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JNMM Journal of Nuclear Materials Management

Summer 2008, Volume XXXVI, No. 4

Special Section: Fifty Years of INMM

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INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Milestones and Anniversaries

By Nancy Jo Nicholas
INMM President

In this special issue of the *JNMM*, we celebrate our past successes and focus our attention on how we can best prepare to meet the growing nuclear material management challenges of the future.

Celebrating Fifty Years of Nuclear Materials Management

On May 17, 1958, a small group of professionals working in the infant field of materials control and accountability gathered in Pittsburgh, Pennsylvania, USA, to discuss the formation of a professional organization to advance various aspects of nuclear materials management. They named it the Institute of Nuclear Materials Management and, in October, elected Dr. Ralph Lumb as the first chair of the INMM. In 2008, an *ad hoc* committee led by Ed Johnson and Debbie Dickman is planning a yearlong series of events that will commemorate INMM's fiftieth anniversary, culminating with the INMM 50th Annual Meeting July 12-16, 2009, in Tucson, Arizona, USA. These are exciting times, and INMM members are on the forefront of the global focus on nuclear materials management.

Forty Years of Safeguards Technology Development at Los Alamos

At Los Alamos National Laboratory, we recently celebrated forty years of nuclear safeguards support, especially the development of measurements using nondestructive assay techniques and nuclear material accounting systems. To commemorate the occasion, LANL hosted an International Safeguards Symposium to share insights about challenges to safeguards and discuss possible directions for the next forty years. The founder of the safeguards programs at Los Alamos, the late G. Robert Keepin, who was INMM chair in 1979-1980, was instrumental in creating many of the safeguards concepts still used today. I hope we can all prove ourselves worthy of his legacy.

Annual Meeting News

The INMM 49th Annual Meeting will again be the Institute's premier event. Abstracts for well over 300 papers and posters have been organized into an outstanding technical program for this year's meeting by Charles Pietri and the Technical Program Committee. INMM Vice President Steve Ortiz has oversight of the Annual Meeting. We have organized special sessions on a broad range of topics that includes safeguards technology for advanced fuel cycles, global threat reduction and the next generation of nuclear materials experts. In addition, we have arranged a number of unique opportunities for students and educators such as a special student orientation and a Student Career Fair and Reception. I'm looking forward to many opportunities to commemorate, and (celebrate!), INMM's fiftieth anniversary with our Annual Meeting attendees.

WINS Update

Over the past two years, INMM has partnered with the Nuclear Threat Initiative (NTI) to explore options for developing a World Institute for Nuclear Security, or WINS. The purpose of such a new international organization would be to promulgate nuclear security "best practices" globally. WINS could enable the implementation of more effective nuclear materials security programs at nuclear facilities worldwide that would reduce their vulnerability to terrorist attack and diversion. INMM has continued to support the WINS concept development effort. In January 2008, INMM introduced a Web-based forum to systematically disseminate and promote global best practices in nuclear materials management. For more information, see www.inmm.org/best_practice online. Plans are in the works to establish WINS as a not-for-profit entity based in Vienna, Austria. To see the latest news on WINS, use the new links available on the INMM home page or go to: www. inmm.org/wins/.

Should you have suggestions, comments, or questions about INMM, I encourage you to contact me. My phone number is 505/667-1194 and my e-mail address is njnicholas@lanl.gov (or contact INMM headquarters at 847/480-9573 or inmm@inmm.org.)

Celebrating Fifty Years of INMM, Forty Years of LANL

By Dennis Mangan
Technical Editor

We have a very special journal issue to kick off our Institute's fiftieth anniversary. We trust it will help set the stage for a well-deserved celebration. Many people have put in hard work to make this issue a realization. When I reflect on the fifty years of our Institute, I'm appreciative that I've been somehow involved for a little more than half of them.

I had heard bits and pieces about the Institute before I became involved, but, in this issue, four articles, one by our secretary Vince Devito and the others by three of our past presidents (chairmen, in their days)—Jim Lovett, John Jaech, and Ed Johnson, are absolutely interesting papers. They were some of the pioneers of our organization who helped paved the way, and they provide us keen insights into our past history. They are articles you won't put down.

The remainder of the articles in this issue appropriately likewise celebrate an anniversary of a laboratory that is tied very closely to the growth of our Institute. These articles reflect the impressive history of Los Alamos National Laboratory's forty years in safeguards. In July 2007, Los Alamos National Laboratory hosted a two-day symposium celebrating this fortieth anniversary of their involvement in safeguards.

These papers include a summary of the symposium by Jim Tape and Doug Reilly; a testimonial by LANL Director Michael Anastasio, and a delightful "pictures-down-memory-lane paper" by one of LANL's fellows, Howard Menlove, and co-authors Reilly and H. S. Lee. An excellent paper by Michael Miller and his co-authors highlighting the challenges and opportunities of the Global Nuclear Energy Partnership (to me an important program that I wish would get a big boost by the U.S. Congress), is followed by a paper by Brian Boyer and Sara Scott discussing the topics and issues of the expansion of nuclear energy.

At the LANL symposium, there were three topical area sessions identifying challenges that need to be addressed and included in this issue are three summary papers: Strengthening Safeguards (G. Sheppard and M. Goodman), Science and Technology R&D Opportunities (E. McKigney and W. Priedhorsky), and Improving Education and Training for Nuclear Safeguards (J. Doyle, N. Sauer, and P. Karpius). These are articles in which the authors seem to have captured the issues.

In the next paper, R. Schenkle and S. Abousahli provide an excellent paper on future of nuclear safeguards, and this issue concludes with a paper entitled "Schematic History of Safeguards Policy, by a distinguished and respectable gentleman, Lawrence Scheinman.

If you have question or suggestions, feel free to contact me.

ANSI N-15 News

INMM's ANSI N-15 Committee, sponsored by the Institute to develop standards for the control of nuclear materials, has completed the development of N15.51, *"American National Standard for Methods of Nuclear Material Control—Measurement Control Program—Nuclear Materials Analytical Chemistry Laboratory"* which is now available through the ANSI standards store (http://webstore.ansi.org/).

Historical Perspective of the Institute of Nuclear Materials Management

By Vince DeVito
INMM Secretary, 1973–present

On May 17, 1958, a few materials control and accountability (MC&A) professionals gathered in Pittsburgh to discuss the formation of a professional organization to advance the aspects of nuclear materials management. After general agreement on the purpose of the organization, they decided to name it the Institute of Nuclear Materials Management (INMM).

They left the meeting agreeing to talk to other colleagues about the institute, and joining them in this new venture.

In a subsequent meeting in October 1958, a formation meeting was held and Dr. Ralph Lumb was elected chair, Richard S. Frankel, vice chair, Shelly Kops, treasurer, and William Thomas, secretary of the INMM. It was recognized that to start achieving the objectives they set for INMM, the most urgent concern was increasing membership and having a general membership meeting. By the end of 1958, there were fifty-five members. Since employees of the U.S. Atomic Energy Commission (AEC) were a key part of this early membership, and to assure a larger audience, it was decided to hold the general membership meeting in conjunction with the annual AEC/Contractors, Source, and Special Materials Management meeting in Washington, DC, in May 1959. It was this group of nuclear material management experts that could provide the basis for increasing membership and promoting the ideals of the INMM. After the meeting, it was decided that subsequent annual meetings would be held and sponsored by INMM so as to provide an independent viewpoint of nuclear materials management. Therefore, the INMM held its first Annual Meeting the following year on June 21-22, 1960, in Columbus, Ohio, USA. Membership continued to grow, mainly by word of mouth, and by the time of the meeting the membership had reached 135.

To establish an operating foundation, the INMM ratified its first constitution and bylaws in 1959, established several standing committees, and began a newsletter that continued until 1972 when the *Journal of Nuclear Materials Management* came into existence.

The purpose of the *Journal* was to increase the dissemination of nuclear materials management knowledge by presenting technical articles in a professional publication. The INMM continues to publish the technical journal four times annually. The year 1960 brought about additional committees, including the appointment of a standards committee that in 1967 led to sponsoring N-15, Methods of Nuclear Material Control for the USA Standards Institute. This met INMM's objective of establishing standards consistent with existing professional norms. The standards group was later renamed the American National Standards Institute (ANSI). In April 1981, INMM assumed the sponsorship of ANSI N-14, Packaging and Transportation of Radioactive and Non-nuclear Hazardous Materials from the American Insurance Association.

In 1961, the Executive Committee reflected on many ideas; the establishment of a certification program for professional recognition, membership levels (Senior, Fellow, Corporate and Life), awards, and a paid secretary. Not all ideas were immediately adopted. A certification program to meet the INMM's objective of establishing professional standards for those working in the nuclear materials management field was adopted in 1962. The program consisted of a peer review of the nominee's application, continued through 1968 when testing and a fee were added to the requirements. After serious consideration in 1972, the Executive Committee decided to discontinue the program largely on legal advice regarding possible liability if one took the test and failed to be certified but continued working in the industry. Professional recognition was again introduced in 1979 when it was thought that certification might become a requirement in the nuclear materials management field. A committee of subject matter experts was appointed to establish a meaningful certification program. They developed a test bank of more than 500 questions and established two levels of certification with a cost schedule. In 1981-1982 five safeguards interns and nine safeguards specialists were certified. However, the requirement for certification was never established and so certification was once more discontinued. Senior membership was introduced as a means to identify a level of professional recognition when membership grades were established in 1983. However, in 1994, requirements for senior members were redefined to denote professional recognition consistent with contributions to INMM. While a few awards were presented in early years, the current Awards Program did not come into existence until 1978 and the INMM Distinguished Service Award was established to recognize long noteworthy service to the nuclear material management profession.

Corporate membership was established in 1962. In 1983, the requirements were changed and it was renamed Sustaining Membership. The idea of a lifetime membership was reconsidered in 1983, and is now known as an Honorary Membership. Other membership grades were not fully established until 1983 when Senior, Student, Fellow, and Emeritus were added to the membership levels.

During the 1960s, changes were made to the constitution and bylaws often to fulfill the requirements of a growing organization. Noteworthy additions included language pertinent to the incorporation of INMM in Ohio in 1967, and a provision for chapters. Although this provision for chapters was also included in the constitution and bylaws in that early period, it was not until 1975 when the first chapter was chartered in Japan. Since then, six regional and three student chapters have been chartered in the United States, and six more chapters have been chartered overseas. The active chapters are:

Regional	Student	International
Central	Texas A&M	Japan
Northeast	Mercyhurst College	Korea
Pacific	University of Missouri	Obninsk
Southwest		Russian
Southeast		Ukraine
California		Urals
		Vienna

There has also been some interest in forming chapters in Great Britain and China. Chapters have been another means of successfully accomplishing the objectives of increasing membership and disseminating nuclear materials management information by having several meetings and seminars each year.

In the 1970s, membership in INMM became more diverse, with members being from disciplines other than MC&A. Recognizing that the dissemination of knowledge in these other disciplines further met INMM's objectives, the first Technical Working Group was established in the physical protection area in 1979. These groups were established to more fully address specific nuclear materials management areas and so as more groups developed and requirements became more formalized, the Technical Working Groups were renamed Technical Divisions and added to the bylaws. There are currently six Technical Divisions that enhance the purpose of the INMM and provide, in their discipline, seminars, meetings, and assistance for the annual meeting technical program. These now include:

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

For its first twenty-three years, the INMM was a volunteer organization. There were insufficient funds to obtain association management services in the early years, and volunteerism was sufficient to maintain the momentum. However, by 1980 the INMM had reached an activity level with a membership of 685, and volunteers could no longer accomplish the central administrative functions. It was felt that to maintain the momentum, it would be necessary to obtain the services of a paid association manager. Therefore, in 1981 after the review of several association management firms, the INMM entered into contract with Messervey and Company, headquartered in Chicago. The firm was later sold to The Sherwood Group, Inc. who continues as INMM's association management team.

The success of the Institute in meeting its charter goals has been due to the considerable sacrifices and hard work (volunteerism) on the part of all its the members and, since 1981, in coordination with The Sherwood Group. Since that first annual meeting in 1960, an annual meeting—along with many other meetings and seminars—have been held each year promoting nuclear materials management activities of all the disciplines. Additionally, the INMM in recent years has sponsored the Packaging and Transportation of Radioactive Materials (PATRAM) meetings for the U.S. Department of Energy (DOE). Although an annual general business meeting is required, the annual meeting itself is technical in nature. From a handful of technical papers presented in 1960, technical presentations at meetings now exceed 300. Annual topical meetings, as well as regional meetings and seminars are expected to continually show an increase in attendance and number of technical papers presented. Membership is approaching 1,100 and it is expected to continue its growth. Student membership is growing—with three student chapters having been formed—and there is potential for additional chapters.

As the interest in nuclear power is renewed, the principles of nuclear materials management must remain in the forefront to assure that adequate safeguards are in place not only for new nuclear activities but for other global safeguards concerns as well. Two of the purposes of the INMM are the advancement of nuclear materials management and the increase and dissemination of this body of information. In recognition of growing concerns about possible nuclear terrorism, Nuclear Threat Initiative (NTI) President Charles Curtis, at the 2005 Annual Meeting opening plenary address, called for a new commitment and initiative to institutionalize the collection and promulgation of best practices in nuclear security. A group of INMM Fellows responded with a conceptual plan to formalize a process for this purpose, and it included the organization of a new entity named the World Institute of Nuclear Security, WINS. As the plan began to evolve, the INMM Executive Committee decided to work with a WINS Coordinating Committee that included representatives from NTI, INMM, and the U.S. Department of Energy (DOE). This committee has interfaced with the International Atomic Energy Agency (IAEA) and reached out to the broader international nuclear security community to evaluate needs, enlist support, and further develop a plan for the establishment of WINS. While WINS is yet to be formally announced and established, the principal players are encouraged and positive about its future.

Materials Accountancy: The Formative Years

James E. Lovett
INMM President, 1971–1972

In 1946, in the aftermath of World War II, the U.S. Congress quickly crafted the Atomic Energy Act of 1946. The Act charged the Atomic Energy Commission (AEC), successor to the Corps of Engineers Manhattan Project, with the production of nuclear weapons and the nuclear materials needed for them in the quantities authorized annually by the president of the United States. (As a practical matter, the AEC prepared estimates of production capabilities, and the president authorized production at that level.) Pursuant to that Act, all nuclear materials, feed or product, were owned by the U.S. government, with production actually occurring in government-owned, contractor-operated (GOCO) facilities.

In 1949 the certified public accounting firm of Lybrand, Ross Brothers, and Montgomery recommended that contractors should be required to submit monthly material balances, showing on the one hand beginning inventory, material produced and received from other facilities, called *material to be accounted for,* and on the other hand ending inventory, shipments to other facilities, and nuclear and other recognized losses, called *material unaccounted for (MUF).* Lybrand recommended the AEC compare these two numbers and question large differences between them.

Thus was born the *science* of nuclear materials accountability, management, control, or safeguards, as it has variously been referred to over the years. As a sideline comment, Lybrand did not coin the acronym MUF, for the term *material unaccounted for (commonly pronounced "muff")* the AEC did that on its own. It is not in common usage in the United States today.

It is important to recognize that the question posed to Lybrand concerned how the AEC could be sure that GOCO facilities were maintaining proper stewardship over the nuclear materials entrusted to them. The question was posed by the Source and Fissionable Materials Accountability Branch, a part of the AEC Division of Production. Neither the branch nor the division had any formal responsibility for protecting against theft or terrorism. Physical and personnel security systems existed but were separately administered. Terrorism was not in the mainstream vocabulary. The question, as posed to Lybrand, was stewardship over materials that were in short supply, that had high production costs, and that were of inestimable value in terms of U.S. military policies.

Given that the question was posed by a group that mainly had an accounting responsibility and that Lybrand was at heart a CPA firm, Lybrand's answer was to be expected. However there were, and still are, several major problems. The first difficulty at the time, for many years thereafter, and to some extent even today, was that the material balance required accurate measurements, not only for feed and product material quantities, for which reasonably accurate measurement methods generally were available, but also for inventory quantities, specifically scrap and waste materials. Nondestructive assay measurements were still a couple of decades away, and "weigh, sample, analyze" measurements of non-homogeneous scrap materials were close to useless (although those working in the field at the time often did not recognize how useless they really were.)

In principle, non-homogeneous scrap materials could be homogenized before being sampled, or multiple samples could be taken, but in the broad picture the object was production, not materials accountancy. Contractors asked how much effort (money) should be devoted to material control. In response, they were instructed to control nuclear materials "appropriate to the strategic and monetary value" of the materials, an answer that was irrefutable in principle but also unquantifiable in practice. The monetary value of enriched uranium or plutonium could be estimated in terms of unit production costs. The concepts of "strategic value" and "appropriate control" were not so easily defined.

For example, if you have uranium or plutonium worth $10,000,000 in monetary value and $10,000,000 in strategic value, how much money should you spend on material control? No practical answer was ever offered. One possible answer buried in the literature bore the acronym FORCE (Formula for Optimizing the Ratio of Cost and Effectiveness). From a theoretical standpoint this idea recognized that the motivating factor should not be the magnitude of MUF, but the uncertainty surrounding it. The actual calculation, however, was not straightforward, and interpretation of the result was even more obscure. The present author may well be the only person in the field who still remembers it.

A second problem faced by early GOCO contractors was that AEC inspectors, often with an accounting background rather than an engineering one, had trouble accepting inventory differences that process engineers, used to working with less valuable materials, thought were perfectly reasonable. How big a difference should the AEC accept as reasonable? Engineers argued one way, AEC auditors argued another. It was agreed that some form of objective statistical evaluation should be used, and in the mid-1950s a panel of statisticians recommended error propagation, the statistical tool that is still universally mandated today.

It is difficult to suggest an alternative to material balance accounting. At the time, a review of other industries handling valuable materials showed that none really attempted to measure physical inventories on any routine basis, but history is full of instances where reliance on book inventory values had serious consequences. The AEC definitely needed to measure and record nuclear production, nuclear loss, and transfers between facilities; the AEC also definitely needed to require periodic measurements of actual physical inventories. More recently a variety of control measures have been folded into nuclear material accountancy, but the material balance remains as the foundation of current material control systems.

It is also difficult to propose an alternative to error propagation. Several alternatives were proposed at the time, but none gained any notable following. More recently, near real-time accountancy is an alternative that has been explored in considerable depth. To whatever extent alternatives have appealing features; however, they all have had two major problems. One is that they are largely facility-specific. Near real-time accountancy was studied in the context of reprocessing; whether it could be adapted to other types of facilities was never studied and is not intuitively obvious. The other is that they assume stable periods of activity; such that one period can be compared to earlier periods. This might have worked for process facilities, but it never had a chance at research facilities.

Error propagation, however, introduced a problem of its own. The calculation required that all sources of measurement uncertainty be identified and quantified. As the theory evolved, three classes of measurement error were identified, long-term systematic error, short-term systematic error, and random error. A classic measurement for enriched uranium involved measuring the bulk weight or volume, the chemical analysis, and the isotopic analysis. Both the chemical and isotopic measurements, moreover, were based on the analysis of samples, so there were two sources of sampling error. All told, each measurement had associated with it some fifteen component measurement uncertainties.

The result, as readers who operate material control systems know, is that programs to determine and control measurement uncertainties may well require as much as half of the total measurement budget. Necessary? Yes, in terms of the accepted requirement that facilities prepare material balances and use error propagation to estimate the uncertainty in those material balances. Intuitively, maybe not quite so clear. The money, or at least some significant part of it, might better be spent on improving measurement quality rather than just documenting it.

And finally, at least in this author's opinion, error propagation became the unwitting justification for sloppy material balance accounting. If the observed MUF/inventory difference (ID) was within the calculated material balance uncertainty, the facility operator was home free. Investigate? What was there to investigate? It had been decided mathematically that the observed MUF/ID, no matter how suspicious it may look in a subjective sense, was the result of nothing more than a chance combination of random and systematic measurement errors. Investigation would be a waste of time. If the observed difference is, say, 40∀ 100, fine. If the observed difference is 95∀ 100, it is probable that the 95 includes both measurement error and an undocumented loss. But statistically the threshold was not reached, and most facilities closed the books on that material balance period and moved on. More recently, the U.S. Nuclear Regulatory Commission regulations specify an upper limit for the combined material balance uncertainty, but in its formative years facility operators were told, at least implicitly, not to worry about the MUF/ID so long as it was within its estimated uncertainty.

The corollary problem was the unfortunate philosophy that, if the MUF/ID was not explained by its calculated uncertainty, it must be because the measurement error structure is not properly documented. Don't look for possible unrecognized losses; look for unrecognized sources of measurement error. Historically, this more than likely was the case. The question, however, is why bother to run a complex statistical test if the results will not be useful, or even believed.

In 1955, Congress completely rewrote the Atomic Energy Act. The GOCO facilities remained, and in terms of high strategic value enriched uranium and plutonium remained the dominant users, but several new categories of users emerged. In terms of the formative years of materials accounting, the important category was the AEC fixed-price contractor. These were the companies that constructed a wide variety of experimental reactor facilities, that fabricated fuel for those reactors, and that fabricated fuel for the growing fleet of naval nuclear facilities. In the early years, fixed-price contractors typically operated privately owned facilities, were responsible to accumulate scrap and waste materials but not to recover them, and were financially responsible for discards or losses above some specified value, often two percent.

The question now was not stewardship; it was financial accountability for losses. Fixed-price contractors were required to prepare material balances, albeit now at semi-annual or annual intervals. Error propagation was not required and was rarely practiced; indeed most fixed-price contractors had no documented understanding of uncertainties inherent in fundamental transfer measurements. The question was one of forcing these contractors either to limit actual losses to the allowed value or to reimburse the AEC for the monetary value of excess losses. Since scrap was not recovered until later, and then was processed by someone else, and since several significant measurement problems still remained, responsibility for losses was difficult to assign. Actual losses sometimes did appear to exceed two percent, or whatever the allowance was, but very few contractors were ever required to pay for excess losses.

In 1966, disturbed by increasing reports of high losses at fixed-price contractors and large MUF/ID swings at some GOCO facilities, the AEC sponsored an invitation-only meeting to discuss fundamental problems with material balance accounting. One result was AEC sponsorship of major programs to develop non-destructive measurement methods. It took time, but today it would be difficult to define a scrap or waste nuclear material that cannot be measured non-destructively, to an adequate degree of accuracy. The material balance today is in much better shape than it was in its formative years.

Material balance accounting and error propagation had its successes and its failures.

- Early on, a uranium mine operator was caught leaving the AEC uranium mill with some of the ore still in his truck. AEC inspectors had inventoried the ore stockpile and concluded that the physical inventory did not measure up to the book inventory, but did not trust their data and had not reported the shortage.
- A Los Alamos National Laboratory (LANL) surface burial site was dug up to recover a small quantity of plutonium inadvertently included in the burial, a loss that material accounting did detect. In the early 1960s, when the Chinese exploded a nuclear test using enriched uranium they were not known to have, nuclear materials accounting was able to state with 100 percent confidence that the uranium was not of U.S. origin.
- There were several instances where unexplainable inventory shortages motivated process engineers to find nuclear material in locations where it was not supposed to be.
- In the late 1960s there was, at least in some minds, a strong suspicion that the Nuclear Materials and Equipment Corporation (NUMEC) had clandestinely shipped enriched uranium to Israel. It was later established positively that this was not true, but poor material control practices at NUMEC at the time made it impossible to make this determination from the accounting records.
- The same NUMEC, getting its material control act together, processed some 2,600 kilograms of plutonium metal into ZPPR fuel plates, delivering 2,300 kilograms as finished product and returning most of the remainder as recovered plutonium nitrate solution. The final contract MUF was eight kilograms plutonium, and LANL, which undertook recovery of some low-level wastes, later reported that some of the eight kilograms plutonium were in the returned waste, which had been understated by NUMEC.

The history of material balance accounting spans close to six decades. In its formative years it was seen as being of primary importance. Unfortunately, for both theoretical and practical reasons, it was then not able to live up to its expectations. Today it could answer the question originally posed, stewardship, but the world has moved on. The question now is primarily one of theft prevention, or as a minimum detection within a time span short enough to permit recovery. Emphasis now is on a palette of physical and personnel security measures, and material balance accounting is assigned a relatively minor role. Nevertheless, the nuclear industry still needs material balance accounting, if for no other reason than to provide assurance that the various security systems are working.

The INMM's First Twenty-Five Years

John L. Jaech
INMM President, 1983–1984

Having jettisoned my INMM journals and proceedings while making eight moves in the twenty-five years since my 1982-1983 term as INMM president, I necessarily relied primarily on my long-term memory in preparing these remarks. My perspective is restricted to the first half of the organization's fifty year history—the era in which I was most active as a contributing member.

The INMM as an organization was preceded by an AEC sponsored annual conference on the accountability of nuclear materials. The attendees were accountability specialists from government facilities, which were managed by private companies as contractors, and their government counterparts. I worked for General Electric (GE) at Hanford at the time and attended the conferences of 1955 and 1957, giving presentations of a statistical nature at each. Oddly, what I recall most clearly about the 1955 meeting is that one of the Hanford AEC attendees managed to stay in a downtown Washington hotel for $6 a night.

