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NUCLEAR MATERIALS MANAGEMENT

Journal of the
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

FEATURE ARTICLES

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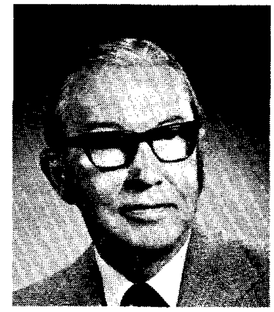
EDITORIAL

DR. WILLIAM A. HIGINBOTHAM
Brookhaven National Laboratory Upton, New York



The paper, *A Methodology for Evaluation of Containment and Surveillance System Performance,* in this issue is one product of a big study of safeguards for future, large reprocessing plants. It may be of interest to some of our readers to mention how this particular development came about, and how it is expected to relate to other safeguards activities.

In 1978, the IAEA convened an Advisory Group to discuss safeguards for reprocessing plants and to comment on draft proposals which the Agency staff had generated. As a result of advice from the Advisory Group, the Director General of the IAEA established International Working Group on Reprocessing Plant Safeguards (IWG/RPS), composed of experts from interested member states to conduct a comprehensive study of safeguards systems and techniques for large, future reprocessing plants, and to report in two years.

The International Nuclear Fuel Cycle Evaluation (INFCE) was at its peak at that time. In a paper on the present status of IAEA safeguards, the IAEA suggested to the INFCE that "safeguards on large reprocessing plants would not be based mainly on traditional material accountancy methods because measurement errors and uncertainties in the material balance would be too great. Safeguards would, instead, be based primarily on the concept of containment, complemented by human and instrumental surveillance and monitoring." This raised an obvious question: how to explain the effectiveness of such a system?

Several States were, at that time, submitting papers to the INFCE on safeguards for future, large bulk-processing facilities, some placing heavy emphasis on containment/surveillance, some on near-real-time accounting, and some on combinations thereof (see INFCE/PC/2/4, Report of Working Group 4, Chapter 9). The IWG/RPS attempted to expand on and to combine these ideas.

At the first meeting of the IWG, in January 1979, four topics were selected: (1) traditional material accountancy, (2) near-real-time accountancy, (3) containment/surveillance, and (4) integration of the above. Papers on these topics were exchanged and then presented and discussed at the second meeting of the IWG in May, at which time it was decided to establish four new working groups: (1) extended containment/ surveillance, (2) facility design considerations to facilitate safeguards, (3) data generation and evaluation, and (4) evaluation of different approaches to advanced safeguards systems.

There were a number of meetings of the working groups and of the IWG before the final report was presented to the Agency in September 1981. As I recall, the major contributors to the containment/surveillance section were the UK, and USA, coauthors of the evaluation methodology paper reproduced in this issue, and France and Japan, which deserve equal credit.

Anyone who is interested in this subject should attempt to obtain the "Overview Report to the Director General of the IAEA" by the International Working Group on Reprocessing Plant Safeguards, Sept. 1, 1981, and possibly the additional reports of the four Working Groups and on Topics 1 and 2.

The IWG/RPS did not succeed in producing a final system design that combined all of the different, proposed approaches into an integrated system. Perhaps this is not possible except in a rather general sense, since an optimum combination will depend to some degree on the design of each particular facility. On the other hand, the IWG produced a number of papers that will be very useful to the Agency and which comprise a solid base on which to continue to build. A random list of topics, in addition to those mentioned above, will suggest the variety and scope of this effort: The Control of Data Quality. Verification of Design Information. Actions in the Event of Alarms and Failures. Combination of Assurances. Impact on Design of Facilities. Impact on Operation of Facilities. Catalogue of Containment/Surveillance Instruments. The Use of Isotopic Correlation Techniques. Inspection During Construction of a Facility. Conceptual Design for One Advanced Reprocessing Plant. Possible Use of Process Monitoring for Safeguards.

As INFCE Working Group 4 concluded: "In all cases the development of safeguards should be a continuous adaptation of present techniques, together with the evolution of new safeguards concepts that would minimize the cost burden on the plant without detriment to the effectiveness of the safeguards system."

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CHAIRMAN'S COLUMN

GARY MOLEN
E.I. duPont de Nemours & Co.
Aiken, South Carolina

I want to take this opportunity to pay tribute to someone who has been singularly responsible for the growth, maturity, and success of the INMM. That individual is none other than our own Bob Keepin. I was both joyful and saddened when I learned that Bob had received a special appointment to the IAEA in Vienna for two years.

We on the Executive Committee will sorely miss Bob, for he has been steadfast in his determination to promote and foster the growth and professionalism of the Institute. Many of you may not realize how much effort Bob has expended toward improving the image and credibility of the Institute. Largely through his efforts, we are now able to go before high offices of government, both national and international, and present our professional views on technical matters dealing with any aspect of safeguards. Not only are we able, but frequently we are requested to present such views. Our counsel is actively sought and considered. Again, Bob Keepin has been instrumental in achieving our acceptance by others.

Speaking on behalf of the Executive Committee, I want to extend our sincere appreciation and gratitude to Bob for his outstanding contributions to our organization. We wish him well in his new assignment and we stand ready and committed to assisting him. Congratulations, Bob!

