE technical experts monitored the process of loading the fuel in the canisters. An AN-12 Russian cargo plane was used to complete the air shipment of the HEU fuel from Bulgaria.

The shipment of HEU from Bulgaria is the second shipment conducted under a tripartite initiative (the United States, the Russian Federation, and the IAEA) to return Russian-supplied HEU research reactor fuel for long-term management and disposition. The first shipment of fresh Russian-origin HEU from Romania to the Russian Federation was carried out on September 2003.

Brazil to Produce HEU by Mid-2004, But Says No to Spot Inspections

Brazil will likely begin producing highly enriched uranium (HEU) by May 2004 and has announced that it intends to begin exporting HEU within a decade. At the same time, the South American nation is refusing to give international inspectors full access to the plant that will produce the nuclear fuel.

The HEU program has only peaceful purposes, Brazilian officials say. But they also maintain that as a peaceful nation, it should not be subject to the same kind of unannounced spot inspections by the International Atomic Energy Agency (IAEA) that countries such as Iran and Libya have accepted.

Brazil has been a party to the Nuclear Nonproliferation Treaty (NPT) since 1997 but has not accepted the Additional Protocol.

JNMM Journal of Nuclear Materials Management

Deadlines for Volume 32

Spring 2004	Volume 32, No. 3
Feb. 10	Editorial Closing
Feb. 17	Ad Space Reservation Due
Feb. 25	Ad Materials Due

Summer 2004	Volume 32, No. 4
May 3	Editorial Closing
May 10	Ad Space Reservation Due
May 18	Ad Materials Due

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