Until the late 1960s, my involvement in what we today call nuclear materials safeguards was rather limited in my work as a statistician at Hanford and later at the GE Vallecitos Atomic Laboratory. With the passage of time, and especially after joining Jersey Nuclear (later to become Exxon Nuclear) in 1970, my involvement in nuclear materials accountability became much more than incidental as did my participation in INMM activities.

Early on, the INMM was a rather informal organization. A highlight of a typical annual business meeting was the selection of the host city for the following year's annual meeting, an activity somewhat resembling today's political caucus in the emotions it generated among attendees. In the early 1970s annual meetings and other INMM activities had grown to the point where the need for professional management was recognized. Further, the *Journal of Nuclear Materials Management* was evolving from a newsletter to a technical publication while continuing to report on INMM activities.

The *Journal* editor at the time, whose name escapes me, would often contact me two or three weeks before each deadline and request that I submit a paper. I suspected that potential contributors were saving possible submissions for the Annual Meeting so their management would permit them to attend. I could usually prepare an article on some relevant subject because my work assignments were often in this area. The first paper, published in 1972, was titled "A New Approach to Calculating LE-MUF." Between 1972 and 1984 I contributed twenty articles. Presumably, receiving a sufficient number of contributions to the *Journal* is no longer a problem today.

As an organization, the INMM continued to grow and develop in enhancing nuclear materials management. In the beginning, the focus was on domestic safeguards and methods of control that included accountancy, weighing and destructive chemical measurements and statistics. By the mid 1980s it had expanded to embrace international safeguards, non-destructive analysis (NDA), physical security, and waste management. It had also developed and implemented a Certified Safeguards Specialist program, contributed many ANSI standards, and sponsored training courses.

I was privileged to serve as INMM chair in 1982 and in the silver anniversary year, 1983. The meeting venues were Vail, Colorado, and Columbus, Ohio, respectively. In contrast to the usual hot, muggy summer venues (chosen to minimize costs), the pleasant weather and mountain location made the meeting at Vail especially noteworthy.

After my final remarks as chair, I handed over the gavel to my successor, Yvonne Ferris, noting that for the first time in its twenty-five year history the gavel was being transferred from one statistician to another. Finally, the important role played by statisticians was being fully acknowledged by the membership.

The INMM was recognized as the leading organization in enhancing nuclear materials safeguards when it was asked in 1983 to form a team of experts to tour Chinese nuclear facilities on a People-to-People mission. Sites in and near Beijing, Chengdu, and Shanghai were visited. The team was led by E.R. Johnson and was mostly comprised of INMM members. Lectures were given on various aspects of nuclear materials control and follow-up discussions were conducted. A panel discussion on the Chinese Mission was included as part of the 1984 INMM Annual Meeting.

The last annual meeting I attended was in Albuquerque in 1988. I did, however, keep informed of INMM activities through the *Journal* and by participating in meetings of the Vienna Chapter until my retirement in the mid-1990s. Although I was active in other professional societies during my career, I regard my involvement in the INMM as the most rewarding.

Reflections on the Past and Future of INMM

Ed Johnson
INMM Chair, 1965-1966

I attended the first INMM Annual Meeting in 1960 where I was one of the nine speakers on the entire program. My interest in INMM stemmed from the fact that I worked for Nuclear Fuel Services Inc. (NFS), a company that produced specialty nuclear materials, including uranium compounds, metal, and alloys at all levels of enrichment. NFS also processed uranium scrap, particularly 93 percent enriched material. In those days all uranium was owned by the U.S. government. You could *lease* it from the government but you had to pay a use charge amounting to about 4 percent of the value of the material/year, plus pay for what was lost or consumed. Thus, in our work our customers had to pay for any losses that we sustained when processing government-furnished uranium into the form desired by the customer. As part of the competitive process prevailing at the time, we had to quote both a fixed price and a guaranteed maximum loss associated with our processing. If we lost more than quoted, we had to pay. Moreover, the customer generally added the value of the guaranteed maximum loss to the processing price in evaluating bids—and competition was fierce (three to four companies provided similar services to those of NFS). The loss situation was even more complicated when we processed scrap for uranium recovery because the scrap uranium content was heterogeneous.

The customers were generally commercial fabricators of fuel for research, test, and naval reactors who worked on the assumption that the difference between the amount of highly enriched uranium contained in the feed material to the fabrication process, and the product of fabrication, was contained in the scrap. This "by difference" determination of the scrap's uranium content meant that the fabricator didn't experience any losses except for what it measured in waste material that might be produced. However, when the scrap processors commenced processing the scrap, they seldom found that the scrap uranium content was as high as that represented by the fabricator. Thus, the scrap processors would only accept a uranium content for the scrap based on measurements they made at the first dissolution stage of the recovery process. At one point Admiral Hyman G. Rickover ordered a cessation in the commercial processing of uranium scrap from the fabrication of navy fuel because the processor's values were less than the "by difference" values of the fabricators. He eventually succumbed to the pressure, and resumed commercial scrap processing and acceptance of the processors' measurements at first dissolution. Thereafter, the customer's inspectors were frequently present to witness the first dissolution measurements because these were the key as to whether or not we met our loss guarantee.

The measurements made had a profound impact on the profit/loss and competitiveness of both fabricators and scrap processors. Consider the facts that highly enriched uranium was valued at about $17,000/kilogram and that the cost of its recovery from scrap would range from $100-$500/kilogram. A one percent loss in excess of a competitive guaranteed maximum loss could mean a financial loss of $170/kilogram—a large percentage of the cost of the scrap processing. While the processing of low-enriched uranium did not involve as highly valuable material as highly enriched uranium, the volumes were much larger and the cost impact of losses were still material.

Therefore, measurement techniques, measurement errors, laboratory differences, accounting methods and reporting, and associated experiences were of profound interest to small private industry in those days. I found that the INMM meetings had papers and panel discussions that were of direct practical application to our business. When my company's president suggested that INMM meetings were only for "accountability people," I told him that the meeting offered information, ideas, and experience for improving our company's accountability systems, and thus, reduce our financial risk—and that it was vital that we have a presence at all of the meetings and be active in the organization. He never interfered, and subsequently became a convert himself.

Until about 1967, the United States had relied on the value of the uranium and plutonium to inspire its safekeeping from theft or diversion, as described previously. Before that, even natural uranium feed material was kept under close accountancy because the United States had few developed resources of uranium and had to obtain its supply through imports—which were both expensive and came with significant restrictions. Thus, the strategic value of the natural uranium that we used in the 1950s, and the concern that foreign supplies could be interrupted at any time, motivated the control and protection of these materials. However, with 1967 came an increased awareness of the need for more effective measures to protect nuclear materials from theft or diversion to unauthorized uses in the United States and worldwide, including the need for improved physical protection and control and accounting of nuclear materials.

The INMM experienced rapid growth in the years following because of the need for better and more timely measurement systems, statistical techniques that allowed the quantification of the significance of inventory differences, and improvements in physical protection methods. Moreover, INMM became involved in international safeguards. This was manifested by INMM establishing its first chapter in Japan in 1976 and Vienna, Austria, in 1978. Since then, the chapters have grown to include four in the former Soviet Union, one in Korea, six U.S. regional chapters, and three student chapters.

In the late 1970s and early 1980s, technical working groups were organized to deal with the principal areas of interest of the Institute and these eventually evolved into the six Technical Divisions that we now have that cover the diverse subject interest that logically fall under the common description "nuclear materials management" (Material Control & Accountability, Physical Protection, International Safeguards, Nonproliferation and Arms Control, Packaging and Transportation, and Waste Management).

A particular highlight of my activities in INMM was when it fell to me to lead a People-to-People Delegation to China for INMM, in September 21-October 12, 1983. The delegation consisted of fourteen technical lecturers and nine spouses who documented the social and cultural activities of the delegation. The then-present INMM chair and two past chairs were among the lecturers. About half of the lectures dealt with physical protection, material control and accountability, measurements, etc. The other half dealt with spent fuel and high-level radioactive waste management and fuel cycle processes. Our hosts in China were the Chinese Association for Science and Technology (CAST), and the Chinese Nuclear Society (CNS). Lectures were given in Beijing (seven), Chengdu, Emei Shan, Leshan, and Shanghai (two), and each were attended by 100-500 Chinese participants. Most lectures were attended by the spouses of the delegation members. On several occasions the delegation was divided into two concurrent sessions—one on physical protection and safeguards, and the other on waste management and fuel cycle related discussions. We were able to establish a relationship with the Chinese audiences in which there was a free and open exchange of information on the subjects discussed and where we were able to convey details of practices followed in the United States for nuclear materials management, and where their thirst for such information was satisfied to a high degree. We also toured nuclear facilities (including a small nuclear power reactor, hot cells, and research facilities), other factories and utility installations, and many points of interest along the way.

It is interesting to note that in the 1970s, the United States of America Standards Institute asked INMM to be the secretariat for a committee on standards for nuclear material control, accounting, and protection. This work involved getting input from a large cross-section of processors of nuclear materials and forging it into a consensus standard that all would recognize. The process for this includes the resolution of all reasonable conflicts and objections, so that the product of the standards effort is one that is universally accepted. This work continues today as the American National Standards Institute (ANSI) Committee N15, with the Institute having the lead in the standards development effort. ANSI recognized the success INMM had with N15 and, as a result, later asked INMM to take the lead on Committee N14 on standards for packaging and transportation of radioactive materials.

From the very beginning the role of INMM has been to serve as a forum for the display and exchange of technical and programmatic information in the areas of nuclear materials management. This we have been doing for fifty years. So it was initially somewhat puzzling when the suggestion was made recently that the Institute might take the lead in initiating the development of best practices with respect to physical protection and material control and accountability. In one respect it was like some were oblivious to the past efforts and successes of the Institute. However, the suggestion implied that a more formalized structure was needed to develop, reach agreement, and voluntarily implement these best practices on an international basis. Accordingly, INMM developed the concept of the World Institute for Nuclear Security (WINS) along with a preliminary business plan therefore, which is now in the preliminary stages of implementation. WINS is being facilitated by the Nuclear Threat Initiative (NTI) and the precise organizational structure is yet to be decided. INMM's ultimate role in WINS has also yet to be decided, but it is clearly in a position to make major contributions to the realization and implementation of best practices on a worldwide basis. This should be a major area for the Institute's future activity.

Another area of future activity for the Institute is in educating decision-makers in the subject areas of expertise of the Institute's technical divisions. This includes the development of policy papers, information pieces, tutorials of a technical and programmatic nature, and the like. The Institute is a professional organization and while it may not be appropriate for it to act in the role of an advocate for nuclear power, it certainly has a professional obligation to correct any misconceptions on nuclear matters that may arise and/or prevail. This should be our goal in future years along with contributing to the success of WINS, and continuation of the works in which we have been involved successfully for the past fifty years.

Executive Summary and Highlights: Los Alamos National Laboratory 40th Anniversary Safeguards Symposium

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Executive Summary and Introduction

The nuclear materials safeguards research and development (R&D) program at Los Alamos National Laboratory (LANL) began in December 1966 under the leadership of G. Robert (Bob) Keepin. Over the intervening forty years, the program grew from a single group with a handful of staff to four groups with more than 200 members and has been recognized as one of the premier safeguards research and development programs in the world.

In July 2007, the laboratory hosted a two-day symposium on the status of international safeguards. The symposium was sponsored by New Mexico Institute for Advanced Studies, and LANL's Nuclear Nonproliferation Program and Division. Approximately 140 participants gathered to celebrate the past accomplishments of the safeguards program, discuss current safeguards challenges, and look to the future of nuclear materials safeguards.

The director of Los Alamos National Laboratory, Dr. Michael Anastasio, opened the symposium. He was followed by Dr. Siegfried Hecker, LANL director emeritus. Other speakers included Ollie Heinonen and Jacques Baute from the International Atomic Energy Agency, Dr. Roland Schenkel, director-general of the Joint Research Centre of EURATOM, and representatives from the Australian Safeguards and Nonproliferation Office, Brookhaven, Pacific Northwest, and Sandia National Laboratories, and various offices of the U.S. Departments of Energy, State, and Defense.

The most difficult challenge for those determined to acquire nuclear weapons is the acquisition of suitable nuclear materials. The term "nuclear materials safeguards" is used here to include all of the technologies, procedures, methods, and policies that, taken together, help to reduce the risk that uncontrolled nuclear materials will contribute to the proliferation of nuclear weapons by nations or by subnational groups (terrorists).

The Los Alamos safeguards program has made seminal contributions to the responsible management and protection of nuclear materials in the U.S. Department of Energy (DOE) nuclear weapons complex, to international safeguards, and to securing nuclear materials in Russia and other states of the former Soviet Union at the end of the Cold War. A key theme of the symposium, sometimes discussed explicitly, but always implicit, is that the safeguards systems must adapt to deal with an ever-evolving nuclear threat.

This executive summary, symposium highlights, and the following eight papers in this issue of the *Journal of Nuclear Materials Management* present a condensed overview of the presentations and discussions during the symposium. The papers that follow touch on safeguards history, challenges of expansion of nuclear energy, and possible responses through strengthening safeguards, science and technology, and education and training. These selection of papers start with the opening remarks by the Director of Los Alamos National Laboratory and close with the paper from Roland Schenkel, the final speaker of symposium from European Commission Joint Research Centre. Jim Sprinkle and Doug Reilly served as LANL technical editors for these papers.

Symposium Highlights

Celebrating 40 Years of Nuclear Safeguards

The keynote speakers observed that efforts to safeguard nuclear materials take place in a larger context of the nuclear nonproliferation regime that started after WWII. Initial policies of secrecy regarding everything nuclear made a fundamental policy shift with the Atoms for Peace concepts and the founding of the International Atomic Energy Agency (IAEA) in 1957. The negotiation and entry into force of the Treaty on the Nonproliferation of Nuclear Weapons (NPT-1970) provided a critical foundation for safeguards.

Keeping nuclear materials secure is more difficult than many appreciate because there is a lot of material, distributed in many locations, in many different chemical and physical forms, and it is difficult to handle and count. A top-five list of proliferation concerns included Pakistan, research reactor inventories of highly enriched uranium, the Democratic People's Republic of Korea (DPRK), insecure materials in Russia, remaining materials in Kazakhstan, and Iran.

The foundation of the LANL Safeguards Research and Development (R&D) program is the development and transfer to the field of nondestructive assay (NDA) methods for the detection and quantitative measurement of nuclear materials of proliferation concern.

Challenges to Safeguards I: Global Issues

This session covered the discussion of challenges to safeguards, focusing on the states that have been found in noncompliance with their safeguards agreements, the prospects for and impacts on safeguards and the nonproliferation regime resulting from the U.S./India nuclear cooperation agreement, the consideration of the changes brought on by the globalization of nuclear industry, and issues associated with progress on nuclear arms reductions, NPT Article VI, and the importance of a Comprehensive Test Ban Treaty (CTBT).

The U.S./India agreement presents challenges that differ from those of the noncompliant states, and at the time of the symposium had not been completed. Questions included why there was not more constraint placed on the Indian nuclear weapons program, and why the Indian nuclear weapons establishment appeared to be against the agreement. It is clear that implementation of IAEA safeguards in India will impact IAEA safeguards resources.

Challenges to Safeguards II: Expansion of Nuclear Energy

The anticipated expansion of nuclear energy provides challenges and opportunities for both domestic and international safeguards. The challenges stem from increases in the numbers of plants under safeguards and the expansion of nuclear facilities into countries with little experience and established infrastructure to support nuclear activities, including domestic safeguards systems.

There are currently 435 operating power reactors, twenty-eight under construction and 222 planned worldwide. New nuclear facilities and processes will present challenges to safeguards technologies and approaches. Some of those highlighted in the discussion include material properties, facility configurations, large nuclear materials throughputs, new processes such as pyroprocessing, potential new diversion pathways, and increases in nuclear materials inventories and transportation requirements. These new safeguards challenges, in turn, drive new safeguards R&D needs such as advanced measurement techniques; approaches to safeguards by design; process monitoring; data integration, protection, and analysis; systems effectiveness evaluation; and modeling and simulation tools.

Responding to Challenges I: Strengthening Safeguards

The revelations of Iraq's clandestine weapons program after the first Gulf War and the noncompliance of the DPRK provided a wake-up call to the international safeguards system. Efforts to strengthen safeguards resulted in the implementation of important new tools, such as environmental sampling and the use of information from open sources, and motivated the negotiation of the Model Additional Protocol in 1997 that provides the IAEA with expanded access to information and locations.

A key element of the information-driven safeguards system is information from other parties, that is, national systems. It was noted that although this is a sensitive and difficult subject, there are concrete nonproliferation benefits from careful sharing of third-party information with the IAEA. The IAEA will never command the remote sensing capabilities of some of its member states; however, the agency inspectors have "boots on the ground" and "eyes under the roof" that can be informed by and complement the assets of national systems.

The state-level approach (SLA) was developed by the Standing Advisory Group on Safeguards Implementation in consultation with the secretariat to address ongoing concerns about the allocation of safeguards resources and the effectiveness of safeguards in less-cooperative states. The SLA builds on a careful and structured analysis of all aspects of a state's nuclear activities and the nuclear weapons materials and technologies acquisition paths available to it that are embodied in the State Evaluation Report, and envisions safeguards customized for each State.

Responding to Challenges II: Science and Technology Opportunities

As has already been discussed, science and technology conducted under safeguards and security R&D programs have made significant contributions to both domestic and international safeguards. The need for technologies to enable safeguards and security policy and approaches is the reason laboratories from around the world, including Los Alamos, have been engaged in safeguards R&D for forty years.

Safeguarding large, high-throughput facilities processing direct-use materials, and detection of undeclared nuclear materials or activities provide a focus for international safeguards needs. Methods to reduce measurement errors, to deal with massive amounts of complex sensor data, and to advance training to produce knowledgeable inspectors and more smart machine power were identified as key R&D needs. Approaches such as those developed for the Rokkasho reprocessing plant in Japan provide a basis for further development.

Safeguards R&D in Europe takes place in the Joint Research Centre, the R&D organization of the European Commission. The twenty-seven member states provide staff and approve the R&D program and budget. A key focus is the measurement of nuclear materials in concentrations over more than ten orders of magnitude for traditional safeguards on declared nuclear materials, environmental sample analysis for the detection of undeclared activities, and support of nuclear security and forensics. Example areas of investigation presented are neutron detection and three-dimensional gamma reconstruction, the development of on-site laboratories at reprocessing facilities, NDA measurements for pyrochemistry, particle analysis for environmental sampling, and nuclear forensics.

The session on science and technologies opportunities concluded with a presentation of the findings of the American

Physical Society Panel on Public Affairs, Nuclear Energy Study Group, "Nuclear Power and Proliferation Resistance: Securing the Benefits and Limiting the Risks." These findings are:

- Significantly enhance the federal technical safeguards R&D program.
- Make proliferation-resistance a stronger constraint on design and development of all future nuclear energy systems.
- Align federal programs to reflect that there is no urgent need to initiate reprocessing or to develop additional national repositories.
- Establish international collaborations on key proliferation-resistance technologies.

Responding to Challenges III: Education and Training

The challenge of replacing and growing the human capital of safeguards was a common theme in the symposium. This session focused on progress and prospects relating to safeguards education and training.

The discussion highlighted the fact that although safeguards training, for example in NDA at Los Alamos, has been ongoing more than forty years in the program, education relating to safeguards has been much more limited in universities. Recently, some universities have begun to develop programs that make specific connections to safeguards. For example, the University of New Mexico is developing a "safeguards certificate" to go with a master's in science in nuclear engineering. Texas A&M has a larger program that includes formal courses in both safeguards instrumentation and safeguards systems analysis.

Some of the points that came out in the panel discussion included the importance of finding U.S. citizens to support national security programs in the labs, the need for broad experience and scientists willing to work in a multidisciplinary environment, the importance of defining career paths in safeguards, motivating students by presenting grand challenges and understanding of the contributions to society, making R&D viable to attract Ph.D.-level students, expanding policy analysis and awareness, and emphasis on the need to improve the interfaces between the labs and universities. It was recognized that although there have been pioneering programs, for example one at Cornell related to nonproliferation, there is clearly a need for more. It was suggested that there are examples of university courses that have come out of the material protection control and accountability program involving key technical institutes in Russia.

Future Directions in Global Nuclear Security

The final session of the symposium looked to the future, covering topics from nuclear security; new powerful technical tools for detection of undeclared activities; a vision for integrating all of the nuclear activities of the DOE; the need to better integrate safeguards, security, and science; and future directions for international safeguards.

In the nuclear security arena, the primary activities relate to prevention of a nuclear event through support to the Cooperative Threat Reduction (Nunn-Lugar) program, the Global Initiative to Combat Nuclear Terrorism announced in July 2006 by Presidents Bush and Putin, and support for U.S. domestic response. The Nunn-Lugar program is fifteen years old, and it is expected to evolve to continue to support, among other things, nuclear security worldwide. The Global Initiative now has fifty countries signed on to its principles with observers from the European Union and the IAEA. Activities are underway, including regional meetings and exchanges.

The use of new tools and technologies was illustrated by the use of commercially available satellite imagery and associated analysis tools. It was noted that such tools (e.g., Google Earth) and associated analysis and visualization tools provide a great starting point for investigations, can be used to improve understanding of suspect sites, have applications as a broad area search tool, and can be used for inspector training and orientation. In addition, there is a community of open source analysts sharing information through Internet blogs (from the term Web log) and wikis (easily modified collaborative Web sites) that are making it increasingly difficult to hide activities visible on the surface of the earth.

The final presentation focused on the future of international safeguards and made the following observations: It is expected that nuclear energy will be more widely used, employing in the near term Gen-III reactors, fuel cycle facilities, geological repositories, and development of Gen-IV systems. It was stated that the NPT is at the crossroads, and that the Global Nuclear Energy Partnership should not increase the "nuclear divide" and create new dependences of nonnuclear weapon states while nuclear weapon states (NWSs) fail to fulfill their obligations under Article VI. Therefore, the NWS needs urgently to act on entry into force of the Comprehensive Test Ban Treaty (CTBT), negotiation of a Fissile Material Cut-off Treaty, and reduction of arsenals. Further regional cooperation to gain security and stability will be important. Future safeguards will be a combination of baseload traditional and information-/intelligence-driven specific investigation and verification. The IAEA should seek authority to investigate weapons programs. Gen-IV-type reactor systems will be more proliferation resistant. Synergies between safeguards/ nonproliferation and nuclear security need to be further exploited.

Dedication

Bob Keepin, the father of the LANL safeguards program, passed away at the end of 2007. He was honored at the December 2006 event that kicked off the 40th anniversary celebration. This documentation of the 40th Anniversary Safeguards Symposium is dedicated to Bob Keepin—in honor of his memory and legacy.

Safeguards at Forty

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The fortieth anniversary of international safeguards offers a chance to reflect on this remarkable story of international security collaboration.

The concept of international safeguards on nuclear material and activities dates from Dwight Eisenhower's "Atoms for Peace" speech to the United Nations in 1953. The International Atomic Energy Agency (IAEA) has, since its creation, applied various technologies and methods to help ensure that nuclear material is not diverted from peaceful to improper uses. Its safeguards system pioneered on-site inspections and involved unprecedented, albeit limited, inroads into member states' sovereignty.

For decades during the Cold War, international safeguards went as far as member states' consensus on nuclear energy and nuclear nonproliferation, along with limits on technologies, would allow. These inspections were not intended to prevent diversion. Indeed, they were designed and administered to deal with only one path to nuclear weapons, that is, diversion to military purposes of material from declared peaceful nuclear activities. Safeguards can in principle deter and, should deterrence fail, detect the diversion of significant quantities of a nuclear-weapons-usable material. But the safeguards developed before the Treaty on the Nonproliferation of Nuclear Weapons (NPT) and then under NPT authorities looked only upon the *correctness* of a declaration.

With the NPT, however, it was increasingly seen as vital that international safeguards be as robust as possible—providing timely warning of diversion—to enable an effective international response. Accordingly, they evolved to meet the challenges posed by new technologies, new international undertakings, and new threats.

A significant factor in the IAEA's continuing improvements in inspections effectiveness during this period was the system of support programs through which member states contribute to technology advances and other activities.

Virtually all of the equipment used by inspectors was developed under such programs, and technical knowledge, training, equipment, and facilities were provided.

Los Alamos National Laboratory, working with domestic and international partners, remains a leader in this effort. The impact of the technology advances achieved on the basis of the system of support programs through which member states contributed was striking.

Innovations in nondestructive assay equipment—including neutron coincidence counters for quantitative measurements of unirradiated plutonium, and gamma spectroscopy instruments for determining isotopics of plutonium and uranium—provided inspectors with rapid *in situ* determinations of the concentration, enrichment, isotopics, and masses of nuclear materials that would be expensive and time consuming and, in some cases, impractical by other means.

Continuous unattended monitoring of activities in nuclear facilities—including video surveillance devices that monitor spent fuel ponds at reactors, core discharge monitors that monitor fuel movements in on-load reactors, and electronic seals that record the time of application—improved the efficiency of inspections by reducing the time spent by inspectors at facilities and the costs to the agency and to operators.

In addition to technology advances during this period, safeguards were strengthened by innovations in procedures that enhanced effectiveness and efficiency. Examples include application of randomized inspections to verify the material flows at low-enriched uranium fuel fabrication plants and earlier reporting requirements for design information relating to new facilities.

As a result, the agency was able to act in a rapid and flexible manner to handle unprecedented situations around the world, from South Africa to the former Soviet Union, as the Cold War was ending.

However, the post-Gulf War Iraqi program, the terrorist attacks of September 11, the discoveries of additional states under the NPT developing clandestine programs and the associated revelation of an extensive non-state nuclear procurement network have presented new challenges to international safeguards, and to the entire nonproliferation regime.

As it had in earlier decades, the IAEA has been transforming its safeguards system to address such issues, many of which it was never designed to handle, as well as to deal with the expected growth in nuclear energy use such as that contemplated by the Global Nuclear Energy Partnership, or GNEP.

The IAEA is adopting a fundamentally new approach to implementing safeguards based on the strengthening measures developed in the 1990s and the lessons learned from Iraq, North Korea, Libya, and Iran. It is recognized that an effective, strengthened international safeguards system, with a strong focus on searching for undeclared nuclear materials and activities, is essential to provide confidence that shared nuclear technologies and expertise, as well as nuclear materials themselves, are not being diverted to weapons programs. *Completeness* as well as *correctness* has become critical.

Central to the transformation is the Additional Protocol (AP), which is an important new tool that needs to be universally accepted as the basis for safeguards and a condition for exports. Although most states with significant nuclear activities have now brought the AP into force, there remain a large number of states that have not yet ratified the AP. The agency and member states are trying to remedy this situation, as well as the problem of the universality of comprehensive safeguards agreements.

Implementing the new measures in the AP, as well integrating traditional NPT safeguards (INFCIRC/153) and new AP safeguards (INFCIRC/540), remains a work in progress. Fundamental to the new approach to IAEA safeguards is information acquisition, evaluation, and analysis, along with inspections. The new approach is designed to provide an evaluation of the nuclear program of a state as a whole and not only of its declared nuclear facilities.

In order to move in the right direction, there is a clear need for capabilities to detect undeclared nuclear facilities and also to address challenges posed by

- large, increasingly complex new facilities with high material throughputs;
- difficult-to-measure materials;
- harsh environments with high dose rates and temperatures;
- measurement of new isotopes and combinations of isotopes; and
- possible diversions without physical change to plant.

Addressing these and other challenges—both anticipated and unanticipated—will require a defense-in-depth approach that includes

- state-of-the-art instrumentation and methodologies for materials measurement, accounting, and tracking, including sensor platform integration;
- enhanced containment and surveillance, including portal and area radiation monitoring, and measures to assure the absence of materials or radiation signals;
- integration of access denial and transparency elements of physical protection and safeguards; and
- integration of traditional process monitoring with nontraditional indicators, such as detection of radiation signals where they should not be, questionable movement of equipment and people, etc.

To support such an approach, it is necessary to revitalize technology research and development and recreate a robust, flexible, and adaptive technology base for next-generation, advanced safeguards technologies.

Given these challenges, it is clear that IAEA safeguards will continue to change in the future as they have evolved over the last four decades. As noted, there is an increased need for capabilities to detect undeclared nuclear facilities, the need for continuing improvements in safeguards at increasingly large and complex declared fuel cycle facilities, and a desire for a more intensive involvement in applying safeguards in new roles.

Los Alamos is working on these and other issues—in collaboration with other labs and agencies—to help the United States and the international community prepare for an uncertain future.

Of course, this evolution of safeguards must reinforce and be reinforced by other nonproliferation initiatives, careful growth in nuclear energy, and other actions to address the changing security environment.

In sum, at a time when nuclear activities are increasing throughout the world, IAEA safeguards face new challenges. It is clear that IAEA safeguards must continue to change in the future as they have evolved over the last four decades.

Safeguards Technical History: Celebrating Forty Years of Nuclear Safeguards at LANL

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Introduction

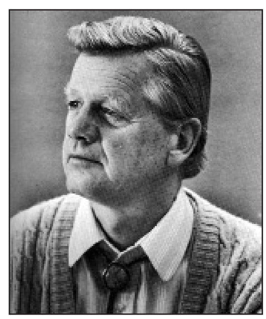
For forty years, Los Alamos National Laboratory's (LANL's) safeguards technology has grown and matured. This technology history parallels, in many ways, the corresponding growth in the importance of safeguards and the changing nature of safeguards challenges—both nationally and internationally. Many papers were published in the past forty years to document and share our research and development findings with the safeguards community. A handful of references are provided here (References 1–5) as keys to unlock the rich technical history of safeguards at LANL for interested readers. This paper presents, instead, a brief historical perspective of the past forty years of LANL's safeguards technology—mostly through pictures and through personal recollections.

The Birth of LANL Safeguards and Early Signature Years (1966–1970)

In the early 1960s, the International Atomic Energy Agency (IAEA) began to recognize that the spread of nuclear materials worldwide must be controlled. During that time, Robert (Bob) Keepin was on a two-year leave from LANL on an assignment to the IAEA in Vienna as the director of the Physics Division. When he returned to Los Alamos, he concluded there was a vital need for technical support for the safeguards activities at the IAEA as well as for U.S. facilities. Keepin won the support of the Los Alamos Scientific Laboratory (LASL) Director Norris Bradbury and Gen. Crowsen of the Atomic Energy Commission (AEC) to launch the Los Alamos Safeguards Research and Development (R&D) Program. The first LANL (still known at that time as LASL) safeguards group was launched on December 1, 1966, under the leadership of Bob Keepin (Figure 1).

Signature development for nondestructive assay (NDA) measurements of nuclear materials was the initial focus of the approximately fifteen staff members who joined Keepin's safeguards group. Because the group had access to neutron generators (the Cockcroft Walton accelerator at Technical Area 18 (TA-18) and a Van de Graaff accelerator at TA-35) and the fast-critical-assembly equipment for experimentation, there was a natural focus on neutron-based NDA research. Figures 2–4 show photos of neutron-based NDA research at Los Alamos. There was also active research in

Figure 1. Photograph of George Robert (Bob) Keepin from the 1980 issue of *Los Alamos Science* that featured the safeguards program in its inaugural publication, Vol. 1, No. 1.



NDA techniques using gamma-ray spectroscopy from the beginning. Figure 5 shows cylinders for the gamma-ray enrichment measurement of UF_6 at the Uranium Enrichment Plant (K-25) in Oak Ridge. The Stabilized Assay Meter (SAM-2) shown in Figure 5 was also capable of passive neutron counting. In addition, the exploitation of x-ray K-edge densitometry in developing signatures of nuclear materials was begun. The calorimetry technique, with its heat measurements, was later added to the group (Figure 6).

The Los Alamos Nuclear Safeguards program was fast becoming the premier safeguards research and development effort in the U.S. and abroad, building as it did on the legacy of more than twenty years of nuclear materials and weapons research and infrastructure. The Laboratory hosted the first international safeguards technology symposium in 1969, with participation by many U.S. and international insti-

Figure 2. TA-18 Fast-neutron interrogation. Henry and Masters performing active assay of a uranium sphere using prompt and delayed neutrons in 1969

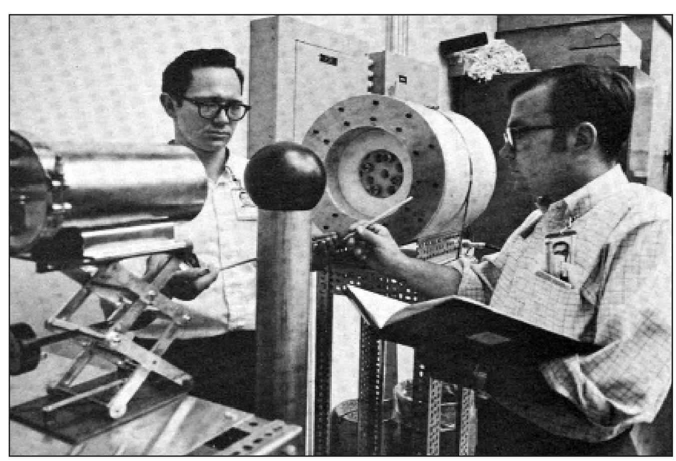


Figure 3. Neutron experiments with fast-scintillation coincidence. Berick and Walton testing a weapons mockup in 1969

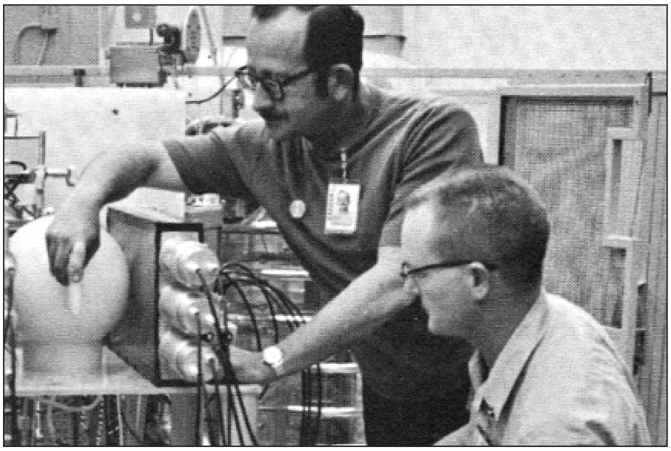


Figure 4. First active neutron interrogation at Ten Site, Bldg. 27. Augustson and Menlove using a neutron generator to measure Materials Test Reactor fuel in 1969

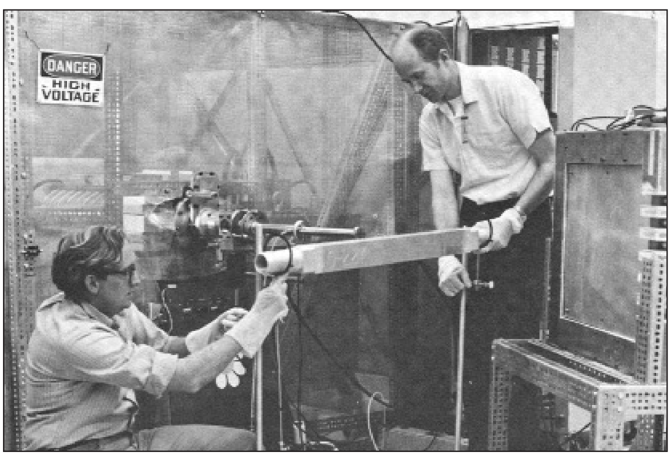
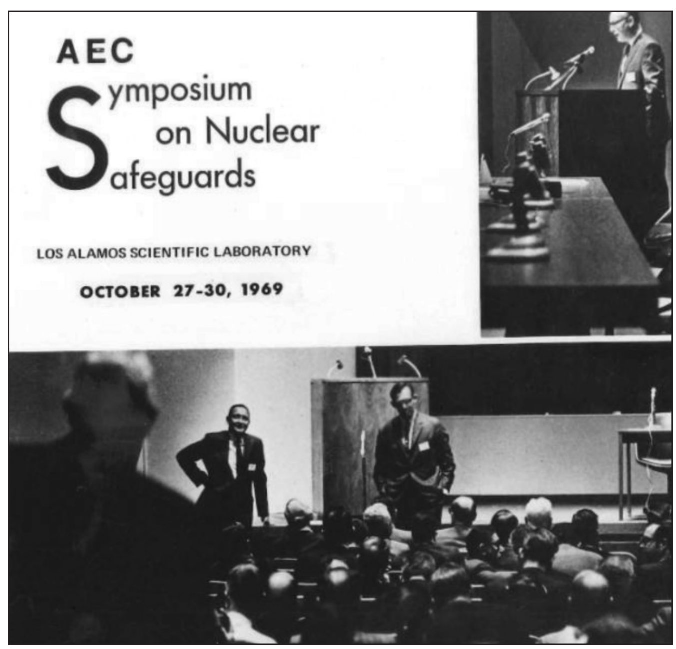


Figure 5. Gamma-ray enrichment measurement by Roddy Walton at the K-25 plant at Oak Ridge in 1969

Figure 6. Calorimeter R&D Program. Heat standards calorimeter is shown

Figure 7. Collage of pictures from the first symposium on safeguards in 1969. WilliamHigginbotham giving a plenary talk, shown in top right photo. Gen. Crowsen, as master of ceremonies, is shown in the lower photo



tutes, including the IAEA Director General Ecklund. Figure 7 shows a collage of pictures from the 1969 symposium, including a photo of W. Higginbotham of Brookhaven, who played a key role during the early years.

Figure 8. Jack Parker, a laboratory fellow, with his dowry from K-Division, used for a gamma-ray-based NDA system in approximately 1969

Safeguards Technical Transitions

There was some optimism in the beginning, that technology support for safeguards would be quickly completed, with a better understanding of NDA signatures and measurement technologies. However, forty years has brought many technical, programmatic, and organizational transitions. This section provides brief sketches of transitions in gamma-ray- and neutron-based NDA systems. A discussion of the shift in focus, from domestic to international safeguards, will also be covered briefly. Other important transitions will only be mentioned in this section. It will not be possible to be comprehensive and technically detailed in this historical overview.

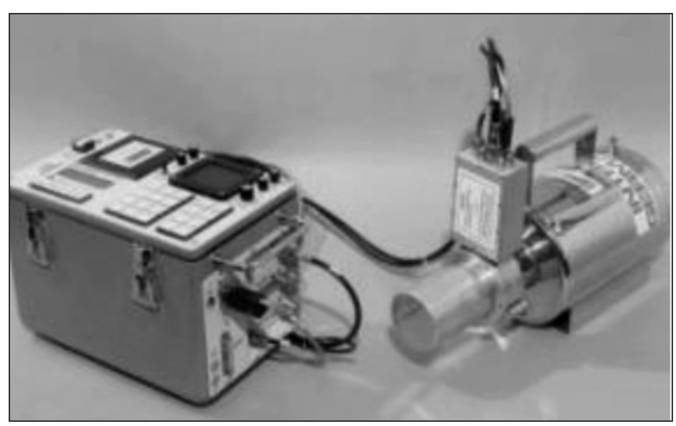
Transitions in Gamma-ray-based NDA Systems

Gamma-ray spectroscopy is useful for determining the isotopic composition of uranium, plutonium, and other nuclear materials. Early gamma-ray NDA systems, like the SAM-2 shown in Figure 5, used NaI as the detector. Working with the Eberline Corporation, Los Alamos improved the SAM instrument's ability to measure ^{235}U enrichment measurements, based on the 185.7-keV gamma ray. These improvements came through the addition of a second single-channel analyzer, a scaler-timer, and a digital-rate multiplier so the unit could read directly in percent ^{235}U. The SAM-2 electronics could be used for both totals-neutron and gamma-ray counting.

One interesting transition in gamma-ray NDA systems can be seen in the electronics. This became increasingly important as high-purity Ge (HPGe) and CdZnTe detectors were later developed to analyze the gamma-ray spectrum of plutonium, a spectrum that is too complex to analyze with NaI. Figure 8 shows a large rack of electronics for the circa 1969 vintage gamma-ray systems. Approximately a decade later, a more compact electronics packaging allowed for a portable system to be delivered to the IAEA by Selena (Figure 9). In the early 1980s, a truly portable multichannel analyzer (MCA) was designed by Jim Halbig and programmed by Shirley Klosterbuer at LANL (Figure 10).

Figure 9. Howard Menlove posing with the Selena transportable 1,000-channel MCA in Vienna to show the system's portability in approximately 1976

Figure 10. The Davidson portable MCA with a HPGe detector.



A sample of today's NDA instruments for the IAEA, from the German Support Program, is shown in Figure 11. Figure 11(a) shows a miniature MCA with more functionality than a full rack of electronics shown in Figure 8. Figure 11(b) shows a hand-held monitor for safeguards and illicit trafficking measurements.

This subsection on the development of the gamma-ray-based

Figure 11. IAEA instruments from the German Support Program. (a) Miniature MCA and (b) the FieldSPEC handheld detector

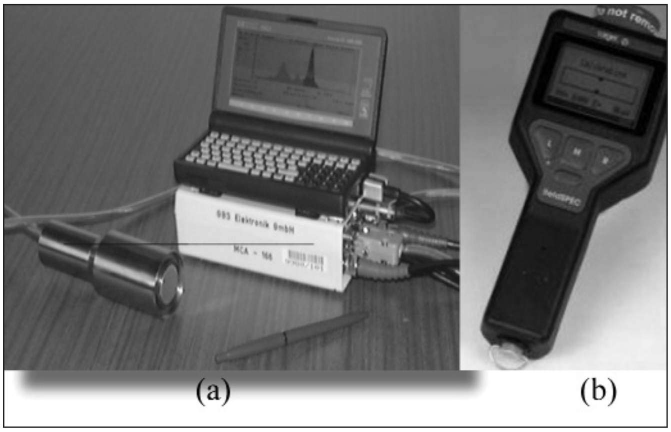


Figure 12. Ray Martin with a segmented gamma scanner (1967–2006)

Figure 13. Greg Sheppard with a tomographic gamma scanner (1967–2006)

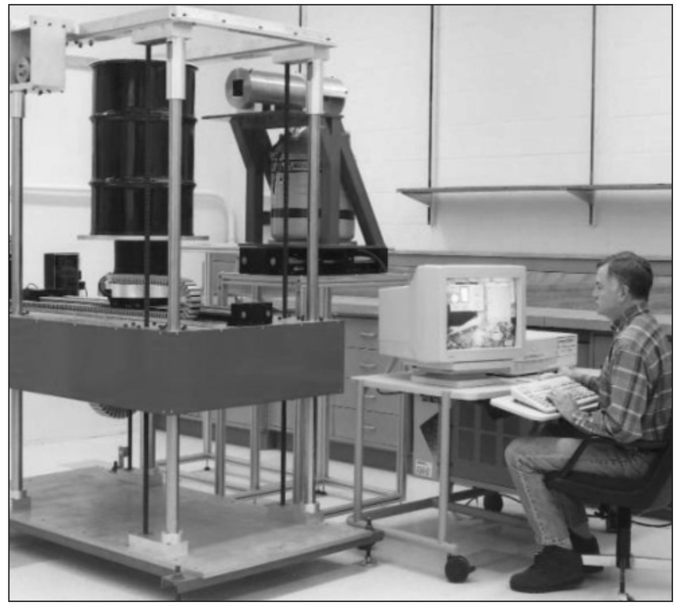
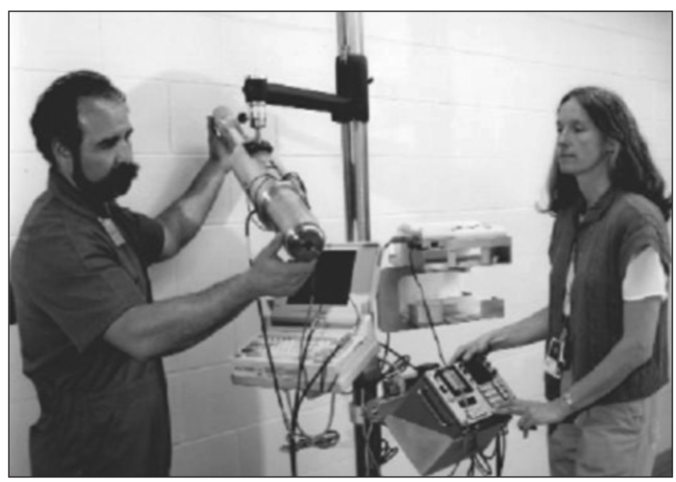


Figure 14. David Garcia and Phyllis Russo with a gamma-ray instrument for holdup measurements (1980–2006)



NDA instruments closes with Figures 12–14. Figure 12 shows a segmented gamma scanner. Ray Martin, shown in Figure 12, became the cofounder of JOMAR Systems, which later transitioned to become part of Canberra (now part of AREVA). Figure 13 shows Greg Sheppard, the current group leader of the Safeguards Science & Technology group, with a tomographic gamma scanner. Gamma rays were also very important in holdup measurements. Figure 14 shows David Garcia and Phyllis Russo with gamma-ray NDA instruments for holdup measurements. Phyllis Russo played a major role in the development of these instruments and the training of holdup practitioners.

Transitions in Neutron-based NDA Systems

One transition that is not likely for neutron-based NDA systems is the kind of miniaturization seen with some gamma-ray sensors (Figure 11). This is because size is important when capturing the penetrating neutrons. This sketch of transitions in neutron-based NDA systems therefore begins with the largest systems. Figure 15 shows the Waste Crate Assay System (WCAS-B), a 4π neutron detector with ^{3}He tubes in the walls. The cavity has sufficient volume to hold seventy-five 200-liter drums. The WCAS-B counter was fabricated by Pajarito Scientific Corp. and is currently measuring waste at the Rokkasho Reprocessing Plant in Japan. Other large systems developed at Los Alamos include the Crated Waste

Figure 15. WCAS-B concrete block load testing in Albuquerque, New Mexico, in October 2001. The WCAS-B is now used in the Rokkasho Reprocessing Plant in Japan.

Figure 16. Mel Stephens with the first shuffler in 1977

Figure 17. A shuffler system built into the hot cell in Scotland

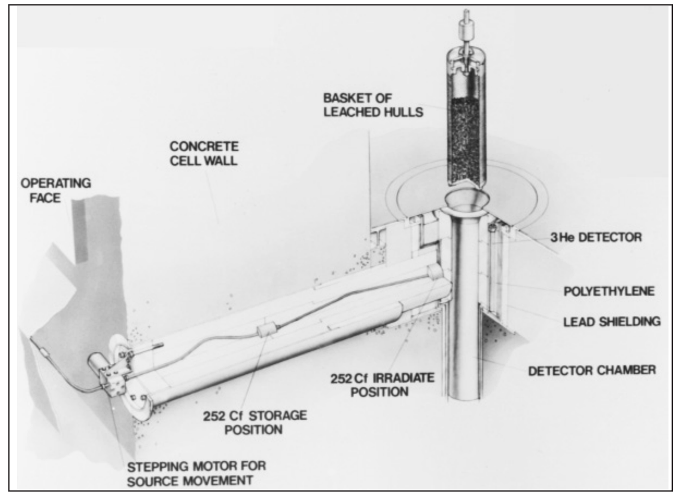
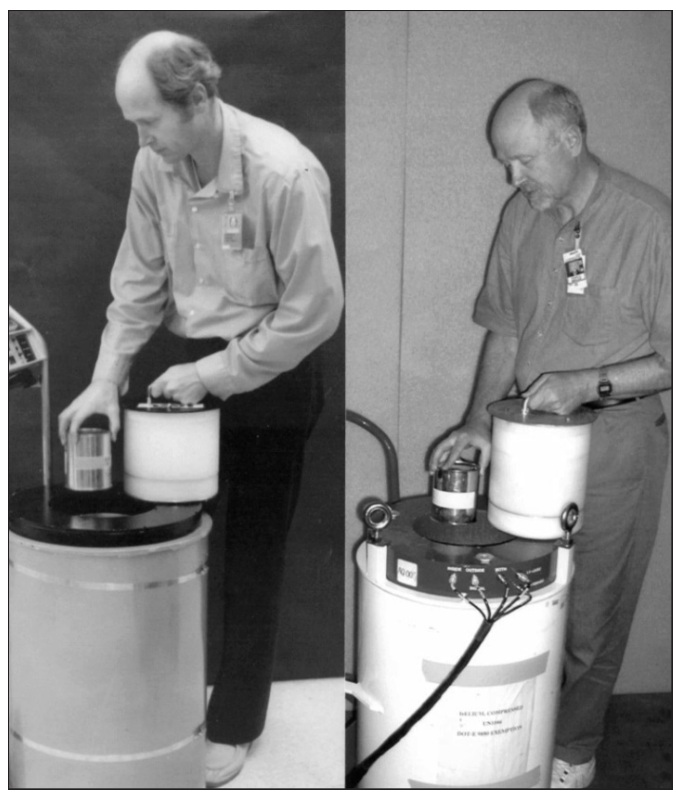


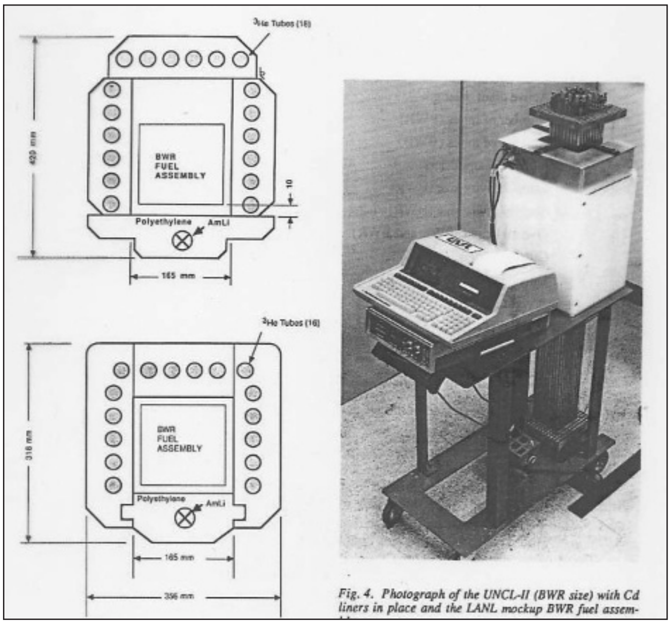
Figure 18. A LANL scientist "frozen" in a lab for twenty-five years illustrating the revival of the AWCC caused by HEU in weapon dismantlement



Assay Monitor, an active neutron die-away system that is also important for waste measurement. The Super HENC Waste Measurement System, a purely passive multiplicity counter with a 41 percent efficiency, is used to measure waste containers prior to shipment to the U.S. Department of Energy Waste Isolation Pilot Plant (WIPP) for underground burial.

A series of neutron shufflers were developed at LANL for

Figure 19. Neutron collar from 1978 with HP-85 INCC software



active neutron interrogation, beginning with the first shuffler in 1977 (Figure 16). The shuffler contains a neutron source in a shield, where the source moves rapidly into and out of the sample interrogation area. When the source is in the sample area, neutrons from the source interrogate the sample. The source is then quickly pulled away, and the delayed neutrons are counted. The shufflers that were built by Los Alamos and deployed include the Idaho National Laboratory (INEL) shuffler, used to measure spent naval fuel, and a shuffler at Savannah River, used to measure the billets that were put into the reactor to produce weapons-grade Pu. Several waste-drum shufflers were also developed by LANL and Canberra Industries. Figure 17 shows a novel installation of a shuffler in Scotland. The shuffler is built into the hot cell wall to measure leached hulls through active neutron interrogation.

The Active Well Coincidence Counter (AWCC) was developed to measure ^{235}U, which has a spontaneous fission rate that is too low for practical passive neutron measurements. The AWCC made use of a pair of AmLi neutron sources, one source in the bottom end-plug and a second in the lid, to interrogate the bulk uranium samples. The body of the AWCC contains forty-two ^{3}He tubes in two rings that surround the sample cavity, which can hold 1- to 50-g samples in the thermal-neutron mode and 50- to 5,000-g samples in the fast-neutron mode (with the Cd liner). Figure 18 shows pictures of the AWCC in a LANL lab taken 25 years apart. The later interest in the AWCC came at the end of the Cold War with weapons dismantlement efforts that produced large masses of HEU.

A uranium neutron coincidence collar (UNCL) operates under the same principle as the AWCC, but the sample volume has changed from a can to a fuel assembly. A single AmLi neutron source is used to interrogate the ^{235}U in fuel assemblies, and coincidence neutron counting is used to determine the ^{235}U mass per unit length. Figure 19 shows a 1978 vintage neutron collar that used the HP-85 INCC (IAEA Neutron Coincidence Counting) software. A key activity for the implementation of the many types of neutron coincidence systems was the development of the INCC software by M. Krick and W. Harker. This software is used

Figure 20. Neutron collar at Resende, Brazil, in 1982

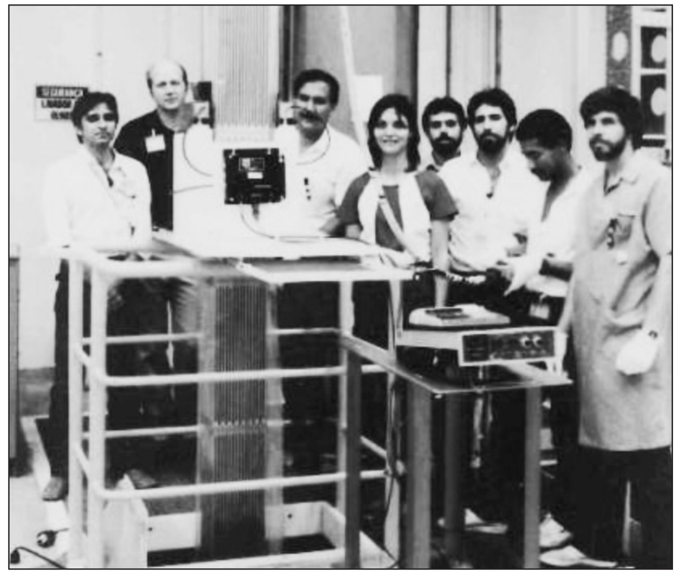


Figure 21. High-Level Neutron Coincidence Counter – HLNC-II

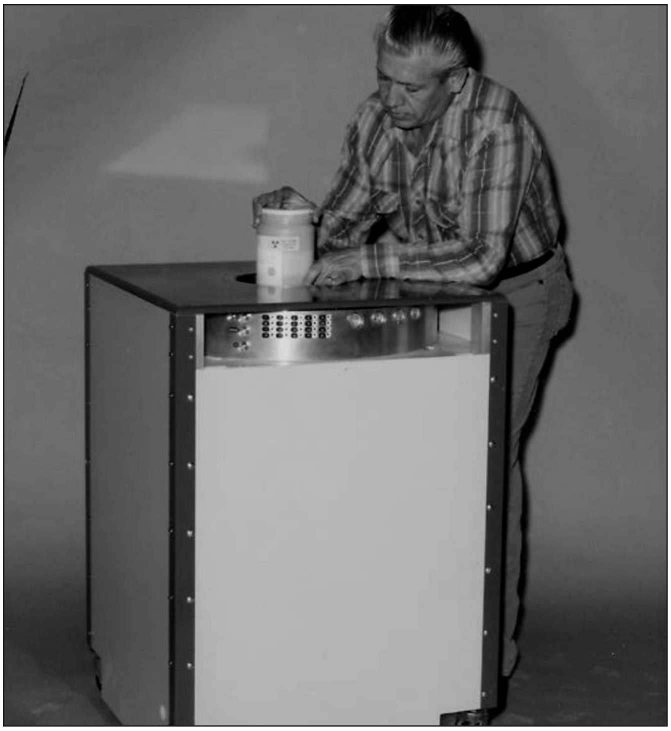


Figure 22. Jake Baca shown with a PSMC in approximately 1995

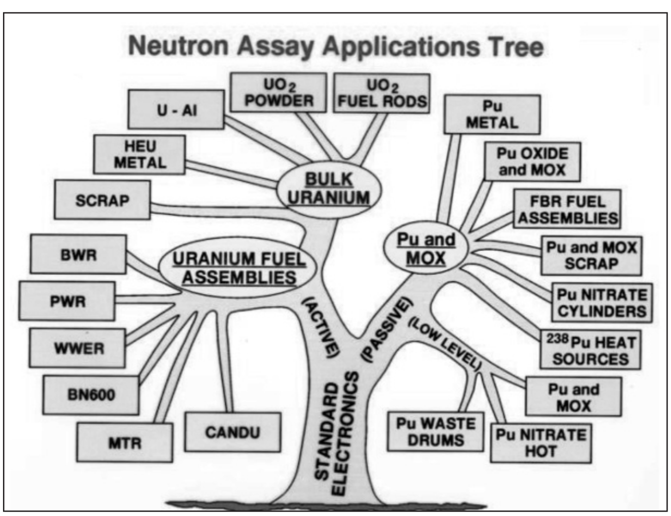


Figure 23. Technology transitions in neutron-based NDA applications

to set detector parameters, collect data, make dead-time and background corrections, calculate statistical errors, perform data quality tests, convert counts to grams of plutonium, and to calibrate the systems. The UNCL is in use at light-water reactor fabrication plants worldwide. Figure 20 shows a neutron collar being deployed in Brazil.

A basic transition in passive neutron counter systems was the evolution of detectors that measure total neutrons (singles), coincidence neutrons (doubles), or multiplicity neutrons (triples). Each step requires an increase in efficiency. Improvements to the original hexagonal well counter (shown in Figure 21) resulted in the High-Level Neutron Coincidence Counter (HLNC). The improvements included eighteen ^{3}He tubes, six internal amplifiers (AMPTEX A111) that provided a much faster counting capability (up to 1.5 MHz), 17.8% efficiency, and the parallel development of shift-register digital electronics. The HLNC-II could measure Pu samples from less than 1 g up to ~7 kg of high burnup Pu. The HLNC-II later transitioned into the Passive Neutron Scrap Multiplicity Counter to handle impure scrap and recycle Pu (the PSMC is shown in Figure 22). The PSMC, first applied at the mixed oxide (MOX) fabrication plant in Japan, contains 80 ^{3}He tubes to provide an efficiency of 55 percent and counting times of fifteen to thirty minutes. Even higher efficiencies are possible with the Epithermal Neutron Multiplicity Counter (ENMC) that has 121 high-pressure ^{3}He tubes to achieve the ENMC's efficiency of 64 percent. The ENMC was developed for the measurement of impure plutonium and MOX samples that have high alpha values. It can also be used for small samples and to create secondary standards from production materials. Current work with the ENMC is to achieve accuracies comparable to destructive analysis for small inventory samples.

Figure 24. AMPTEK and 3He-tube-based neutron-based NDA family

To conclude this subsection on transitions in neutron-based NDA systems, consider the applications tree diagram in Figure 23. Common electronics form the tree trunk, with passive applications on the right side for plutonium measurements and active applications on the left side for uranium measurements. A "family photo" of neutron NDA systems that operate with a single electronic module, called a shift register, is illustrated in Figure 24.

Transition in Focus from Domestic to International Safeguards

Research and development efforts in the early years were focused on domestic safeguards issues. The original safeguards group provided support to the AEC Office of Safeguards and Material Management, and the Division of Safeguards in the AEC Regulatory Branch (now the Nuclear Regulatory Commission).

Figure 25 shows a model of the Mobile Nondestructive Assay

Figure 25. MONAL Trailer in approximately 1975. Much credit goes to Menzel and Reilly for developing the trailer

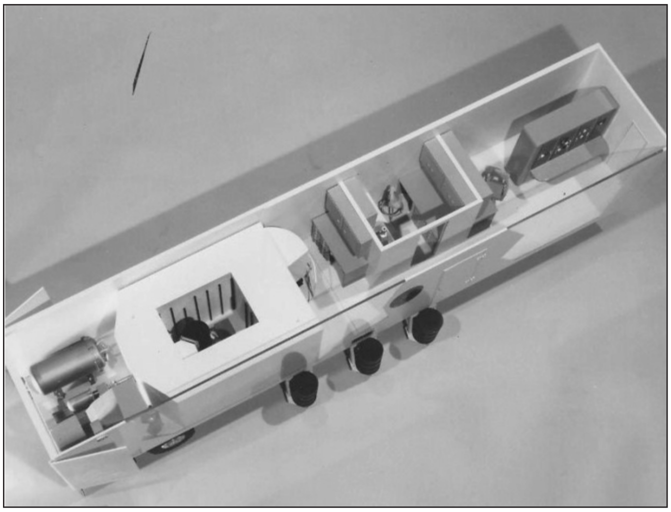


Figure 26. NDA systems under test for the Receipts Assay Facility — SRS (1984–1985).

Laboratory (MONAL) trailer with a D,T generator for active assay in the left compartment and gamma-ray spectroscopy in the central section. The mechanical design was capable of NDA measurements of 200-L drums (drums shown along the side of the trailers). In the 1970s, the MONAL trailer was taken all over the U.S. to support domestic safeguards. Figure 26 shows NDA systems developed in the 1980s to provide assay capability for incoming shipments of special nuclear material (plutonium oxide and ash) at the SRS. Through transferring safeguards measurement technology and by offering training programs, Los Alamos has supported domestic safeguards efforts in such places as Hanford, INEL, the Nevada Test Site, Rocky Flats, WIPP, Antec in Colorado, Reuter Stokes in Cleveland, Portsmouth, Meridian, B&W Lynchburg, Nuclear Fuel Services - Erwin, Savannah River, Oak Ridge, Sandia, and Pantex.

Figure 27. Highly enriched uranium physical inventory verification exercise. Training at Los Alamos, New Mexico, September 10–18, 1985

Figure 28. SSAC Course with the IAEA. Doug Reilly (standing second from the left) was instrumental in developing these courses

Early in the Los Alamos program (approximately 1970), the Laboratory organized and set up the nuclear safeguards exhibit area at the Atoms for Peace Conference in Geneva, Switzerland. This activity helped trigger the Los Alamos technical-support effort to the IAEA, and for the past thirty years, Los Alamos has been the foremost supplier of technical support to the IAEA. Many NDA technology transitions described above, including the push toward portability and simplicity, were driven by the changing needs of international safeguards. More recent transitions toward installed NDA systems, and integrated and unattended systems, are also driven by the growing challenges of international safeguards.

Figure 29. Russian MPC&A program sites

LANL has also hosted IAEA training courses each year for the past three decades, and essentially all of the past and present IAEA inspectors have received training at Los Alamos. Shown in Figure 27 is a photo from a 1985 training class of new inspectors at the IAEA. The student in the middle of the picture is Ollie Heinonen, the current deputy director general for safeguards at the IAEA. Los Alamos also supports IAEA's training in "a state system for accounting and control of nuclear material" (SSAC) because an effective international safeguards regime depends not only on a well-trained IAEA inspectorate but also on an effective national or state system for nuclear-material control. SSAC courses are now provided in the United States, Russia, Argentina, Brazil, Japan, South Korea, Australia, and South Africa. Participants from more than 60 countries have attended these courses in Los Alamos and Santa Fe for the past two decades. Figure 28 shows a photo from an SSAC course.

The shift toward international safeguards has been the most profound during the past twenty years. Los Alamos has been actively engaged in training and technical support for the IAEA and international collaborations. Our international safeguards support has included such countries as Belgium, the UK, Canada, France, Brazil, Argentina, Luxembourg, Netherlands, Germany, Italy, Bulgaria, Iraq, Sweden, Finland, Latvia, Uzbekistan, India, Australia, China, Korea, Japan, Kazakhstan, Armenia, Belarus, Ukraine, and Russia. In the space remaining in this paper, it would not be possible to adequately describe LANL's role in any one country or our collaborations with laboratories in the United States or abroad. To mark the importance of our international collaborations, a few pictures (Figures 29–31) are shown in the following pages. Figure 29 shows the sites of the Materials Protection, Control, and Accounting (MPC&A) program cooperation with Russia from 1978 to present. Figure 30 shows the BN-350 reactor in Kazakhstan, where there has been involvement from Los Alamos from 1988 to the present. Los Alamos has also had more than 20 years of safeguards experience working with Japan and their next-generation plants, such as the Rokkasho Reprocessing Plant shown in Figure 31.

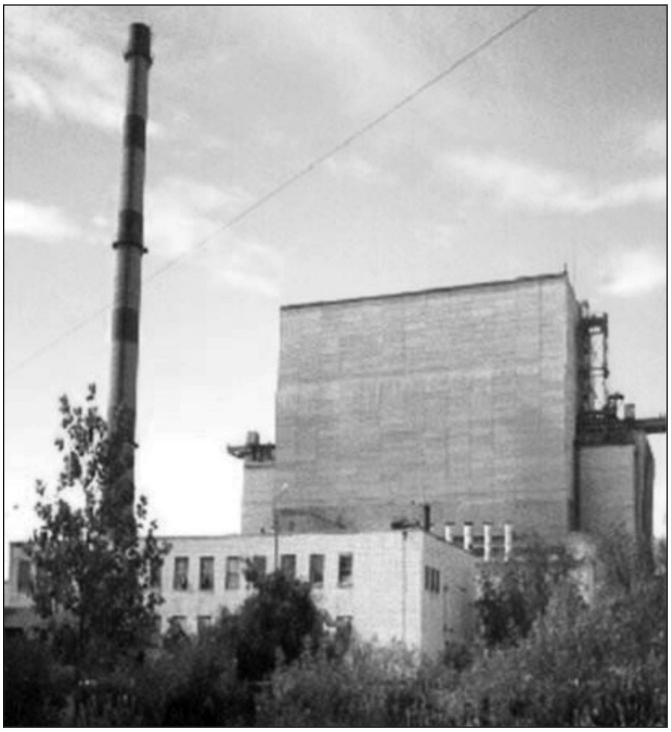


Figure 30. BN-350 breeder reactor, Aqtau, Kazakhstan

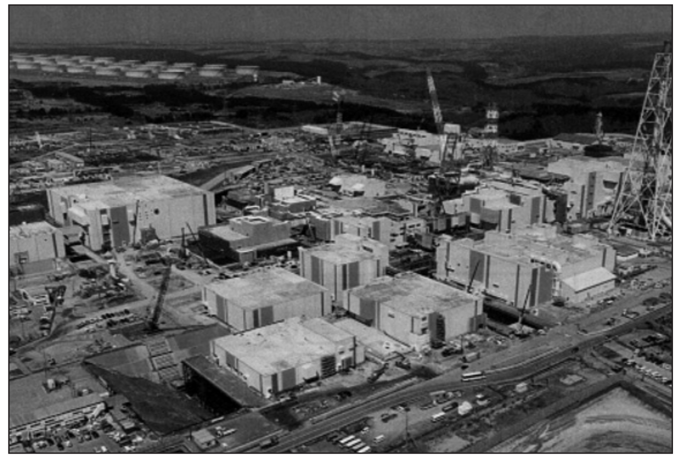


Figure 31. New Rokkasho Reprocessing Plant in Japan

Conclusions

The future of safeguards technologies will necessarily be colored by the threats posed by terrorists and rogue nations. There is also the expectation of a global rise in the use of nuclear power and large-scale automated nuclear plants. Los Alamos is prepared to meet the safeguards challenges in the future by building on our legacy of the past forty years and working with colleagues around the world to develop new technologies and systems. Today, we are still inspired by Bob Keepin's original vision for safeguards—to make the world a safer place.

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The Global Nuclear Energy Partnership—A Challenge and Opportunity for Nonproliferation and International Security

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Abstract

One of the cornerstones of the Global Nuclear Energy Partnership (GNEP) program is enhanced nonproliferation and safeguards to facilitate the safe and secure global expansion of nuclear energy. To this end, GNEP proposes developing and implementing advanced safeguards into new fuel cycle processing and reactor facilities, and setting up an assured fuel services framework, including spent fuel takeback, to limit the spread of enrichment and reprocessing technology. The mission of the Safeguards Campaign is to perform the research and technology development required to achieve this GNEP vision of advanced safeguards. Key areas of investigation include a) advanced instrumentation (nondestructive and destructive), b) use of process monitoring for safeguards, c) fully integrated, real-time knowledge of facility operations, and d) advanced modeling and simulation tools.

Introduction

World energy demand is increasing, and with it the demand for nuclear power.[1–3] The Energy Information Administration's 2007 forecast predicts an increase of 57 percent in world energy consumption through 2030.[1] Rather than decreasing as a result of generating plant retirement and a lack of new construction, as in previous projections, nuclear power is now projected to increase,[2] as evidenced by 70 new plants under construction and an additional 86 on order or planned as of September 2007.[3]

In February 2006, as part of the Advanced Energy Initiative, the President of the United States announced the Global Nuclear Energy Partnership (GNEP) program, which introduced an advanced fuel cycle concept that addresses increasing energy demand, minimizes the volume, heat load, and radiotoxicity resulting from spent nuclear fuel, and employs both intrinsic and extrinsic measures to address proliferation issues.[4] GNEP is a voluntary international partnership where member states (numbering twenty-one nations as of February 2008[5]) agree to the objectives of 1) sustainable nuclear power expansion in a way that promotes safe operations and management of wastes; 2) development, with the International Atomic Energy Agency (IAEA) of enhanced nuclear safeguards; 3) establishment of international supply frameworks to enhance reliable, cost-effective fuel services, thereby creating a viable alternative to the acquisition of sensitive fuel cycle technologies (such as enrichment and reprocessing); 4) development, demonstration, and deployment of advanced fast reactors that consume transuranic elements from recycled spent fuel; 5) promotion of the development of advanced, grid-appropriate reactors; 6) development and demonstration of advanced technologies for recycling spent nuclear fuel; and 7) taking advantage of the best available fuel-cycle approaches.[6]

The nonproliferation vision of the GNEP program provides for a strengthened nonproliferation regime as an integral part of the global expansion of nuclear energy by a) discouraging the spread of enrichment and reprocessing technologies by providing reliable fuel services, b) reducing the stocks of separated civil plutonium, c) incorporating safeguards and nonproliferation goals into the design of fuel cycle facilities, and d) developing advanced technologies to support enhanced safeguards and nonproliferation. There is no individual technological solution that will ensure the peaceful use of nuclear power, but rather the system and governance framework of nonproliferation and international security must be implemented in an integrated fashion. The challenges faced by the GNEP program also represent an opportunity to enhance the safeguardability of the future nuclear fuel cycle and thereby achieve increased confidence and assurance that such facilities are used only for peaceful purposes.

A significant research and technology development effort will be required to provide the foundation for achieving the GNEP vision, and as a result, a GNEP safeguards campaign has been established to focus on both near-term demonstration of advanced technologies as well as foundational research for the longer term. The GNEP safeguards campaign benefits from strong cooperation between the Department of Energy's (DOE) Office of Nuclear Energy, and the National Nuclear Security Administration's (NNSA's) Office of Nonproliferation and International Security (NA-24). Technologies developed by the campaign will specifically address domestic safeguards requirements for U.S. GNEP facilities as well as provide the technological basis for additional international safeguards advancement.

Office of Nonproliferation and International Security

The NNSA's Office of Nonproliferation and International Security has a long history of providing leadership in enhancing the international nonproliferation regime and supporting the IAEA through a combination of programs that focus on assessments, safeguards technology, export controls, infrastructure, and international engagement.

Many of the drivers for research and technology development for international safeguards are common to those of the proposed domestic U.S. GNEP enabling technology facilities (the Consolidated Fuel Treatment Center, the Advanced Recycling Reactor, and the Advanced Fuel Cycle Facility [AFCF]). As such, there is a natural synergism in research and technology development interests and the requirements to license these facilities. The licensing must meet domestic regulatory requirements along with enabling enhanced international safeguards.

Office of Nuclear Energy—GNEP Domestic Safeguards Campaign

The research and development (R&D) component of the GNEP program is housed in the Advanced Fuel Cycle Initiative R&D program, which is organized in thrust areas called campaigns, that are integral experimental and simulation efforts focused on developing key capabilities required for the implementation of the GNEP. In addition to campaigns, the R&D program includes crosscutting efforts in modeling and simulation as well as safety and regulatory efforts. A technical integration office coordinates and integrates the R&D efforts of the campaigns and crosscuts. Major technology thrust areas of the program are transmutation fuels, advanced separation technologies, systems analysis, domestic safeguards, durable waste forms, and both fast reactors and grid-appropriate reactors.[7]

The GNEP safeguards campaign has three core responsibilities: 1) support the GNEP-enabling technology facilities with domestic safeguards expertise, 2) provide research and technology development in support of meeting safeguards requirements and to support advanced safeguards, and 3) interface with other campaigns and crosscutting areas. In addition, the campaign provides expertise in the area of domestic regulatory requirements and implementation, and can provide input into the review of regulations by both DOE and the Nuclear Regulatory Commission. International safeguards are the responsibility of NNSA's Office of Nonproliferation and International Security, with whom the campaign coordinates closely.

International and Domestic Safeguards Challenges

The global expansion of nuclear energy presents both challenges and opportunities to safeguards and nonproliferation. Challenges range from issues such as increased transportation of nuclear materials and the need to maintain global nuclear material controls to addressing timeliness goals for detection of nuclear material misuse for large throughput facilities. GNEP addresses these challenges directly by providing a governance framework for the future nuclear fuel cycle that has enhanced nonproliferation and safeguards as a central tenant of the program. As such, the GNEP program provides the opportunity to apply new technologies and approaches to strengthen nonproliferation and safeguards.

One of the fundamental challenges to safeguards presented by the growth of civil nuclear power is offered by the large bulk-handling facilities that could be built. Another issue from advanced fuel cycle concepts is in the intrinsic properties of the materials that potentially would be present throughout the fuel cycle. Concern over the accumulation of separated plutonium has helped drive these concepts, including the GNEP, to use enhanced radiation as a barrier to misuse. Although this is a benefit from the perspective of hindering access, these same properties can make quantitative measurement more difficult.

Associated with intrinsic materials properties is a practical challenge to safeguards, namely the extensive use of hot cells and remote handling throughout the recycling and fuel fabrication process. This translates to equipment that must operate remotely and reliably in a much harsher environment. Not only will instrumentation need to be robust in a high radiation environment, maintenance schemes will be needed to accommodate the restricted access associated with such facilities.

Facility throughput represents another challenge. As throughput increases, the IAEA goal of 8 kg Pu for the detection of protracted and abrupt diversion represents an ever increasingly smaller fraction of the total, and at some point, additional measures are taken to supplement standard nuclear material measurements. For facilities with annual throughputs on the order of 1,000 tons of heavy metal or more, the 8 kg Pu goal represents less than 0.1 percent of the total. On the other end of the spectrum, there are challenges for small throughput facilities in the case where the safeguards detection goals are based on a percentage of the active inventory, such as the case for both NRC and DOE licensed facilities (0.1 percent and 1 percent respectively).

Electrochemical processing technology is being evaluated as a recycling option and presents a special case because there is not an input accountability tank with which to establish the initial inventory as there is for aqueous processing. The potential non-homogenous nature of this process presents a particular challenge to analyses that rely on small samples. An effective safeguards approach may require even greater reliance on containment, surveillance, and process monitoring than for equivalent aqueous reprocessing.

Fast reactors present a challenge to maintaining continuity of knowledge, given that the core is typically in liquid metal and not accessible through traditional viewing devices (for example, camera surveillance and Cerenkov radiation).

Finally, the expansion of nuclear power will result in greater transportation of nuclear materials. This represents a challenge for maintenance of continuity of knowledge and for shipper-receiver differences.

Research and Technology Development Needs

Any research and technology development needed for the GNEP program would, in general, also benefit the general safeguards community—particularly international safeguards implemented by the IAEA for existing and planned fuel cycle facilities in Japan and elsewhere.

Addressing these challenges requires advances in instrumentation, systems analysis and modeling, and data integration and knowledge extraction, but also provides an opportunity to evaluate the application of safeguards in an integral sense and to develop a "defense in depth" approach.[8,9] The opportunity also exists for including safeguards requirements in the design process, thereby maximizing their efficacy and minimizing the associated costs and impacts to the operator. This "safeguards by design" approach is being employed for the U.S. GNEP facilities and is being developed as a potential new standard for facility design.[10]

The research and technology development needs of the GNEP fall into three broad categories:

- *Advanced Instrumentation*—Online and at-line, near-real-time monitoring methods based on radiation and nonradiation signatures operated in active and passive mode and encompassing destructive and nondestructive analyses are needed. Process monitoring should be incorporated in a quantitative manner, and include tracking both hot (Pu and other radioactive species) and cold (nonradioactive) streams. There are fundamental data needs that support improving advanced instrumentation, the evaluation of existing data, and developing new data to enable new techniques. Modeling and simulation tools to support sensor design are needed; opportunities exist in new materials by design and in materials evaluation in high radiation environments.
- *Safeguards by Design*—Incorporating design features that facilitate safeguards and physical security requirements into the design of new facilities at the earliest possible stage is one of the best opportunities to maximize the efficacy of the safeguards system and minimize the cost and impact to the operator. Models of safeguards performance play a key role to inform decision makers regarding the investment of R&D funds as well as to identify advanced approaches.[11,12] Analysis of the safeguards system needs to occur at adequate levels, including facility, site, regional, and global. The implementation of safeguards by design relies on both experimental and theoretical development along with lab-scale and large-scale experimental demonstration.
- *Advanced Control and Integration*—The accuracy and precision required to meet both domestic and IAEA goals using a single measurement technique are somewhere between impossible and impractical with today's technology, and as such, modern facility safeguards employ a variety of tailored instruments in optimized configurations along with additional measures such as containment and surveillance, tags and seals, and integrated safeguards. In addition to developing advanced instrumentation, technology also must involve the development of an integrated control system that uses all available instruments and other information through an intelligent data analyzer. The development of the advanced control system relies heavily on plant modeling and simulation, basic information management, including data security, and it requires an engineering-scale facility for demonstration and optimization.

Modeling and simulation crosscuts all three of the basic thrust areas and plays an important role in sensor and advanced instrumentation development, design of the overall safeguards system for a facility, and analysis of components within the safeguards system, as well as the analysis of the nonproliferation regime. Putting it all together is the concept of the "safeguards envelope," where data from traditional safeguards, process monitoring, containment and surveillance, personnel movements, etc., is folded together to form a confidence measure that a facility is operating normally.[13] In addition, experience with such a system could lead to indicators that are more predictive as opposed to reactive in nature, much like observation-based preventative maintenance in nonnuclear industries. Integrated systems models, with adequate levels of fidelity will be an important component of such an analysis. The AFCF, which has as one of its missions to provide a test bed for advanced safeguards, will be particularly useful in demonstrating safeguards systems' technologies and approaches.

As progress is made in the laboratory along all of these lines of research and technology development, the ability to test and demonstrate in a variety of real world settings will be crucial. Facilities at existing DOE sites need to be fully engaged in the program to provide this type of experience and benchmarking. In addition, opportunities that arise with our bilateral partners should be pursued with an eye on enabling new technologies. Finally, collaborations with universities will make up another important aspect of advancing the state of the art and developing the next generation of professionals. The safeguards campaign is developing an advanced safeguards technology roadmap, which will provide guidance to the research and technology developments needed to advance the current state-of-the-art.[14,15] This roadmap will be a living document and will be updated on a regular basis to incorporate recent R&D results as well as to reflect the priorities of the overall program.

Summary

The GNEP program provides both challenges and opportunities for nonproliferation, security, and safeguards. These challenges are manageable and can be addressed through a combination of research and technology development. The GNEP safeguards campaign has been formed to address the research and technology development needs of the GNEP-enabling technology facilities. A robust program of advanced instrumentation, safeguards analysis and evaluation, data integration and protection, and accompanying modeling and simulation has been put together to enhance safeguards effectiveness, to enable the domestic GNEP facilities to meet requirements in an efficient and effective manner, and to provide a foundation for the next generation of safeguards systems.

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Expansion of Nuclear Energy: Demand, Domestic and International Initiatives, and Nonproliferation and Safeguards Challenges

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Abstract
This session dealt with the safeguards challenges inherent in the expansions in nuclear power. The panelists examined the resulting challenges to domestic and regional safeguards and nuclear power infrastructures in light of opportunities to address the challenges by technology, institutional advances and changes, policy, and better understanding of the safeguards system and the relationships between various entities such as state safeguards systems, the International Atomic Energy Agency (IAEA), regional safeguards bodies, and national governments. The panelists also described what their vision is of future nuclear power developments in their states and regions with respect to growth in nuclear power plants, fuel cycle facility creation and expansion, waste disposal issues, international movement of nuclear materials, and public acceptance. Joseph Pilat and Mark Goodman focused on the questions in light of assured fuel supply issues and "state-level safeguards by design," respectively. Dorothy Davidson of AREVA gave the industry perspective on expansion of its full nuclear fuel cycle services and the safeguards implications. Russell Leslie of Australia gave the Australian perspective as a present user nation with vast uranium resources to possible nuclear expansion and moving from uranium supplier to enrichment services and fuel fabrication to the region. Philip Casey Durst, a long-time IAEA inspector in Japan, gave his views on Japan and reprocessing safeguards, especially expanded reprocessing facilities. Susan Voss gave her views on Russia and U.S.-Russian cooperation in future energy ventures such as nuclear fuel cycle centers. Doug Reilly discussed the safeguards and nuclear power industry in South America from the U.S. perspective.

American Perspectives on South American Nuclear Programs
Brazil and Argentina have a need and desire for nuclear power. With a harsh winter in South America, reservoirs down and a consequent drop in the ability for hydropower to provide electricity for heating, there is a need for more power sources. On the level of national prestige, both Argentina and Brazil want to be seen as leaders in high technology by operating nuclear facilities. For both nations, there is doubt that the Global Nuclear Energy Partnership (GNEP) will assist in accelerating the pace of their nuclear programs. Since the GNEP wants to put brakes on the spread of enrichment technology, Brazil, especially, finds this aspect of the GNEP a problem because it has developed a novel gas centrifuge technology. Furthermore, this technology has been the pride of the Brazilian navy. Argentina has a small gaseous diffusion program and shutting down this energy intensive and almost obsolete technology is not such a sacrifice. Hence, elements of national pride and the desire to develop southern hemisphere enrichment market shares will create friction with the GNEP vision in Brazil. Venezuela's president, Hugo Chavez, has stated that Venezuela is interested in a nuclear program. Therefore, the GNEP vision will also be colliding with the deep mistrust in Latin America of U.S. aims and interests in the region.

Australian Perspective
Australia has limited nuclear activities but they have been in existence for a considerable period. In the past, Australia carried out significant nuclear fuel cycle research and development activities. Australia is currently the second largest exporter of uranium and has the largest reserves. Australia today has around 40 percent of global uranium resources at reasonably assured low cost (under US$40/kg), with three operating mines and a fourth approved for operation. However, despite abundant uranium resources, nuclear power is not an economic option for Australia because of abundant reserves of low-cost coal convenient to most major population centers.

The Australian uranium mining industry had its origins over a century ago with the discovery of uranium in 1894. Australia produced small quantities of uranium as a by-product of radium mining in the 1930s. Major uranium ore production started in 1954. There was a hiatus in mining from 1964, but the development of an international civil nuclear power industry stimulated a second wave of exploration activity in the late 1960s. This led to the discovery of most of Australia's major uranium ore bodies, and mining recommenced in 1975.

Apart from the mines, the nuclear activities in Australia are concentrated in only a few organizations, primarily the Australian Nuclear Science and Technology Organisation (ANSTO) and Silex Systems Limited. In 1953 the Atomic Energy Act was passed creating the Australian Atomic Energy Commission (AAEC) and the Lucas Heights Science and Technology Centre (LHSTC) on the outskirts of Sydney was established (Australia's nearest equivalent to a U.S. national laboratory). The AAEC carried out a range of research programs related to the nuclear fuel cycle including conversion, enrichment, fuel fabrication, and waste treatment. AAEC developed Australia's indigenous centrifuge technology at the LHSTC from the 1960s, and Australia was one of the original Hexapartite States. Australia never developed centrifuge technology commercially and shut down the development project in 1983. ANSTO replaced the AAEC in 1987.

Australia's first research reactor was the High Flux Australian Reactor (HIFAR). HIFAR commenced operations at Lucas Heights in 1958. HIFAR finally shut down in March of 2007. Australia's new research reactor, OPAL, was formally opened in April. ANSTO holds most of the nuclear related materials, equipment, and technology in Australia.

The Silex enrichment process is of serious interest to the GNEP and safeguards. Silex Systems Limited (a private company) has a significant holding of nuclear related technology as well as small amounts of nuclear material at their laboratories, also on the Lucas Heights site. The company is researching and developing laser based enrichment technologies for a range of elements, including uranium. Silex's uranium enrichment technology has been sold, under exclusive license, to General Electric, and any commercialization of this technology will happen in the United States.

On the issue of nuclear power reactors in Australia, the Uranium Mining, Processing, and Nuclear Power Review (UMPNER) noted the following:

"Nuclear power is likely to be between 20 and 50 percent more costly to produce than power from a new coal-fired plant at current fossil fuel prices in Australia. This gap may close in the decades ahead, but nuclear power, and renewable energy sources, are only likely to become competitive in Australia in a system where the costs of greenhouse gas emissions are explicitly recognised. Even then, private investment in the first-built nuclear reactors may require some form of government support or directive.

"The earliest that nuclear electricity could be delivered to the grid would be ten years, with fifteen years more probable. At the outset, the establishment of a single national nuclear regulator supported by an organisation with skilled staff would be required. In one scenario, deployment of nuclear power starting in 2020 could see twenty reactors producing about a third of the nation's electricity by 2050 (a position already surpassed by France, South Korea, Sweden, Belgium, Bulgaria, and Hungary, among others)."

Safeguards Challenges Posed by New Reprocessing Facilities

The major challenges in the expansion of reprocessing in the commercial fuel cycle will likely include more plants in Japan and India and others under International Atomic Energy Agency (IAEA) safeguards. The current technical challenge lies in information overload and need for timely data, that is, for online plutonium assay. However, the biggest challenge lies in taking this data and making sense of the data so that it is a viable tool to supplement traditional material accountancy. If the online system supplies voluminous data without any data analysis, the inspector will be overwhelmed by data and unable to make any conclusions. Hence, development of process monitoring and data analysis will need to be a major thrust of the GNEP safeguards research and development to allow for practical and effective reprocessing safeguards approaches.

Another problem is the lack of trained and knowledgeable reprocessing personnel in inspectorate bodies. With commercial reprocessing now located in the UK, France, and Japan, and the UK program's future looking fragile, there is a dearth of experienced reprocessing experts available to work in the state authorities, the regional authorities such as EURATOM, and the IAEA.

Safeguarding very large-scale PUREX (plutonium and uranium recovery by extraction) facilities and pyro-reprocessing is problematic and needs more attention. With the GNEP proposing the Consolidated Fuel Treatment Center on the scale of being four-factors larger than the Rokkasho Reprocessing Plant, there will be a need to consider more flexible inspection regimes. Such inspection regimes could include "statistical process control" verification and regional partnerships to supplement traditional IAEA material accountancy measures to move beyond rigid "criteria-driven" safeguards to draw conclusions on material diversion and facility misuse.

Russia and U.S.-Russian Cooperation in Future Energy Ventures

In 2003, the Russian government established a framework for energy expansion and export. Russia integrated a program to expand the use of nuclear, coal, and hydroelectric generation while increasing the export of oil and gas. Russia estimated four to five times the monetary returns for the export of oil and gas outside of Russia. In November 2005, Sergei Kiriyenko became the Rosatom head and established nuclear power expansion with $55 billion to be spent through 2015, including nuclear and radiation safety budgets of $6 billion for 2008 through 2015. In an interesting counterpoint to the GNEP's desire for fast reactor development, fast breeder reactor development program funding is on the table. However, Russia still has not determined the exact amount to fund.

Kiriyenko reorganized Rosatom toward a government-owned commercial enterprise working through other government-owned entities that purchase the major industrial manufacturing capabilities necessary for nuclear power. Russia will emphasize a primary long-term goal to close the fuel cycle using fast breeder reactors (FBR) and a plutonium-based fuel with reprocessed uranium. The Russian approach would create mixed oxide (MOX) taking in the reprocessed uranium. This differs from the GNEP desire to close the fuel cycle by burning actinides but not separating plutonium. Hence, the Russian vision would be more proliferation sensitive than the GNEP vision or desire. Russia also will grant life extension of existing nuclear power plants. Construction of new VVER-1000/1100 reactors, the construction of the BN-800 breeder by 2012, and advancement of FBR technology—combined with developing advanced fuel with higher burnup and longer lifetimes—would signal an upsurge in Russian nuclear commercial technology. Russia also looks to get into the small reactor market by the planned construction of floating reactors.

Russia is establishing a pilot plant at the Mining and Chemical Combine (MCC) for spent nuclear reprocessing and increased domestic uranium mining, international cooperation, and advanced centrifuges for enrichment, which would be in the spirit of the U.S. GNEP program but with a Russian spin. With the predicted crunch in separative work services and with the nuclear renaissance and the desire to slow the spread of enrichment technology, establishing the international center for uranium enrichment at Angarsk would be a key nonproliferation move that could act to feed an international fuel bank.

This opens up many possibilities for U.S-Russian cooperation. With Russia leading the way in uranium enrichment centers at Angarsk, it has encouraged the United States to create a similar capability. Russia has established the MCC as the pilot center for reprocessing technology. The United States could team with Russia to complete risk analysis of each technique from an integrated fuel manufacturing and safeguards perspective. A joint U.S.-Russian team could evaluate the potential risk of the floating reactors for the diversion of nuclear fuel or terrorist attacks and identify potential ways to mitigate the safeguards and terrorist risks. In the internationally sensitive expansion of India's nuclear program, the United States and Russia could team to establish the advanced measurement capability and integrated safeguards required for a thorium/^{233}U fuel cycle. Hence, there appear to be many ways the United States and Russia could dovetail their nuclear programs to the mutual economic benefit of both states and to the international safeguards effort by working in tandem to strengthen safeguards while expanding nuclear power.

AREVA: An Industry Perspective

In AREVA's home base of France, fifty-eight reactors produce approximately 80 percent of France's electricity. Électricité de France is constructing the European Pressurized Reactor in Flamanville, with electricity production to begin in 2012. The planned Georges Besse II (GB II) Enrichment Facility at Pierrelatte, using centrifuge technology, will eventually replace the present large gaseous diffusion plant now operating at Pierrelatte. GB II is licensed for 8.2M SWU, with the first cascade operating in 2009. AREVA is also evaluating building a centrifuge enrichment facility in the United States. If this project is realized, it could begin operation in 2013 and reach full capacity in 2017. AREVA is also renewing and upgrading conversion capabilities with the planned Comhurex II. In the back end of the fuel cycle, the La Hague Reprocessing Plant will be upgraded to a next-generation reprocessing plant around 2040.

AREVA must abide with the latest waste disposal legislation. French law provides the following statute about waste: "Importation [of spent fuel] for reprocessing can be allowed only in the framework of intergovernmental agreements, if and only if the radioactive waste, generated by this substances after being reprocessed, cannot be stored in France beyond a deadline fixed in such agreements. Agreements include tentative periods for reception and reprocessing of such substances and, if relevant, the future reuse prospects of the radioactive materials recovered during reprocessing." French law is pushing for the final disposal of waste in the parent country. Therefore, French law would not be in the spirit of the GNEP, where the supplier state takes back spent fuel and retains the waste.

The expansion of nuclear energy is possible without increasing the proliferation risk. Industry's key responsibility is to economically and efficiently ensure the supply of reactor and fuel cycle materials and services, in strict compliance with the nonproliferation regime. AREVA already provides fuel cycle services worldwide and is familiar with nonproliferation and physical security norms. Current safeguards and security practices are proven and reliable, as evidenced by the absence of any diversion from a commercial recycling plant. At present, by the fiat of the Euratom Treaty, all of AREVA's facilities are under EURATOM safeguards. There are voluntary safeguards agreements between France, the IAEA, and EURATOM, where some facilities in France are inspected by the IAEA. France, in keeping with the spirit of the Hexapartite Safeguards Project, placed GB II on the list of facilities eligible for IAEA safeguards.

There is work to be done by both industry and inspectorates to keep the nonproliferation regime afloat. There continues to be a need for *guarantees* through extrinsic measures such as international controls and safeguards, which should increase the effectiveness of the IAEA. There is a need to develop new instruments and skills to increase the operator's capacity to implement online, accurate material monitoring that serves national and international safeguards purposes and increases the ability to detect material theft and/or diversion.

In the spirit of the GNEP and the IAEA's integrated safeguards efforts, improvements to safeguards could decrease the need for precious labor and technical safeguards resources. For example, safeguards by design should be incorporated into facilities. We should view safeguards and security in a holistic manner to facilitate the application of safeguards. The industry responsible for the GNEP facilities must be mindful of safeguards and security objectives from the design phase. The GNEP principle is that the nuclear supplier side of the GNEP equation should be concentrated in a few states and the security of the supply of fuel should be increased. The GNEP is a bold big step and gives the impression that industry is looking forward to the nuclear renaissance coupled with the GNEP.

Challenges of Nuclear Expansion: National Nuclear Security Administration

"State-level safeguards by design" is a combination of two terms that are currently in vogue: "state-level approach" and "safeguards by design." "State-level approach" is the name for the IAEA's current overall approach to safeguards implementation. The basic idea is that one starts with the overall objectives of safeguards for the state as a whole and builds down to define activities at specific facilities and locations. This is in contrast to the more traditional approach of defining safeguards objectives at the facility level. In a way, this is returning safeguards to its roots. Although the model Nuclear Nonproliferation Treaty safeguards agreement defines material accountancy measures at the facility level—or more precisely, at the material balance area—the underlying objectives of safeguards are defined for the state as a whole. The fundamental objective is to verify that nuclear material is not diverted. INFCIRC/153 defines the technical goal of safeguards as "the timely detection of the diversion of a significant quantity of nuclear material . . . from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection." This has been interpreted broadly, to include detection of undeclared activities at both declared and undeclared locations.

In the state-level approach, conclusions are essentially qualitative, though conclusions of nondiversion are based mainly on quantitative material accountancy information.

"Safeguards by design" is usually described as designing safeguards into a facility from the start. However, that is not what it means—or at least not all that it means. Designing safeguards into a facility should be old news. The IAEA Board of Governors decided in 1992 that design information should be provided and verified early and often, beginning with initial planning and design. The purpose is to incorporate safeguards into the facility as it is being built rather than to add them on after the fact. The aim of safeguards by design is to go beyond that goal and design facilities for "safeguardability," or to be "safeguards-friendly." Some elements might include

- Use material forms that are easy to measure;
- Make diversion easy to detect (e.g., through choke-points or the use of large, tamper-indicating items);
- Make facility misuse difficult to accomplish and/or easy to detect; and
- Minimize holdup and in-process inventories.

What does the combination of the terms "state-level safeguards by design" mean? At the most basic level, it means designing safeguards into a state's new nuclear energy program from the start. This is already a prominent part of the IAEA's work on nuclear power, to develop the necessary infrastructure for a country to manage nuclear power responsibly. It is much better to build this capacity into an emerging nuclear program rather than to remedy shortcomings after the fact.

But by analogy to safeguards by design, "state-level safeguards by design" should do more than that. It should aim to make a state's nuclear program "safeguards-friendly," by a combination of institutional and technical measures. The technical measures would obviously include design of individual facilities—such as the grid-appropriate reactors that the GNEP aims to develop—to be safeguards friendly. Institutional measures would include capacity building through infrastructure development, as well as the international fuel service arrangements such as those proposed under the GNEP or through the Russian proposal for international fuel cycle centers. The July 3 Joint Declaration on Nuclear Energy and Nonproliferation by Presidents Bush and Putin offers an even more comprehensive set of institutional measures.

Public acceptance of a renewed nuclear development is a very important issue. Surveys show that public acceptance of nuclear power is growing almost everywhere, but it is particularly strong near existing nuclear plants. Regarding the GNEP, the principal nonproliferation benefits of the program are based in large part on an argument about public acceptance. Specifically, the GNEP is supposed to discourage the spread of enrichment and reprocessing by offering comprehensive fuel services that include both assured supply and take-back. Why would a country go to the trouble of developing its own fuel cycle if it could depend on international supply? Spent fuel take-back has huge problems of public acceptance. No one wants to live near "a nuclear dumping ground." The GNEP aims to solve that problem by minimizing the waste burden. The thesis of GNEP is that by making nuclear waste relatively benign, it will alleviate those fears.

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Responding to Challenges I: Strengthening Safeguards

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Introduction

After the first Gulf War, inspections revealed that Iraq had been conducting a large, multifaceted program to develop the means for producing weapons-usable nuclear material. This program had gone undetected by safeguards as well as by national intelligence activities. Reflecting in 1991 on lessons learned from Iraq, then International Atomic Energy Agency (IAEA) Director General Hans Blix concluded that the IAEA can uncover clandestine nuclear activities with a high degree of assurance if three major conditions are fulfilled: 1) access is provided to information obtained, *inter alia* through national technical means, regarding sites that may require inspection; 2) access to any such sites, even at short notice, is an unequivocal right of the IAEA; and 3) access to the Security Council is available for backing and support that may be necessary to perform the inspection.

Subsequently, there was initiated a fruitful six-year effort to strengthen the IAEA safeguards system. This included a reaffirmation of existing authorities and agreement of additional authorities to strengthen the IAEA's ability to respond to undeclared activities. These corrective measures included a change in the focus of safeguards from declared activities alone to the detection or confirmation of undeclared activities as well. In overcoming the declared materials limitation, the IAEA's Board of Governors—scarcely six months after the end of the first Gulf War—reaffirmed that safeguards extend to all nuclear material, whether declared or undeclared; that safeguards access may take place anywhere in a state through use of the IAEA's special inspection authority; and that all relevant information could be used for safeguards purposes.

The importance of this change was dramatically demonstrated soon thereafter when the board found the Democratic People's Republic of Korea to be in noncompliance with its safeguards agreement by denying requested access to undeclared waste tanks, triggering the first remedial enforcement process applied to a potential proliferator as a result of safeguards noncompliance. It is especially relevant to later events that this finding of noncompliance took place without the requested access ever having been achieved and without knowledge of the quantity of plutonium diverted. In short, the denial of access that the State was legally obligated to provide spoke for itself. In 1997, the Model Additional Protocol was negotiated, formalizing the IAEA's expanded access to information and locations.

Some progress has been made since then, such as the increase in the safeguards budget and agreement to strengthen safeguards measures for countries that have no significant nuclear activities, but the following problems remain:

- More than a decade after the board adopted the Model Additional Protocol, progress on adherence remains slow. More than half of the states signed up with the Nonproliferation Treaty do not have protocols in force, including fifteen nonnuclear weapon states with significant nuclear activities.
- The A. Q. Khan network has shown how illicit networks of nonstate actors can spread the most sensitive nuclear technologies.
- Critical cases of safeguards noncompliance in Iran and North Korea remain unresolved.
- The Committee on Safeguards and Verification failed to reach agreement on any measures to strengthen safeguards and even called into question previously agreed-upon measures.

Information Acquisition, Management, and Sharing

With the dynamic advances in the digital world and the even more spectacular development of telecommunications and associated portable devices in the last decade, processing and managing copious information presents challenges to everyone. In view of the challenges identified at the end of the twentieth century, maybe nowhere else than in the area of international nuclear security has the need for extended data collection, advanced information evaluation and analysis, and proper dissemination of pertinent knowledge become more important.

Central to the IAEA's approach to safeguards is the state evaluation process, which evaluates and draws conclusions from a state's nuclear activities and the assets it needs for proliferation. The result is a coherent picture that supports findings of no evidence for diversion of declared nuclear materials and no evidence for undeclared nuclear materials or activities. The modern safeguards system, therefore, is information driven, and the sharing and management of information is coming to play a more prominent role in the implementation of safeguards. It is crucial, therefore, to ensure the mastery of safeguards information and to achieve optimal benefit from relevant technological breakthroughs so that, as often stated by its director general, the IAEA remains ahead of the game.

The goal of the IAEA's information management systems is to efficiently convert raw safeguards data into knowledge that supports safeguards conclusions. Therefore, the raw data must be credible and of high quality, its acquisition must be appropriately designed and implemented, and it must be protected and authenticated from its source all the way through to its analysis. The analysis of safeguards data often requires the application of unique and specialized expertise. However, limitations on the IAEA's human resources require as many automated solutions as possible. As the volume of safeguards data continues to increase rapidly, so do the needs for improved analytical tools, analysis algorithms, data integration techniques, and knowledge extraction engines. The challenge to globally manage nuclear materials demands no less.

Although the IAEA is allowed by its statute to accept relevant third-party information, there inevitably are restrictions on the sharing of such information. States and the nuclear enterprises therein are naturally concerned about protecting their methods, sources, and capabilities from their adversaries and competitors; therefore, limits are established. Were all parties to focus on the mutual nonproliferation benefit, perhaps information sharing could be further optimized without compromising state secrets and proprietary information. This could include, for instance, sharing strategies for communication and management of information, along with approaches for optimal usage and analysis of the information.

Member states may at times be frustrated that their sharing of information with the IAEA is asymmetric, but the IAEA is bound by confidentiality agreements with all the member states. Consequently, less information comes out of the agency than goes in. Nevertheless, the information exchange benefits common interests because it serves to reduce global proliferation risks. The national intelligence services have rarely, if ever, been surprised by the existence of a nuclear weapons program, even if they have not always been able to provide comprehensive insight into the scope, status, and location of weaponization activities. It is far beyond the IAEA's capabilities to duplicate the national technical means of many of the member states; therefore it relies on information they supply in order to know under which roofs to look and what lines of investigation to pursue. IAEA inspectors, because they have boots on the ground, eyes under the roofs, and relationships with facility personnel, can complement the assets of national systems.

Integrated Safeguards and the State-level Approach

The IAEA's implementation of the traditional safeguards approach entails applying the same safeguards activities at similar facilities in all nonnuclear-weapons states with comprehensive safeguards agreements. Developed to ensure consistency in safeguards applications and to facilitate the evaluation of safeguards implementation, this criteria-based, checklist-type approach has a number of limitations: it may not provide sufficient flexibility to deal with the variety of situations in the different states under safeguards; it does not necessarily motivate inspectors to look beyond the checklist; and it can result in an inefficient allocation of safeguards resources. Consequently, it is unable to deal effectively with the challenges of detecting undeclared nuclear materials and activities. On the other hand, the criteria-based system is unarguably nondiscriminatory—applying equally to all—and is relatively easy to implement and evaluate.

The integrated safeguards (IS) concept and the state-level approach (SLA) are the most recent outcomes of the evolution of safeguards and are designed to ensure the continued effectiveness and credibility of IAEA safeguards. The concept of IS, which uses an optimal combination of safeguards measures available under both INFCIRCs 153 and 540, was developed by the secretariat and endorsed by the IAEA Board of Governors to define how to achieve safeguards results using the IAEA's new authorities. It was also, in significant measure, a response to member state concerns about the cost of safeguards and the associated impacts on their civil nuclear industries.

Under the IS concept, as implemented by the secretariat, a state with a comprehensive safeguards agreement and an Additional Protocol in force is evaluated over a length of time that depends, among other things, on the complexity of the state's fuel cycle and the availability of safeguards-relevant information that provides indications of diversion of declared nuclear materials and indications of undeclared nuclear materials and activities. Once the secretariat has completed its examination of all information available to it, and finds no indication of diversion of declared materials and no indication of undeclared nuclear materials and activities, it concludes that all nuclear material remains in peaceful activities in the state. Following this *broader conclusion,* the secretariat, in consultation with the state, develops an IS approach with the state that usually involves reductions of safeguards efforts on declared materials and facilities, for example, less frequent interim inspections, random selection of facilities to be inspected from a population of facilities, or lower detection probability goals. Achieving this *broader conclusion* and coming under IS has become politically important to many member states, such as Japan and Canada.

Even though IS is politically important and helps to extend scarce resources, the future of safeguards may lie in the SLA. The SLA was developed by the Standing Advisory Group on Safeguards Implementation, in consultation with the secretariat, to address ongoing concerns about the allocation of safeguards resources and the effectiveness of safeguards in less-cooperative states. The SLA is information driven, with a uniform analytical process applied to all states, but with the prospect of nonuniform implementation of safeguards at similar facility types in different states. An essential premise of the SLA process is that information-driven differentiation in safeguards implementation and evaluation does not constitute discrimination. When a large fraction of available resources are applied to states clearly intent on compliance (e.g., Canada, Germany, and Japan), it limits the ability of the IAEA to direct increased resources at states that demonstrate through their own behavior that they should be subject to more intense scrutiny.

The SLA builds on a careful and structured analysis of all aspects of a state's nuclear activities and the nuclear weapons materials and technology acquisition paths available to it. As part of its state evaluation process, the IAEA monitors technical, programmatic, and political indicators that suggest a state may have a potential or active interest in nuclear weapons and is able to develop a realistic sense of which countries present the greatest risk in that area. This state evaluation process is embodied in the State Evaluation Report (SER), which envisions safeguards customized for each state. The factors that go into the SER must be objective and must be derived from information rather than opinion. When performing evaluations that could lead to changes in safeguards activities for a particular state, the secretariat considers such factors as the quality of the State System of Accounting and Control, the willingness of the state and its nuclear facility operators to employ safeguards measures (such as unattended and remote monitoring, short-notice random inspections and timely mailbox declarations), and the availability of information about the state's nuclear activities. In practice, most adjustments have increased safeguards effectiveness as well as efficiency.

IAEA Missions and Authorities

Among its missions and authorities, the IAEA now has unambiguous responsibility for detecting undeclared nuclear facilities in states with comprehensive safeguards agreements. Now and in the future, the IAEA will need to balance and to distinguish between the tasks of searching for undeclared sites and resolving questions raised by information made available to it. The scope of these two tasks and the tools required to perform them are different.

A number of new responsibilities have been proposed for the IAEA—many of which have been considered before—and could have major implications for the agency's future needs. These proposed missions and authorities pertain to the following:

Reliable Fuel Supply
The IAEA recently published a review of proposals for a reliable fuel supply. These proposals came from many sectors and suggested a wide range of roles for the IAEA, from providing certification of certain nonproliferation credentials, to market broker for sensitive fuel cycle services, to a more direct role in multinational fuel center operations. If implemented, this could represent a major expansion in IAEA responsibilities.

Nuclear Terrorism
Since September 11, the IAEA's role in promoting the physical protection of nuclear material around the world has been reexamined. The IAEA promotes improved physical protection primarily through voluntary measures. These measures are currently the province of national governments, but the possibility of increased IAEA oversight is under debate. Depending on how far such oversight might go, new authorities would be necessary, as well as significant additional resources.

Nuclear Commerce
Expanded IAEA monitoring of commercial nuclear activities to uncover illicit supply networks and possible undeclared activities has been suggested in response to the A. Q. Kahn network. Options for enhanced IAEA cooperation with the Nuclear Suppliers Group have been considered. Although certain declarations are required under the Additional Protocol, the ultimate reach of the IAEA may be limited. Questions of commercial sensitivities also remain.

Weaponization
The IAEA's role in detecting and verifying weaponization activities is a sensitive issue. Efforts to detect such activities will necessarily be balanced with risks of spreading sensitive information. If it is ultimately judged to be desirable, it may be necessary to accord the IAEA new authorities.

IAEA Enduring Challenges

With regard to IAEA capabilities, enduring safeguards challenges remain. Although understood for some time, they are nevertheless difficult to address. They can be categorized in terms of measures to address safeguards requirements at declared nuclear facilities, to detect undeclared facilities, to address the chronic issue of resources (both human and financial), and to advance safeguards-related technologies.

Declared Facilities
Certain challenges exist in effectively safeguarding declared industrial-scale bulk-handling facilities (both enrichment and reprocessing facilities). Measures for dealing decisively with the problems of protracted diversion at large reprocessing facilities and undeclared enrichment of nuclear material at enrichment facilities are needed. Additional containment/surveillance measures have been employed to fill the gap. Increased use of operator data has great potential but authentication issues must be addressed and proprietary information must be protected.

Undeclared Facilities
The challenges before the IAEA to detect undeclared facili-

ties are myriad and daunting. Having the ability to affirm the absence of undeclared activities is not just a matter of proving a negative because some activities, such as reprocessing, can be done on scales small enough to defy detection. Often with mixed results, states expend a significant amount of effort and resources—far exceeding IAEA limits—in this area. Rather than duplicating national technical means, tools and capabilities must be sought that maximize IAEA effectiveness when triggered by other information. These capabilities might include increased capacity to analyze environmental samples; persistent, limited-area surveillance to sustain continuity of knowledge; and portable in-field analysis to guide inspections.

Financial Resources

Having borne since the late 1990s—with zero real budget growth—the dual responsibility of verifying member state declarations and investigating indications of undeclared activities, the additional work resulting from strengthened safeguards is straining the IAEA's safeguards budget, even with the recent increase approved by the member states. The limited budget provided by the member states for safeguards keeps the agency from functioning optimally and forces it to carefully weigh where to apply its resources. How the IAEA divides its resources now is very important because member states seeking to deceive the safeguards system would seek to exploit the weakest link.

In an ideal world, the IAEA would have the financial and human resources necessary to allow it to meet its entire mission independently. However, even in such a world, there are justifiable roles for member state support programs (MSSPs) to play. In the United States for example, it is difficult if not impossible, due to contracting practices, for the national laboratories to work directly for the IAEA. One of the reasons for the establishment of the U.S. support program (USSP) in 1977 was to provide a mechanism to make U.S. national laboratory technology available to the IAEA. Approximately 40 percent of the current USSP annual budget is directed towards work by the national laboratories for the IAEA. MSSPs also provide the use of their facilities for training of inspectors. Without this source of training, IAEA inspectors would not be able to practice their skills in the field or with special nuclear material. MSSPs also provide facilities for the testing of new equipment such as surveillance systems or remote monitoring technology.

The practice of MSSPs providing cost-free experts (CFEs) will continue to be justifiable. CFEs address special projects for which the IAEA does not have in-house expertise. They are meant to work for a short time, typically two to four years, on the project and then to leave the IAEA when it is complete. This enables the IAEA to pursue the project without having to create the necessary staff positions for the job.

If all member states were to assist the IAEA with its uncovered needs, concerns about its independence would be mitigated. As it is, the United States has the largest MSSP and makes the largest voluntary contribution. Only a handful of member states have joined the United States in supporting the ISIS Re-engineering Project, a critical project to replace the antiquated safeguards information system. More recently, the IAEA is looking principally to the U.S. to fund the upgrade or replacement of the Seibersdorf Safeguards Analytical Laboratory. These are very costly projects that have significant impact on the IAEA's ability to carry out its safeguards mission.

Human Resources

High attrition in the Safeguards Department is exacerbating the issue of IAEA effectiveness by decreasing the experience level of the average inspector. A challenge for the safeguards community will be to ensure a pipeline of well-qualified scientists and engineers adequate to keep the Department of Safeguards fully staffed in the decades to come. In the past five years, several programs to educate and train students have been started in response to this problem. One of the factors contributing to sustaining the cadre of safeguards professionals at U.S. national laboratories is their research and development programs, which are appealing to entry-level scientists and engineers. This, unfortunately, is not a drawing card for the IAEA because it lacks similar research and development capabilities.

Technological Advances

Forty years ago, safeguards research and development activities were broad-based and focused on identifying signatures and developing analytical approaches, especially nondestructive assay, to augment traditional chemical analysis. For the past thirty years, the safeguards community has been deriving technology from the efforts of the first decade, taking advantage of advances in science and technology that enable evolutionary improvements in the basic techniques and methods. To meet the challenges of the information revolution and to support continued strengthening of the safeguards system, research and development (R&D) in the areas of information management systems and systems analysis and evaluation will also be needed. By sustaining a holistic, integrated point of view, the community may yet be able to leverage scientific and technological advances to enable new levels of performance to be achieved. This can enable new approaches, more efficient use of limited resources, rapid response to new challenges and threats, and recruitment and retention of the next generation of safeguards professionals. Domestic funding for safeguards R&D has declined in recent years, forcing U.S. safeguards professionals to international work-for-others programs in order to continue to make advances. Recent news that U.S. policy makers are recognizing the need for research and technology development is encouraging.

Addressing Noncompliance

Blix's 1991 assertion that "a high degree of assurance can be obtained that the IAEA can uncover clandestine nuclear activities" if certain conditions are fulfilled deserves some examination. It is noteworthy that he referred to "clandestine nuclear activities," which does not necessarily specify a nuclear weapons program. In the past few years, the IAEA director general has commented that the IAEA has limited capabilities and authorities to make a full investigation to determine whether, in fact, a nuclear weapons program exists. It is important to keep in mind that the IAEA spends its efforts looking for indicators of noncompliance with safeguards agreements. There is a great difference between looking for the indicators of noncompliance and drawing conclusions about a nuclear weapons program. Raising the bar to the level of finding "smoking gun" proof that there is a nuclear weapons program before reporting a finding of noncompliance to the Security Council would constitute a grave erosion of the authorities that underpin safeguards effectiveness. History and common sense indicate that when the IAEA is denied access to information or locations, that such action may be sufficient to conclude that a State is not in compliance with its safeguards obligations because it is in direct conflict with the principle expressed in INFICRC/153 that "diversion to purposes unknown" constitutes noncompliance.

Following the Iraqi experience after the first Gulf War, the IAEA promptly undertook a review of the reasons for the failure to discover in order to take action concerning the Iraqi noncompliance. This review, which was conducted by the IAEA itself with some participation by outside experts, led directly to the board's reaffirmation of the IAEA's special inspection and related rights and to the development and adoption of the Additional Protocol.

It may be expedient to undertake a similar review in connection with Iran's eighteen-year concealment of its sensitive nuclear activities and the illicit supply network that has been linked to undeclared nuclear programs in Iran, Libya, and North Korea. Such a review should include consideration of whether information indicative of these activities might have been available or ascertainable and identification of any obstacles to the IAEA's rights to take action on any such indications. To help assess the need for further strengthening, it would also be useful to examine whether the Additional Protocol, had it been in force in Iran, would have spotlighted Iran's noncompliance, and whether and how a response to such information might have been made.

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Responding to Challenges II: Science & Technology R&D Opportunities

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Abstract

This panel discussed some of the research and development opportunities that could help address the safeguards challenges discussed in the other sessions. The opportunities range from novel sensor materials to new ways to combine data sets and to miniaturize traditional measurement approaches. The challenge will be to decrease the costs of these approaches while improving the speed and quality of the conclusions that can be drawn.

Introduction

This panel discussion on research and development (R&D) opportunities in safeguards science and technology addressed the question of how both evolutionary and revolutionary science and technology advances can help to address the challenges outlined in other sessions of the symposium. The discussion was guided by five major questions, as follows:

- Can technological advances drive down the cost of nuclear detection so that it becomes part of a ubiquitous network, rather than a specialized point application?
- What can we expect from persistent surveillance of activities both inside and beyond a facility perimeter; for example, using miniature UAVs or distributed point sensors?
- What opportunities will emerge from advances in the sensitivity and speed of trace detection?
- What advances can be expected for information technology in exploiting complex data sets (e.g., images) and integrating heterogeneous information sources?
- How else might new technology track all nuclear material, all of the time (e.g., highly enriched uranium) in a large, complex facility?

Several themes emerged, common to multiple topics. One was that underlying physics constraints dictate the size and mass of neutral particle detectors. Another was the potential for using multiple sensor types, integrating the data streams and cuing one type of data stream with another. A third theme was the idea of pushing trace-detection analysis into field instruments capable of real-time or near-real-time operation.

Novel Detectors and Sensors

Because the cross sections for gamma-ray and neutron interactions are fixed by nature, the prospect of significant size reduction for gamma-ray and neutron detectors is not good. However, the prospects for developing detectors with better performance and lower cost are good.

In particular, the development of large-size detectors made of organic-inorganic composites has the potential to substantially reduce the cost of detectors, moving instrumentation toward more ubiquitous sensor systems. Although networks of nuclear sensors can never be microminiaturized, their cost can be driven down substantially, given lower-cost detection materials. One common misconception among the radiation detection community, with respect to nanoparticle-based detector technologies, is that somehow the claim is being made that a size reduction is possible. In fact, the underlying concept is to use two related properties of these new materials to improve detectors. One property of interest is the fact that the optical and electronic properties of these materials can be tuned in ways that are not available for macroscopic single crystals. The other interesting property is that because the synthesis methods used are often amenable to cost-effective scale-up, the cost of these materials can be significantly lower than for single crystalline materials. Combining these properties allows the possibility of creating composite detector materials that are simultaneously of higher performance and lower cost than existing materials.

Another topic related to the fundamental limits of detection was the idea of using neutrino radiation to monitor reactor activity. It was pointed out that it is possible to use detectors such as Super Kamiokande and KamLAND to indicate whether an identified reactor is on or off. Given a detector of size 1 kiloton consisting of a liquid scintillator located 1,000 meters underground, the range of detection could well be on the order of one to a few hundred km. It is clear that physics poses some practical limits on what may be achieved. In particular, such schemes are likely to be useful mainly in countries willing to grant extensive access, so that either a monitoring facility can be located within their borders or a smaller detector can be located directly adjacent to or within their facilities.

Combining Detectors

The potential to use multiple sensor types was highlighted with several examples. Compton imaging combined with LIDAR imaging was used as an example from which a great deal of information can be extracted, even though the energy resolution of the Compton imager limits the possibility of spectral identification. By overlaying the images from different sensor technologies, the location of sources within the structure of the room could be determined by simple visual inspection. Another example was analysis of the count rates in an array of simple neutron counters and the possibility of combining this with imaging information to understand facility material movements and then to look for anomalies.

Using other sensors to cue video imagery for analysis is a particularly powerful technique. It is already being used, but offers a great possibility for refinement. There are likely other examples of sensor fusion that are equally valuable.

Finally, it was pointed out a number of times that it is likely that humans will have to be involved in the analysis and resolution of anomalies, but that automatic systems can help to remove some of the background and to locate potential anomalies for human examination. This is required, among other reasons, because of the high potential for false alarms.

Trace-Element Detection

In the area of trace-element detection, there are several opportunities. One opportunity is to miniaturize existing laboratory-based techniques to move trace analysis into the field. Additionally, the laboratory techniques could themselves be improved by greater automation or standardization to yield increases in throughput. Advances in the area of microfluidics may make these improvements possible.

Another opportunity is to get more information from the data that we have. Currently, trace analysis is generally restricted to elemental and isotopic composition. By obtaining more chemical information, it may be possible to gain a greater understanding of what processes are being used and how they are being run and when they are being run. This could be complemented by developing a better understanding of the transport and fate of analytes in the environment, in order to better help identify the age and source of origin. Another area of interest is in-plant monitoring of processes. At this time, the focus is primarily on the mass balance of actinides. By monitoring nonactinide process variables, it should be possible to ensure that there is no attempt to modify the process chemistry in an effort to divert material. Online analytical chemistry is still an area of interest, especially in complex facilities. Trace analysis may become important as part of tagging and tracking of nuclear materials.

One particular technology that was mentioned was alpha particle spectroscopy using recently developed microcalorimeter technology. This technique gives a factor of four in resolution over silicon detectors and may speed up trace analysis by eliminating the need for mass spectroscopy.

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Responding to Challenges III: Improving Education and Training for Nuclear Safeguards

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Abstract
As the world enters a revival in the use and development of nuclear energy, new partners in this field may contribute not only to its advancement but also, inadvertently or not, to the risk of a growing global nuclear threat. Increased global use of nuclear energy could open new avenues for the illicit production, acquisition, and use of nuclear materials by states and groups who have heretofore not had this capability. To counter the specter of nuclear terrorism, we must seek to educate a new cadre of individuals in both the policy as well as the science of nuclear safeguards. As part of the Fortieth Anniversary Safeguards Symposium, held in July 2007 at Los Alamos National Laboratory, a panel of safeguards practitioners from various subdisciplines reflected upon the challenges germane to the future of nuclear safeguards education and training. This paper summarizes the ideas put forth in that discussion.

Introduction
Broad expertise in safeguarding and protecting nuclear materials from unauthorized uses is critical to national and global security. This will be even more true in the future as the potential threats of nuclear terrorism, nuclear proliferation, and illicit nuclear trade are likely to increase. The expected expansion of nuclear energy use worldwide only sharpens the need for people trained in the policy and technology of nuclear safeguards. Yet there remain few university graduate-education programs that provide in-depth training in both the policy and technology of nuclear safeguards.[1] While this is beginning to change, nuclear safeguards experience has traditionally been gained through on-the-job and ad hoc training by governments, commercial nuclear operators, or the International Atomic Energy Agency (IAEA). An increase in formal educational opportunities in these fields for students and early career professionals will be critical to sustaining adequate numbers of technically trained individuals to meet the future needs of government and industry worldwide. The development of more specialized and continuing relationships between providers and consumers of nuclear safeguards training is also critical to meeting the growing need for skilled personnel.

To investigate potential actions to improve the effectiveness of nuclear safeguards training and education worldwide, Los Alamos National Laboratory convened a panel on this topic during its Fortieth Anniversary Safeguards Symposium in July 2007. The panel included experts and early career nuclear scientists with a broad range of experience as educators and practitioners of nuclear safeguards and nonproliferation policy. The panel considered the topic of safeguards training comprehensively and focused on a set of questions provided by the symposium organizers.

Observations of the panelists and comments from the symposium participants in response to each question are summarized below. Following this are some concluding remarks that summarize common themes, raise future challenges, and recommend some specific actions on the part of members of the nuclear safeguards community.

How can safeguards education and training be improved to meet the growing demand resulting from an expanded use of nuclear energy worldwide?

The greatest increase in nuclear energy use is forecast to be in the developing countries. This means that experts who will increasingly be from countries previously unfamiliar with international nuclear nonproliferation and safeguards regimes will need to learn the basic values of a nuclear safeguards culture and the existing mechanisms through which they are established at nuclear facilities and regulatory agencies. This is a tremendous challenge. The IAEA and developed nations with a stake in the expanded use of nuclear energy will have to increase their abilities to provide safeguards training and education to countries that deploy nuclear energy systems in the future. One way to do this is through partnerships with universities and nongovernmental organizations that have international studies programs with established ties to the developing world or that have held international nonproliferation or safeguards symposia in the past.

One of the key findings of the session was that there are potential benefits to coordinating the structure of domestic safeguards training internationally. This means developing a common safeguards curriculum that includes international "best practices" for nuclear materials protection, control and accounting, and the creation of a more standardized legal requirement for domestic safeguards in every country. Another clear challenge to an expanding global nuclear energy industry is to make safeguards at commercial facilities as nonintrusive and complementary to operational demands as possible, so that implementing a state's international safeguards obligations is affordable and never in conflict with effective plant operation.

Universities can be key partners in a strategy for improving nuclear safeguards training. Nuclear safeguards is by nature a multidisciplinary field of study that contains elements of several traditional academic disciplines, including nuclear engineering, computer science, information technology, history, international security studies, and law. Until recently universities have not chosen to create customized degree or certificate programs in nuclear nonproliferation or safeguards that combine selected courses from across the multiple disciplines mentioned above. Notable exceptions to this are programs at Texas A&M University, the University of Missouri, Georgetown University, the University of Washington, and Washington State.

The challenges that universities face in creating these programs include the lack of financial support, uncertainty regarding the ability to attract enough students for such a specialized program, and a limited number of faculty with the needed interest, training, and experience. Adequate laboratory resources, and even access to nuclear research facilities, are other challenges to offering a well-rounded concentration in nuclear safeguards.

Other interested stakeholders could help universities overcome these challenges and, in turn, establish relationships with universities that improve the skill level and value of students entering the workplace after completing programs that focus on nuclear nonproliferation and safeguards. Some examples of collaborative activities that could improve safeguards education include the following:

- Government support for nuclear research reactors and other university facilities justified by the benefit these facilities provide to the future safeguards workforce.
- Input from the National Nuclear Security Administration, the U.S. Nuclear Regulatory Commission, and private industry should be provided to university departments that offer nuclear safeguards programs to help establish specific courses or curricula that would most meet their hiring needs.
- Consumers of safeguards training should provide opportunities and financial support for early and midcareer staff to attend appropriate university programs.
- Universities should seek out guest lecturers and temporary faculty from among experienced nuclear safeguards professionals who, in turn, should be encouraged by their organizations to perform such activities.
- In general, government and IAEA officials should stress the critical importance of nuclear nonproliferation and safeguards training for their nuclear security and energy security missions. They should also forecast their anticipated workforce needs. This would generate more interest in establishing safeguards training programs at the university level.

What diverse education/training is needed to produce an outstanding nuclear safeguards specialist?

Nuclear safeguards specialists need a well-rounded education. Depending on which area of safeguards is chosen as a career focus, further education in the diverse fields of nuclear technology, political science, and regulation enforcement will be beneficial. The technical training facet may include courses in radiation dosimetry, nuclear engineering, computer programming, electrical engineering, nuclear physics, and/or radiochemistry. A background in political science as related to U.S. nuclear policy and international efforts to control the spread of nuclear weapons would be helpful. Additionally, a basic understanding of the legal and regulatory structure relevant to nuclear operations and international agreements would be useful for individuals choosing to enter the broad field of nuclear safeguards. Finally, also important is a solid grounding in the *why* and *how* international safeguards are considered to serve the interests of national and international security. This would include a thorough exposure to the early history of nuclear weapons proliferation and the international efforts to limit it.

The fundamentals of nuclear nonproliferation and safeguards can be taught at the university level. These programs need to be improved through formal or informal integration with official government or IAEA nuclear safeguards training curriculum. Mechanisms for achieving this integration are university/national laboratory collaborations; internships for students; fellowships that provide opportunities for the temporary rotation of safeguards experts and faculty between academia, industry, and government; and guest lecture programs that expose students to the challenges of implementing nuclear safeguards at operating facilities.

Some detailed subjects for advanced nuclear safeguards training could include the following:

- Elements of a safeguards agreement
- Creation of a state system of accounting and control for nuclear materials
- Statistical techniques for nuclear material accountancy
- Containment and surveillance of nuclear processes
- Conducting surprise inspections
- Environmental monitoring for safeguards
- Destructive analysis and nuclear forensics
- Information collection and analysis for strengthened safeguards
- Nondestructive analysis for nuclear material measurements

For this type of training, the national laboratories are both experienced in designing and conducting such training and have the facilities necessary for working in real nuclear installations.

What near-term activities can be taken to improve education/training at the university, national laboratory, and international levels?

A theme for near-term improvement of education and training is realization that nuclear safeguards represents a truly multidisciplinary field of study and application that require both academic study and field experience. A mixture of lectures and facility experience is necessary to retard the potential for stovepiping between the policy and technical personnel. Within a university environment, a near-term mechanism for exposing the student to the multidisciplinary nature of safeguards could be the addition of a seminar series presented by faculty from a variety of departments and disciplines (in addition to nuclear engineering); physics, chemistry, electrical and computing engineering, mechanical engineering, business, and political science are possibilities.

Again, there needs to be communication between the potential hiring organizations (governments, industry, IAEA) and the training organizations. The government should help to make it a priority to better integrate national laboratory personnel within the university system. This could be accomplished through training held at the laboratories to educate university faculty or to have exchange programs for laboratory individuals to take *sabbaticals* to universities to teach and interact with both students and faculty.

Universities, national laboratories, corporations, and governments (both U.S. and international) must work together to develop and disseminate this course material to students to ensure a competent workforce for the future. The vast majority of safeguards knowledge in the U.S. resides at the national laboratories, and filtering that knowledge to university students and faculties is an absolute requirement for its retention.

What are the weaknesses or limitations of the safeguards training community, and should the safeguards education and training mandate be expanded, or evolved?

Efforts to expand the use of nuclear energy will rely somewhat on public perceptions that such use will not increase risks to the public or the environment and will not lead to a heightened chance of nuclear weapons proliferation or nuclear terrorism. The safeguards community can impress upon both the public and those involved in nuclear systems development the important role that safeguards plays in both nuclear energy system operation and in how such systems and technology are perceived by society at large. Effective nuclear safeguards and the institutions that implement them are essential to meeting this challenge.

As new nuclear energy technologies mature and are deployed, safeguards specialists will have to learn new skills. For example, safeguards training will need to be enhanced to address the complexities of new materials that are expected to be used in future nuclear fuel cycles, such as fuels for advanced burner reactors and the products of advanced reprocessing technologies. As costs to operate laboratory facilities continue to rise, more use of simulation and modeling tools will help contain costs but cannot completely replace all laboratory facilities, or there will be no place to learn the skills necessary to function safely in an operating facility.

Safeguards inspectors will also need training to support a wider choice of tools available in the future. Some training will have to be conducted in very realistic laboratory or facility settings to be of maximum value and to prepare the student for conditions to be encountered in the field. Techniques for performing the best nuclear measurements achievable in uncertain situations will require the development of technical judgment and innovation. The ability to make order-of-magnitude, back-of-the-envelope calculations to check the reasonableness of a measurement or troubleshoot an equipment problem is also a vital skill that can only be acquired by solving real safeguards problems under working conditions.

Final Observations

An expansion of nuclear energy use worldwide will sharply expand the need for nuclear safeguards specialists in at least three categories: national nuclear facility regulators, commercial plant operators, and safeguards inspectors at the IAEA. Without significant new investment by all of these organizations in the human, institutional, and technical capital of safeguards, it is likely that the challenge of preventing a rise in global nuclear energy use from causing a corresponding increase in the risks of nuclear proliferation, nuclear terrorism, and illicit nuclear trade will not be met. One way to improve safeguards training is to acknowledge that it is a shared objective and to coordinate the application of resources by the major nuclear safeguards stakeholders towards achieving this objective. This requires the articulation of an international safeguards training vision and strategy and the formation of a consensus to translate that strategy into action.

Another important thrust for improving nuclear safeguards training over time is to maintain a robust safeguards technology research and development program. Only a strong R&D program will attract the students with an inclination toward hands-on experimental work, who then become the next generation of first-line facility operators and measurement experts. This can only be funded by governments, and in ideal situations, with additional contributions by industry. A safeguards R&D program offers a distinctly different activity that provides valuable input to safeguards training programs by articulating a roadmap for safeguards technology development and by providing an additional pool of safeguards experts with a different skill set who can rotate through university and IAEA programs. Increased support for open-ended safeguards-based research should be part of a robust R&D program. Funds to support safeguards experimentation will attract doctoral students and can aid in proof-of-principle demonstrations that can lead to innovation that reduces safeguards costs or the degree of disruption caused by inspections to plant operations.

Note

For a good survey of university programs existing in 2006, see the *Journal of Nuclear Materials Management,* Volume XXXIV, No. 4 (Summer 2006). In addition to the programs featured in this issue, the University of Missouri-Columbia, with assistance from Brookhaven National Laboratory, has initiated a Graduate Certificate Program in Nuclear Safeguards Technology. See "A Graduate Certificate Program in Nuclear Safeguards Technology," J. Neustrom, J. Gahl, W. Miller, M. Prelas, K. Trauth, T. Ghosh, G. Neumeyer, University of Missouri-Columbia, Nuclear Science and Engineering Institute; L. Fishbone, B. Siskind, S. Pepper, Brookhaven National Laboratory, presented at the INMM 46th Annual Meeting, Phoenix, Arizona, July 10–14, 2005, http://www.pubs.bnl.gov/documents/30221.pdf (September 2007).

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The Future of Nuclear Safeguards

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Introduction

The international nuclear nonproliferation regime has undergone significant change in the last two decades because of the creation of the strengthened safeguards system. The effort by the safeguards community is to be applauded; in particular, the effort by the International Atomic Energy Agency (IAEA) to translate the new measures and provisions into an implementation and verification system without compromising its independence.

The provisions in the Additional Protocol concerning extended access, additional information, and powerful instruments for verification give the IAEA significantly enhanced power. Environmental sampling, satellite imagery, and open-source information, as well as other information, are key elements of the strengthened safeguards system.

Despite these additional provisions and instruments for the IAEA, we encounter massive failure of the international verification system to detect the comprehensive supply networks, like the A. Q. Khan network, involving many Western countries and companies.

In December 2003, the Libyan government announced that it would give up its nuclear, chemical, and long-range missile programs. The first IAEA report sketched the outlines of Libya's clandestine uranium-enrichment program, which had been underway since the early 1980s. The program planned to use thousands of gas centrifuges to increase the concentration of weapons-grade uranium-235. The IAEA board adopted a resolution in March 2004 finding that Libya's past clandestine nuclear activities "constituted noncompliance" with its IAEA safeguards agreement but also praising Libya's subsequent cooperation and dismantlement efforts.[1] Since that time, the most important components of Libya's nuclear weapons program have been removed.

Nuclear weapons require either highly enriched uranium, produced by enrichment, or weapons-grade plutonium, recovered from irradiated nuclear material. Not only has Iran carried out work on enrichment technology, but it has also successfully carried out the recovery of plutonium from irradiated material. Whatever the position may now be concerning Iran, there are, and have been, many doubts about its program in the past. The IAEA report of November 2007 stated that, *". . . bearing in mind the long history and complexity of the program and the dual nature of enrichment technology, the Agency is not in a position, based on the information currently available to it, to draw conclusions about the original underlying nature of parts of the program."* [2]

Libya, Iran, North Korea, and probably other states received considerable foreign assistance for their nuclear programs, especially from a clandestine procurement network run by Abdul Qadeer Khan, the father of Pakistan's nuclear weapons program.[3]

All these events raise questions about the future of nuclear safeguards. A question such as how we can avoid new cases of proliferation can be addressed only if we assess the new changes and look at how we can better meet the future challenges.

Incentives/Disincentives for Nuclear Weapons Acquisition

The incentives to acquire nuclear weapons are widely known but vary depending on the country and area concerned. A major motivation is the feeling of a lack of security, but the wish for prestige or the intention to achieve hegemony in a region are also factors. This is why a security policy plays a key role in preventing countries from acquiring nuclear weapons.

After looking at such countries all over the world, it becomes clear that the (predominantly) bilateral security agreements have not achieved their purpose. Regional and global security guaranties (in particular, those involving most of the superpowers) may actually provide stronger disincentives to abolish nuclear military options than bilateral arrangements.

The European Union is an excellent example where stability was created by getting the countries to work together under a "neighbors are watching neighbors" approach to achieve confidence and trust about the peaceful nuclear developments in all its member states. A similar approach was implemented successfully in Argentina and Brazil with the creation of a joint inspectorate (ABACC). This successful model should be pursued in other regions in the world with security problems; for example, in the Middle East and South East Asia.

Some other options are also possible as incentives to abandon nuclear military options. For example, the acquisition of a weapons capability in several cases was, *de facto,* rewarded by supporting these countries economically, technologically, or through trade preferences.

Other options are related to the important role that the IAEA should play in implementing the Nuclear Nonproliferation Treaty (NPT). The lack of effective assurances of nuclear supply (NPT Article 4) until now and the sudden appearance of many unilateral or bilateral initiatives under the proliferation constraints show the necessity of strengthening the IAEA's role in ensuring full transparency in a fair market.

In addition, there is a new tendency to limit technical cooperation in the peaceful uses of nuclear energy while nuclear weapons states continue their weapon modernization programs rather than provide credible implementation of disarmament undertakings according to NPT Article 6. Finally, the non-adherence or withdrawal of states to/from the NPT appears to have no major consequences for them.

Expected Expansion of Nuclear Energy

Today, there is an important debate on global warming and the possible contribution of the energy used in human activity to its observed acceleration. In addition to the *cleanness*, the current debates on energy include consideration of the security of the supply as well as the economics of the process. This leads more and more governments to revisit "new nuclear" in order to leave the nuclear option open for the future.

A number of developed countries that have nuclear energy as a well-established part of their energy mix are now looking to further expand the internal and external development of nuclear reactors and the fuel cycle. Several other countries that do not currently generate nuclear power have indicated their interest in building nuclear power plants. Obviously, this renaissance of nuclear energy will impact international security.

The technology for nuclear energy production will not substantially change in the next twenty to forty years. The evolutionary design of the Generation III reactors will be dominant. Smaller scale modular reactors with long core lifetimes may enter the market for power and heat production. But no major immediate technological changes in the fuel cycle (aqueous/reprocessing/gas centrifuge enrichment and MOX fabrication) are expected.

The Generation IV International Forum was initiated with the main objective "to support research and development, within a time frame from fifteen to twenty years, of concepts for one or more Generation IV systems that will provide competitively priced and reliable supply of energy to the country(s) where such systems may be deployed, while satisfactorily addressing nuclear safety, waste, proliferation and public perception concerns."[4]

Generation IV systems are designed to be inherently more proliferation resistant. This includes the proliferation technical difficulty (the technical sophistication), proliferation cost (economic and staffing investment required), proliferation time (total time planned by the host state for the project), fissile material type (characteristics not appropriate for nuclear explosives), detection probability (ease of detecting a proliferation scenario), and detection resource efficiency (application of international safeguards).

It should be noted that Generation IV fuel cannot be used for weapons as it contains highly radioactive minor actinides (americium, curium and neptunium) and reactor plutonium with high amounts of Pu-240 and Pu-238, which mean *dirty* fuel. Although reprocessing is an essential feature for sustainability, the coprocessing of plutonium with minor actinides does not involve the separation of plutonium.

In addition to these intrinsic features that make advanced nuclear systems more secure, existing safeguards technologies can be adapted to future Generation IV systems. They will benefit from the experience gained operating existing fast reactors and reprocessing technologies. Nevertheless, new safeguards and verification technologies will need to be developed for fabrication and reprocessing plants, especially for these dealing with the recycling of minor actinides in order to establish tailored measurement procedures adapted to assay these highly active materials under remote-handling conditions. Dry reprocessing will require a substantially higher development effort than aqueous reprocessing technology to better cope with special measurement problems, such as matrix effects and sampling problems. (Due to the very nature of the pyrochemical process, sample taking is not as straightforward and representative as it is in the aqueous process. For example, it is almost inevitable that samples taken from the metal phase will also include some admixtures of salt. The amount of undesired salt in this example is estimated to be a few weight percent.)

A step further in the recycling strategy of minor actinides is to separate them from spent fuel, thus opening the way for their burning in a fast-neutron system. Burning the actinides will reduce the burden of long-term waste management in terms of the radiotoxicity, volume, and heat load that must be disposed of in final repositories. This will have a very positive impact not only on the amelioration of the public perception of nuclear energy but also in terms of reducing the number of repositories (regional repositories are envisaged) and suppressing the nuclear safeguards burdens associated with the surveillance of nuclear spent fuel storage. However, to make these scenarios more realistic, a number of rather involved institutional (e.g., shared repository) and practical (e.g., material transports) issues have still to be tackled and discussed in depth.

How to Better Meet Future Challenges

We suggest three possible categories of verification: political, institutional, and technical verification systems.

Political Action Required

- Adherence to the NPT, with the Additional Protocol to become the norm
- Clear consequences for non-adherence or withdrawal
- Nuclear weapons states to foster disarmament rather than modernization of a weapons arsenal
- Creation of regional/global security systems for regions with strong tensions
- Nuclear weapons states to accept safeguards for their own sensitive facilities
- Develop a regime to assure fuel supply and fuel cycle services on a nondiscriminatory basis

- Preserve adherence/implementation of Comprehensive Test Ban and Fissile Material Cutoff treaties
- Support design of future nuclear systems: no weapons-usable materials, ease of safeguardability, early provision of information

Institutional (Legal Action)

- Extend IAEA's responsibility to cover weaponization programs
- Increase IAEA role in export/import control (at least better exchange on rejected exports)
- Strengthen the role of the IAEA in assurance of the supply
- Foster widest possible adherence of states to additional protocol
- Whenever the Board of Governors acts in unified manner, IAEA has clear authority and gets best results

Verification System/Technological Issues

- Maintain integrity and impartiality of IAEA verification system
- Pursue integrated safeguards: keep reduction of traditional safeguards at level so that deterrence to diversion from civil cycle remains high and consider further efficiency gains for uranium and spent fuel handling facilities
- Foster establishment and make maximum use of independent regional systems ("neighbors watching neighbors" is a powerful concept and an excellent confidence-building measure)
- Detection of clandestine activities in countries remains major challenge:
  - Toolbox needs to be strengthened: wide-area monitoring, environmental sampling, satellites, open and other sources
- Nuclear knowledge and technology less confined, technical barriers to enrichment, reprocessing, and even weapons design have eroded; export control is more complex and challenging
- More information received from states: handling of confidential information, protection of sources and methods, maintaining IAEA's impartiality and independence requires careful corroboration (control of validity) of information
- Single most important technical measure is environmental sampling. This technique has high potential beyond current application (i.e., usage of facilities, forensic evaluation going back several decades, morphology of particles, other materials present in sampled areas, reprocessing, cutoff treaty facilities, etc.)
- Increase open-source analysis (Web mining, satellites) for nuclear country profiles, nuclear experts/specialists in country and links, procurements/capability related to weaponization programs, energy situation, and resources of country.
- A. Q. Khan network was successful due to the following tactics:
  - Providing false final destinations
  - Misstating intended use
  - Exporting items falling just below specifications of trigger, and dual-use lists
  - Differences in catch-all clauses of different countries
- Custom authorities need more support
- Overall tendency toward a base-load traditional verification system supplemented by information triggered investigation and verification

Some JRC Science and Technology Activities to Support Safeguards Challenges

After having more than thirty years experience in the implementation of nuclear safeguards in most civil nuclear facilities worldwide (for IAEA in Vienna) and throughout Europe (for European Commission safeguards authority in Luxembourg), and having faced the challenge of efficient followup of nuclear material throughout several facilities, the Joint Research Centre (JRC) continues to contribute to the effectiveness of nuclear safeguards. Here is the outlook for some JRC science and technology activities to support future challenges in safeguards and nuclear security, covering aspects such as the exploitation of satellite imagery and open-source information, tracking suspicious containers, advances in the analyses of environmental samples, adapting conventional safeguards equipment to safeguard advanced fuel cycles, novel training courses for enhancing the nuclear inspectors' observation and soft skills, and issues of proliferation resistance and the safeguards of future nuclear energy systems.

Web Mining and Intelligence

The European Media Monitoring system (EMM) forms the backbone of the JRC open-source information extraction. EMM monitors news media sources on the Web from all around the world in multiple languages, classifies the news, analyses the news using information extraction techniques, aggregates the information, provides notifications depending on their content, and provides visual presentation of the information found. The fact that this system monitors, in real time, 40,000 news articles per day from 1,500 news Web sites worldwide in forty-two different languages makes the system unique. The system automatically groups articles by subject, based on content analysis. A story-tracker module analyzes the differences between subsequent executions to effectively track the development of a story in time. A new module added this year identifies known people and organizations in the text by matching them with a machine-generated database containing millions of entries. In a similar fashion, another new module determines the geographical locations mentioned. The results from these modules are used in the clustering process to determine the best geographical position, based on the location of all the articles in the group, which can then be visualized on interactive maps like Google Earth. The NewsExplorer application performs a daily analysis, in multiple languages, of articles extracted from EMM to extract all mentioned entities (people, organizations, etc.) and to link news reports across languages and over time. The NewsExplorer also allows social network entity role matching in order to visualize related and associated persons in the news articles.

JRC Observatory for Nonproliferation Compliance

On the basis of analyses of both open-source information and satellite images, the JRC has gained competence in monitoring the evolution of the fuel cycle and nuclear research and development activities for individual states (or regions); the JRC has developed so-called "nuclear country profiles" for a series of countries. Use is made of the information gathered by the EMM system. This information is combined with open-source data on the status of installations, the import of materials and technology, commercial circuits used, scientific and technical capabilities, satellite imagery, and personal identification or tracking. On the satellite images, JRC collaborates with the European Council Satellite Centre in Torrejon. Web searches, geographic information systems, and techniques for open-source information retrieval and analysis represent a future area for technical support with the IAEA.

ConTraffic

Container traffic represents approximately 90 percent of all cargo shipments, amounting to approximately 250 million moves annually. Fraud and security are major concerns. Risk analysis and the proper sealing of containers have gained increasing importance in addressing these concerns. Conventional sealing methods cannot guarantee container integrity and detect intrusion, nor can they provide information on what is happening in the cargo and to goods stored in it.

The JRC has developed, a semi-operational, route-based automatic data gathering and risk analysis system *(ConTraffic)* to automatically collect and analyze data on maritime container movements from Web-based open sources, in order to track and identify suspicious container movements that may be associated with the fraudulent importation of goods. The system has been tested successfully for cases involving the false declaration of origin to circumvent anti-dumping duties, quotas, etc.

The *ConTraffic* database is populated with more than 220 million records relative to the movements of more than 4.4 million containers, covering a time period of four years. Moreover, *ConTraffic* also keeps records of the leasing status of more than 2.6 million containers owned by seven leasing companies that offer leasing-status Web sites. It goes without saying that in terms of the world container fleet (estimated at about 15 million units), the present database coverage is still incomplete. Nonetheless, *ConTraffic* data is already sufficiently comprehensive to allow a route-based risk analysis based on a sound statistical base.

ConTraffic can be viewed as one of the components of a risk-analysis layered model: containers considered suspicious from the route-basis analysis are reported to the member states of the destination port in order to be further screened by using local risk indicators, other documentary evidence, nonintrusive detection technologies (scanning), and—if necessary—physical checks.

Environmental Sampling and Analyses of Nuclear Material

In order to detect undeclared nuclear activities, the safeguards authorities need to apply the most advanced techniques available. In particular, the application of the environmental sampling methodology was enforced in the late 1990s by the Additional Protocol. One of the major techniques in environmental sampling is particle analysis performed on dust samples from surfaces of equipment or infrastructure inside buildings, collected by safeguards inspectors using cotton swipes. The JRC has been active in this field for several years and was early member of the IAEA's Network of Analytical Laboratories. The JRC predominantly uses a technique for these measurements that is based on secondary-ion mass spectrometry. The JRC is increasing its efforts to strengthen its technical capabilities; in particular, the improvement of the measurement precision of minor isotopes (^{234}U and ^{236}U) is important. These isotopes can provide essential information about enrichment facilities and the type of feed materials used. Cooperation with the IAEA has recently been extended beyond the particle detection work to the analysis of bulk nuclear material. One example is the determination of trace elements in bulk uranium samples.[5]

Modeling of LEU Production in Gas Centrifuge Enrichment Plants

The IAEA has developed a new model safeguards approach for gas centrifuge enrichment plants (GCEPs), and one of the objectives of this new approach is to confirm that there is no undeclared production of low enriched uranium (LEU). To meet this objective, several measures have been proposed. One measure consists of analyzing the mass balances randomly, complemented with operational declarations through a mailbox. Because cascades in industrial GCEPs have relatively small inventories and short equilibrium times, random inspections can be enhanced by analyzing mass balance data collected continuously in the plant. This proposed real-time mass evaluation system analyzes weight data that is collected continuously from the feed, tails, and product stations.

Since load cells are already part of the operational process, their exploitation for safeguards purposes is an obvious development. Real-time evaluation of load-cell data by mass balancing is an attractive proposition because it is not intrusive. It neither looks inside the cascade hall nor impinges on plant operation. JRC has investigated this concept relying on centrifuge and cascade modeling. Current development is on examining, in more detail, cascade hall inventory variations for the interpretation of cumulative mass balance plots. This work is also facilitating diversion scenario hypotheses.

Proliferation Resistance and Safeguard Tools of Future Nuclear Energy Systems

In order to streamline the research and to prepare the nuclear energy systems of the future, international initiatives are working on the so-called Generation IV nuclear energy systems, which should be ready for deployment in 2020–2030. The European Commission represents EURATOM in the Generation IV International Forum (GIF), and the JRC is actively involved in several GIF issues. On the basis of the criteria of sustainability, economics, safety and reliability, and proliferation resistance and physical protection (PR&PP), six reactor concepts have been retained by the GIF for further consideration. These nuclear energy systems will have to demonstrate their proliferation resistance based on both intrinsic features, such as fuel composition, and extrinsic measures, such as the deployment of international safeguards. JRC, together with the IAEA, is actively contributing to the PR&PP Expert Group of GIF developing an evaluation methodology for PR&PP aspects of Generation IV systems.[6] An issue also addressed by the PR&PP group is that of the safeguardability of the reactor concept at the design stage so that more effective and efficient safeguards measures can be implemented. In this area, JRC also contributes to the IAEA-driven International Project on Innovative Nuclear Reactors and Fuel Cycles, which addresses this issue of proliferation resistance and physical protection robustness in parallel and synergy with GIF.[7]

Most of the future Generation IV reactors are expected to operate in a fully closed fuel cycle in which the actinides must be recovered from appropriate reprocessing units. At present, two reprocessing routes, based on advanced aqueous and on pyrochemical processes, are considered. It can be anticipated that a physical verification measurements tool will continue to play an important role in future safeguards measures. Because of the very nature of the nuclear materials encountered in the future fuel cycles, straightforward nondestructive measurement techniques will gain increased importance for the respective safeguards verification measurements. JRC is currently pursuing substantial research work on the future reprocessing processes as well as on the development of appropriate nuclear fuels for the future Generation IV reactors and transmutation facilities. Along with this research work, appropriate nondestructive assay techniques are being developed and tested for the control and assay of process samples from the respective pilot test facilities and for the assay of the special fuel specimens produced for the new fast reactors. As an example, JRC is currently setting up a multipurpose NDA station for the direct measurement of actinides in process samples originating from its pyrochemical test facility. The NDA station incorporates a variety of nondestructive radiometric assay techniques (K-edge absorptiometry, X-ray fluorescence, high-resolution gamma spectrometry, neutron coincidence counting), which can be employed individually or in combination, depending on the assay requirements.[8]

Novel Training Courses for Enhancing the Nuclear Inspector's Observation and Soft Skills

In close collaboration with both the IAEA and the directorate-general for energy and transport, JRC is participating in the development of dedicated training with respect to the Additional Protocol (AP) and Complementary Access. A first course was organized in March 2007. In this course, several Complementary Access exercises are simulated in some of the nuclear facilities: a spent fuel pond (a visit), a reactor, hot cells and a tritium laboratory. The goal is to test and improve the investigative skills and also to focus on the observational, communication, negotiating, and team building skills currently required of nuclear inspectors in the detection of undeclared activities. To do that, a modified AP site declaration is used with deliberately missing or wrong information. The inspectors are challenged to discover the inconsistencies and the possible indicators of clandestine nuclear activities. The JRC provides *operators* who are briefed on role playing activities to assist in the challenges, particularly with respect to the soft skills required from the inspectors in completing their tasks. The agency has highly appreciated the first workshop, which could permanently become a part of the IAEA training scheme. The added value of this training lies both in the relevance and variety of the sites inspected and in the tools (or lack of tools) available to execute the Complementary Access. Such tools are available for both technical and soft skills, both of which are evaluated on their value and need for further development.[9]

Conclusion

The recent failures of the international verification system, especially in detecting the comprehensive supply networks, have raised many questions about the future of nuclear safeguards. Meanwhile, nuclear energy seems to be entering a new phase of renaissance with the decision of many countries to have nuclear energy as a well-established part of their energy mix. New designs of nuclear reactor systems, Generation IV, are under study and should be more secure and proliferation resistant.

Safeguards for these future systems would benefit from the experience gained with existing safeguards technologies applied to existing fast reactors and reprocessing technologies. But new safeguards and verification technologies will need to be developed for fabrication and reprocessing plants, especially for these dealing with the recycling of minor actinides. The JRC continues its contribution to the effectiveness of nuclear safeguards by developing new methods, approaches, and technologies such as the exploitation of satellite imagery and open-source information, tracking suspicious containers, advances in the analyses of environmental samples, adapting conventional safeguards equipment to the safeguards of advanced fuel cycles, novel training courses for enhancing the nuclear inspectors observation and soft skills, and examining issues of proliferation resistance and the safeguards of future nuclear energy systems.

However, the challenges for future safeguards would be more political/institutional than technological and aim at creating conditions to impede the acquisition of a weapons capability by countries. Among these, the most importance challenges include the assurance of a supply of nuclear fuel, collaboration on nuclear technologies for peaceful use, a credible implementation of disarmament of the nuclear weapon States and safeguards for their own sensitive facilities, and adherence to the NPT with additional protocol to become norm and clear consequences for non-adherence or withdrawal. The IAEA is obviously at the center of these challenges and should have clear authority and additional authority in the control of the exportation of dual-use technology or, even better, the control of weaponization programs.

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A Schematic History of Safeguards Policy

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Safeguards are a central feature of the nuclear nonproliferation regime and of the era introduced with President Eisenhower's December 1953 Atoms for Peace initiative at the United Nations. Their importance to a viable and effective international nonproliferation regime cannot be exaggerated. They are for all intents and purposes a condition *sine qua non* for cooperative development of civil nuclear energy and practicable international nuclear commerce. There is no identifiable and acceptable substitute short of some form of international ownership and control of the nuclear fuel cycle, a formulation (based on the judgment of the Acheson-Lilienthal Report that a system of inspection superimposed on an otherwise uncontrolled exploitation of atomic energy by national governments will not be an adequate safeguard and could not ensure effective separation of civil and military uses of nuclear energy) advanced by the United States in 1946 at the onset of the nuclear age as the Baruch Plan. This approach is being revisited today in the form of initiatives for multilateral/multinational fuel cycle arrangements for enrichment and reprocessing as the international community grapples with the challenges raised by i) the decreased relevance of the disciplines imposed on proliferation by the superpowers during the Cold War; ii) the increasing spread of nuclear knowledge; iii) the diversification of sources of supply of nuclear materials, equipment, and technology including the emergence of a nuclear black market, epitomized by the A.Q. Khan network; iv) the prospect of states in regions of tension developing fuel cycle capabilities that put them in a position to quickly proliferate if the political decision to do so is taken, and v) the rising threat of non-state actors including apocalyptic terrorists acquiring nuclear explosives or the means to produce them which was an important stimulant to the passage of UN Security Council Resolution 1540. Viable institutional arrangements such as multinational enterprises would provide additive stability and security to international nuclear activity, but safeguards are and will remain indispensable to an effective and credible nonproliferation regime.

In the absence of agreement on the Baruch proposals, the United States embraced a policy of secrecy and denial, (formalized in the McMahon Atomic Energy Act of 1946) prohibiting any exchange of nuclear information with any other state. That policy was superceded in 1954 in favor of Atoms for Peace, an initiative for nuclear cooperation and assistance. This was in response to a change in circumstance—the entrance of the Soviet Union and the United Kingdom into the nuclear club; mounting concern about the security implications of a nuclear arms race; and the emergence of an increasing number of national nuclear programs not subject to any form of control. The International Atomic Energy Agency (IAEA), created as an outcome of the Atoms for Peace initiative, was charged with two missions: to promote the peaceful uses of atomic energy, and to ensure, as far as it is able, that assistance provided by the agency, or under its supervision and control, not be used to further any military purpose. International safeguards got off to a slow start. Nothing in the agency statute required a member state to accept safeguards on its own nuclear activities, or to require IAEA safeguards on bilateral transactions. IAEA safeguards were limited by statute to three types of situation: project agreements where the agency was the supplier; when a state unilaterally requested safeguards on its activities (as Mexico did); or when requested by parties to a bilateral or multilateral agreement (which is the basis for NPT safeguards). By the time the IAEA was established in 1957, Atoms for Peace had been in effect for three years, the United States had amended its atomic energy act to permit civil nuclear cooperation, and had concluded nuclear cooperation agreements with more than twenty states that incorporated bilateral safeguards rights in all but the agreement with European Atomic Energy Community (EURATOM) to whom it had entrusted safeguards responsibility for U.S. supplied nuclear material and equipment—an action dictated by U.S. political interest to support the European integration movement, and to empower its institutions to the extent possible.

Where safeguards were to apply, the IAEA statute spelled out unprecedented rights and responsibilities for an international institution, in particular the right to send into states inspectors "who shall have access at all times to all places and data and to any person who by reason of his occupation deals with materials, equipment, or facilities, which are required by this Statute to be safeguarded…and to determine whether there is compliance with the undertaking against use in furtherance of any military purpose…." (A. XII.A.6)

The rights entrusted to the agency were to be set forth in detailed agreements obligating parties through specific language. No safeguards agreement has ever fully embraced the language quoted.

The pace of development of the safeguards system was determined by two considerations, one political and the other pragmatic. Politically, important member states, in particular India, supported by the Soviet Union, saw no urgency in translating the statutory provisions on safeguards into operational form, effectively blocking early progress on safeguards development. A 1959 Japanese request for agency assistance in procuring nuclear material for a research reactor triggered the need to put safeguards in place. Pragmatically, the agency lacked any hands-on experience comparable to that of the principal suppliers and when it became necessary to move forward with an operational system, the agency wisely chose to do so incrementally, beginning in 1961 (INFCIRC/26)covering reactors up to 100MW (th) and extending coverage by 1968 to reactors of all sizes as well as conversion, fabrication and reprocessing facilities, (INFCIRC/66./Rev.2) leaving aside only uranium enrichment to which only a few countries had technological access and which was not subject to international transfer by the technology holders.

The experience gained by the IAEA in implementing facility-specific safeguards and the confidence it enjoyed among its members made it the logical choice to administer safeguards required by the 1968 Nuclear Nonproliferation Treaty of all non-nuclear weapon states party to the Treaty. Many of these states were prepared to foreswear the acquisition of nuclear weapons (given the undertaking of the weapon states to pursue nuclear disarmament) and accept international safeguards on their peaceful nuclear activities, even though nuclear weapon states were not so required, (though all of them did make voluntary safeguards offers on civil facilities ranging from limited to more comprehensive coverage). They were, however, not prepared to accept an extension of discrimination to the civil nuclear field, even for a limited time—hence the insistence on Article IV providing for an "inalienable right" to develop nuclear energy for peaceful purposes and for standing up a safeguards regime that minimized intrusion and maximized the opportunity to develop nuclear energy for peaceful purposes while at the same time standing the test of credibility and providing the necessary level of confidence regarding non-proliferation. Among their principal concerns were: protecting proprietary and commercial interests such as being able to compete on equal footing with the weapon states in the civil nuclear marketplace, limiting the intrusiveness of on-site inspections (in particular capping the frequency of on-site inspections), minimizing the discretionary authority of the international inspectorate, and protecting sovereign prerogatives in general.

The comprehensive safeguards system developed to implement NPT safeguards requirements (INFCIRC/153) concentrated on the flow of nuclear material; limited on-site inspections under *normal or routine* circumstances to pre-agreed "strategic points" where inspectors could conduct independent verification activities, while providing for special inspections, which could be carried out anywhere in the state, if the agency were unable to meet its verification responsibility through routine inspections. Material accountancy, complemented by containment and surveillance, was the heart of the system based on a reciprocal *obligation* of the state and *right and obligation* of the IAEA to apply safeguards on all source and special fissionable material in all peaceful activities to verify non-diversion. In practice the emphasis on material accountancy during the 1970s and 1980s meant focused attention on the *correctness* of state declarations and less on whether the declarations were complete, and this became a **cultural attribute** of the inspectorate as time went on. It is important to bear in mind that *in law, as distinguished from practice, safeguards extend to all nuclear material whether or not declared, and access to any place may be had under the IAEA's special inspection authority, if need be, to verify full accountability.*

From the 1970s until the North Korean situation in 1993, insofar as the traditional comprehensive safeguards system is concerned no diversion of nuclear *material under safeguards* was ever detected. However, the revelations in the wake of the 1991 Gulf War of extensive undeclared nuclear activity and a significant clandestine nuclear weapons program in Iraq underscored the limitations of the safeguards system as it was practiced. In the wake of these revelations the Board of Governors, starting in 1992, took a number of decisions for which legal authority already existed including reaffirming the requirement that safeguards provide assurance about the *completeness* as well as the *correctness* of nuclear material declarations, reaffirming the right of special inspections (unfortunately with a caveat that it would be used rarely); environmental sampling at locations already accessible to inspectors, requiring states to present design information on new facilities or changes in existing facilities handling safeguarded nuclear material as soon *as the decision to construct or modify is made* (in lieu of the practice that developed that such information needed to be made 180 days before introducing nuclear material into a facility), introducing unattended and remote monitoring to detect movements of declared nuclear material, calling for voluntary reporting of imports and exports not only of nuclear material, but specified equipment as well, and using instruments and other techniques at strategic points to the extent present *or future* technology permits.

Of equal if not greater significance was agreement on a model Additional Protocol (INFCIRC/540) granting new authority related to information a state is required to provide to the agency and complementary access aimed at ferreting out undeclared nuclear materials or activities: With an additional protocol in place the IAEA is better positioned to draw statewide conclusions regarding whether all nuclear material and activities has been declared and placed under safeguards, leading to the ability of the IAEA to draw broader safeguards conclusions. It is a case of more information and more access leading to more comprehensive understanding of a state's nuclear status; it raises the level of confidence in one's conclusions about a state but it is not absolutely indisputable.

To summarize: the traditional comprehensive safeguards system focused on verification of state declarations using quantitative measures supported by containment and surveillance. This system provided a high degree of confidence regarding the accountability of all declared nuclear material but did not answer the question of whether undeclared nuclear activity might be present on the territory or under the control of a safeguarded state, although the system incorporated the principle that safeguards extended to undeclared activity as well as declared. The strengthened safeguarded system, which is state-wide rather than facility or material balance area-specific, builds out from that base and focuses on verifying not only the correctness of state declarations regarding nuclear material but also the absence of undeclared nuclear material and activities. To build a state nuclear profile the strengthened safeguard system puts much greater emphasis on qualitative measures including export and import information, on expanded declarations of nuclear and nuclear-related activities in the state, and on information analysis supported by environmental sampling and qualitative indicators. As well, it provides broader access for inspections of declared and undeclared activities. Greater access to information and broader access to sites and locations in the state are accompanied by access to the UNSC in the event of non-compliance with safeguards undertakings.

On its face the Additional Protocol, in conjunction with measures adopted earlier by the Board of Governors, provides the foundation for a robust verification system based on a comprehensive picture of a safeguarded state's nuclear fuel cycle, inventory of nuclear materials, material production capabilities, nuclear related infrastructure, and overall nuclear activities. The AP with its significantly increased information base and right of access, when fully implemented, offers greater transparency of nuclear assets and nuclear cooperation and a correspondingly greater insight into plans and intentions of safeguarded states and to this extent contributes to increased credibility of and confidence in verification regime. Often overlooked is that, even under the comprehensive safeguards system, rights of ad hoc inspections and special inspections where conditions warrant it provide significant access to locations anywhere in the state.

The strengthened safeguards system is a work in progress in several respects. The legal and technical requirements have been identified and agreed upon, and the foundations for both have been or are being put in place. Much however remains to be done on both counts. For example at least thirty states party to the NPT still have not signed safeguards agreements despite the obligation to do so within eighteen months of adherence, and the agency had not been pressing those states to fulfill their obligations. Without a safeguards agreement there is no basis for carrying out verification activities. Many states with safeguards agreements have Small Quantity Protocols that absolve them from some of the obligations in comprehensive safeguards agreements. But many of these have not put in place State Systems of Accountancy and Control that would provide the legal and administrative mechanism to take actions to help the governments develop means by which to ensure against the risk of non-state actors setting up shop in their jurisdiction and pursuing nuclear relevant activities without state knowledge that could undermine the regime. There is a need to more comprehensively integrate safeguards, export control and information flow. The international system is dynamic, not static, and measures to address the evolution of challenges need to be dynamic as well. The nonproliferation regime was not created in one fell swoop but has evolved over time, addressing new challenges with new responses. This applies as much to safeguards as to any other dimension of the nonproliferation regime. In the final analysis success or failure will depend on political will, strong leadership at both the state and international level and providing the regime with adequate resources to meet and fulfill the objectives assigned to it.

State willingness to adopt and incorporate **new verification approaches and technologies** depends on a balance of considerations about effectiveness, intrusiveness, expense, and equity. This relates to environmental sampling; remote and unattended monitoring devices; satellite imagery; and, if ultimately approved by the Board of Governors, wide area environmental sampling. For some it's a question of redistribution of resources relieving some of the effort devoted to material accounting which weighs most heavily on states with substantial nuclear activities (e.g., Japan), and for others it may be a question of whether all or only some states are expected to endorse and implement a more robust and intrusive safeguards regime. For more than one state it comes down to the question of whether the nuclear weapon states are moving toward the elimination of nuclear weapons or retaining them and perpetuating inequality. How far one can go in strengthening the safeguards system may well depend on how much progress is made on devaluing and ultimately eliminating nuclear weapons globally.

GNEP Members Convene in Jordan for Second Steering Group Meeting

Representatives from twenty-eight countries and three intergovernmental organizations attended a meeting of the Global Nuclear Energy Partnership's (GNEP's) second Steering Group in the Kingdom of Jordan. The two-day meeting was hosted by the Jordanian Atomic Energy Commission. The Steering Group discussed the formation of a third working group on the development of grid-appropriate reactors in order to promote the development of advanced, more proliferation-resistant nuclear power reactors appropriate for the needs and capabilities of countries with limited resources or small and medium electric power grids. Actions will be undertaken to pursue formation of such a working group and to present the proposed working group to the executive committee for its consideration and approval.

The two-day meeting consisted of full progress reports from the two existing working groups that were established at the first GNEP steering group meeting in December 2007 at the International Atomic Energy Agency in Vienna, Austria. The two working groups brought together a host of experts to take a hard look at fundamental subjects that are at the core of GNEP's goal. The groups addressed two of the timely and important issues facing the safe and secure global expansion of civil nuclear energy: infrastructure development and reliable nuclear fuel services. Both working groups presented program plans to the steering group outlining initial activities, defining potential near-term impacts and identifying the long-term challenges in their respective areas relative to nuclear power's global expansion.

The first round of working group meetings were held in March and April 2008, bringing together numerous experts from GNEP partner and observer nations. The Infrastructure Development Working Group meeting took place this March in Vienna, Austria, and began the cooperative activities to identify and address critical elements needed for the implementation of an effective nuclear energy infrastructure. GNEP's Reliable Nuclear Fuel Services Working Group met in April in Wilmington, North Carolina, and began activities aimed at reaffirming international supply frameworks to enhance reliable cost-effective fuel services and supplies to the world market, fostering future energy development.

The GNEP steering group also worked to set the agenda for the next executive committee or ministerial meeting expected to take place this fall. The agenda for the executive committee will cover a range of issues, including identifying further areas of cooperation for the partnership, the next round of GNEP invitees, and resources that GNEP partners can provide as cooperative activities continue to increase. Attendees in Jordan included nineteen of GNEP's twenty-one members, Australia, Bulgaria, Canada, China, France, Ghana, Hungary, Italy, Japan, Jordan, Lithuania, Poland, Republic of Korea, Romania, Russia, Slovenia, Ukraine, United Kingdom, and United States, as well as nine observer nations, Argentina, Germany, Belgium, Egypt, Mexico, Netherlands, Slovak Republic, South Africa, and Spain and three international organizations.

U.S. Department of Energy and Tennessee Valley Authority Increase Cooperation on Nuclear Fuel Cycle Data

The U.S. Department of Energy (DOE) and the Tennessee Valley Authority (TVA) agreed in April 2008 to collaborate on developing and exchanging information on advanced fuel cycle technologies through a Memorandum of Understanding (MOU). This joint effort furthers DOE's ongoing nuclear research and development activities and will help to determine the best path forward for the Global Nuclear Energy Partnership (GNEP).

This MOU establishes the overall framework for the exchange of information and conduct of activities between the two organizations. Future work associated with this MOU, which would be detailed in an interagency agreement to be developed subsequent to the MOU, would be focused on providing supporting data and information to help inform DOE on advanced fuel cycle technology development concepts and include conceptual plans, utility perspectives, suitable business models and additional research and development needed for the advancement of nuclear technology.

TVA currently operates six nuclear reactors as part of its power system, which serves approximately 8.8 million consumers in seven southeastern states. TVA recently restarted a nuclear unit at its Browns Ferry plant, has submitted a Combined License application to the U.S. Nuclear Regulatory Commission for two advanced reactor design nuclear units at its Bellefonte site and has resumed efforts to complete a second nuclear unit at its Watts Bar plant. TVA is the nation's largest public power provider and is completely self-financing. TVA also manages the Tennessee River and its tributaries to provide multiple benefits, including flood damage reduction, navigation, water quality and recreation.

DOE Seeks to Invest up to $15 Million in Funding for Nuclear Fuel Cycle Technology Research and Development

The U.S. Department of Energy (DOE) has issued a Funding Opportunity Announcement (FOA) inviting universities, national laboratories, and industry to compete for up to $15 million to advance nuclear technologies closing the nuclear fuel cycle. These projects will provide necessary data and analyses to further U.S. nuclear fuel cycle technology development, as part of the Department's Advanced Fuel Cycle Initiative (AFCI), the domestic technology R&D component of the Global Nuclear Energy Partnership (GNEP). Studies resulting from this FOA will include computing and simulation of spent fuel technology, advanced fuel systems analyses and properties of future waste forms. This announcement builds on over $328 million that DOE has provided to universities, national labs and industry since GNEP was announced in February 2006.

In the FOA, DOE is seeking applicants from industry, universities and national laboratories to conduct R&D in the following areas: used fuel separations technology, advanced nuclear fuel development, fast burner reactors and advanced transmutation systems, advanced fuel cycle systems analysis, advanced computing and simulation, safeguards and advanced waste forms.

As part of President Bush's Advanced Energy Initiative, GNEP aims to accelerate development and deployment of advanced fuel cycle technologies to encourage clean energy development worldwide, responsibly manage nuclear waste, and reduce the risk of nuclear proliferation. In March 2008, DOE announced the next stage of awards to four industry consortia, AREVA Federal Services, LLC; EnergySolutions, LLC; GE-Hitachi Nuclear Americas, LLC; and General Atomics, which included $18 million for additional studies on GNEP conceptual design, technology development roadmaps, and business plans. (See next item for details.) Over the past two years, DOE has also awarded universities approximately $39 million for research grants and fellowships, to upgrade laboratories and reactor facilities and purchase state-of-the-art equipment for researching advanced nuclear fuel cycle technology. DOE's national labs received approximately $182 million to advance domestic nuclear technology development through AFCI.

DOE Awards $18.3 Million to Nuclear Industry Consortia for GNEP Studies

The U.S. Department of Energy (DOE) has awarded $18.3 million to four industry teams to further develop plans for an initial nuclear fuel recycling center and advanced recycling reactor as part of the Global Nuclear Energy Partnership (GNEP). These awards include $5.9 million to EnergySolutions; $5.7 million to the International Nuclear Recycling Alliance, led by AREVA and Mitsubishi Heavy Industries; $5.5 million to General Electric-Hitachi; and $1.3 million to General Atomics. These firms will further develop detailed studies that build on conceptual design studies, technology development roadmaps, business plans submitted earlier this year by these four industry consortia.

DOE will use the information and recommendations provided by these studies, as well as other information and analyses, to determine the cost, feasibility, and technical aspects of proposed GNEP activities. In January 2008, the four consortia presented their analysis to DOE, which helped determine where additional studies were needed and provided the basis for today's awards. DOE may make another round of awards for additional GNEP studies later this year.

DOE Announces Strategic Engineering and Technology Roadmap for Cleanup of Cold War Era Nuclear Waste

The U.S. Department of Energy (DOE) released an engineering and technology roadmap that details initiatives aimed at reducing the technical risks and uncertainties associated with cleaning up Cold War era nuclear waste over the next ten years. The roadmap also outlines strategies to minimize such risks and proposes how these strategies would be implemented, furthering the DOE's goal of protecting the environment by providing a responsible resolution to the environmental legacy of nuclear weapons production.

Specifically, the roadmap consists of thirteen strategic initiatives that address anticipated technical risks and uncertainties in the following six areas: waste processing; groundwater and soil remediation; deactivation and decommissioning and facility engineering; spent nuclear fuel; challenging materials; and integration and cross-cutting initiatives. The initiatives in the Roadmap will help ensure continued success in completing the cleanup of contaminated nuclear weapons manufacturing and testing sites across the United States.

The department's national laboratories, led by Savannah River National Laboratory, will spearhead the integration of these engineering and technology efforts. Input for the roadmap was provided by DOE's National Laboratories and the Office of Environmental Management's (EM) project directors, stakeholders, site contractors, and the National Academy of Sciences (NAS). In February 2008, the NAS National Research Council issued its Interim Report on the EM Engineering and Technology program. The council agreed with the major program areas for strategic research and development presented in the roadmap.

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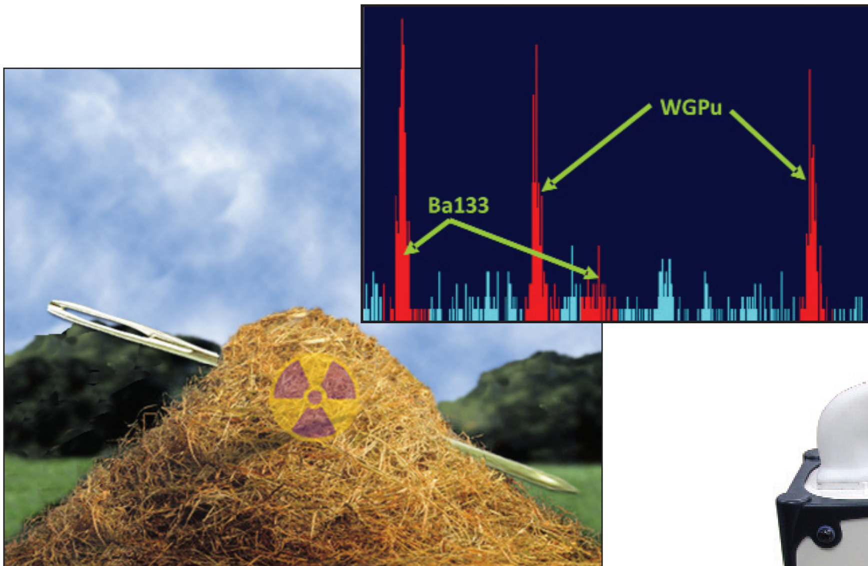

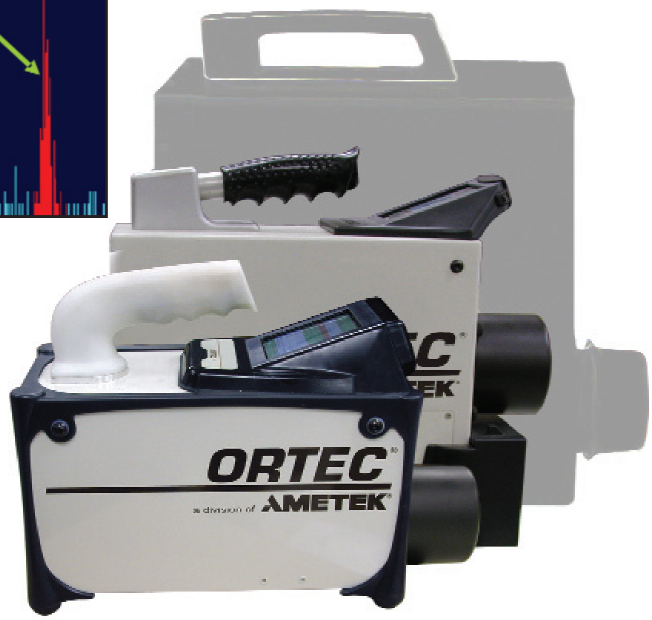

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[1]Layman's definition of "signal-to-noise ratio."
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