VICE-CHAIRMAN'S COLUMN

JOHN L. JAECH
Exxon Nuclear Co., Inc.
Bellevue, Washington

In my years of involvement with the INMM, I have been impressed time and time again with the hard work and dedication of those many members with whom I've had the privilege to associate in a number of capacities. As Annual Meeting Chairman for the past two years, I am tremendously grateful for the assistance of all the many INMM members helping in so many ways to make our annual meetings such successful endeavors. The behind-the-scenes activities needed to carry off an annual meeting can only be appreciated by those close to the action. Many hours of planning and execution are required; many are unstintingly given. The high professional calibre of the work done by this volunteer corps was noted recently by our Executive Director, John Messervey, who indicated to me how impressed he has been with the capabilities and performance of our membership in planning and executing the various tasks. Please take time at the annual meeting to convey your appreciation to those working on the Annual Committee for a job well done!

As INMM Vice-Chairman, I also have responsibility for the Technical Working Groups. The track record of our Physical Protection Working Group has been phenomenal, and let me go on record as stating publicly that *none* of this success is due to my own efforts. The Working Group Chairmen, first Tom Sellers and now Jim Williams, are to be commended for their truly outstanding contributions to the success of this endeavor. They also, I am sure, would want to give proper recognition to all those who have worked hard toward making the many workshops so successful. Please convey your appreciation to these members also when you have the opportunity.

As the last item I would like to note in this column, I would like to extend my sincere appreciation to our Site Selection Chairman of many year's standing, Ray Lang, for the outstanding job he has done in this capacity. In February, the INMM Executive Committee took action to dissolve the Site Selection Committee, having previously directed our Executive Director to take over this responsibility. I know that all the INMM membership joins me in thanking Ray for his past efforts. I also know that our Executive Director plans to take advantage of Ray's experience, knowledge of INMM membership preferences, and other intangibles that Ray can bring to bear in helping to choose future meeting sites.

2:00 p.m.–4:00 p.m.
continued

SESSION B

NUCLEAR MATERIAL ACCOUNTABILITY—
Contributed Papers
Chairman: Garland Proco, U.S. Department of Energy, Oak Ridge Operations Office

"The Totally Automated Nuclear Materials Accountability Function at MRC-Mound", Mose Baston, J.A. Jackson, E.A. De Ver, Monsanto Reserch Corporation-Mound Facility

"Automated 741 Document Preparation Oak Ridge National Laboratory's Automated Safeguards Information System (OASIS)", H.C. Austin, L.M. Gray, Oak Ridge National Laboratory

"Combining Item and Bulk Material Loss Detection Uncertainties", R.F. Eggers, Battelle Pacific Northwest Laboratory

"Planning for Effective Safeguards Audits", D.B. James, General Electric Company

"An Assessment Method to Predict the Rate of Unresolved False Alarms", P.T. Reardon, S.W. Heaberlin, R.F. Eggers, Battelle Pacific Northwest Laboratory

ADJOURNMENT

UNION CARBIDE WITHDRAWS FROM OAK RIDGE CONTRACT

DANBURY, CT, May 3—Union Carbide Corporation announced today that it has informed the Department of Energy of its intention to withdraw as the contractor for the four government-owned nuclear energy facilities it has operated in Oak Ridge, Tennessee, and Paducah, Kentucky, since the mid-1940s. The Corporation has offered to extend the current contract, which expires on September 30, 1983, for a period of up to three years to provide the Department adequate opportunity to secure a qualified replacement contractor.

The decision not to renew the contract is based on Union Carbide's strategy of concentrating its resources and management attention on businesses in which it has achieved a leadership position. The corporation has no other defense-related operations.

The Corporation said it takes pride in the many significant contributions of its employees in uranium enrichment, energy research and development, and weapons fabrication.

Union Carbide and the DOE will cooperate in the operation of the facilities to provide a smooth transition of the activities, with maximum concern for the 18,000 Union Carbide employees in the complex.

The Corporation understands that a definitive plan for a successor contractor is under development by the Department of Energy. This change is expected to have little, if any, impact on employment at these facilities.

Union Carbide Corporation first began its contract activities in Oak Ridge in January of 1943 under the Army's Manhattan Engineer District at the Oak Ridge Gaseous Diffusion Plant and subsequently assumed responsibility for operation of the Oak Ridge Y-12 Plant in 1947, the Oak Ridge National Laboratory in 1948, and the Paducah Gaseous Diffusion Plant in 1950.

Through its Nuclear Division, the Corporation currently employs almost 17,000 at Oak Ridge and 1,400 at Paducah under a single cost-plus-fixed-fee contract. The operating cost of these facilities is in excess of one billion dollars annually.

NOTE:

R.J. Hart, Manager of the Department of Energy's (DOE) Oak Ridge Operations, lauded Union Carbide for being an exceptionally effective operating contractor here at Oak Ridge for the Department of the Army, the Atomic Energy Commission, the Energy Research and Development Administration and the Department of Energy for almost forty years.

The Oak Ridge DOE staff will begin a study of the various options available for contracting the operation of the four facilities. It is highly unlikely that the DOE will seek to provide for operation of the current complex of four major facilities and the provision of all their support services by a single contractor. The current thinking, at least at the moment, suggests a segmentation of the complex and the selection of several contractors to operate portions of it.

SANDIA TECHNIQUE SIMULATES NUCLEAR WASTE FORM CHANGES

ALBUQUERQUE, N.M.—A technique to simulate changes in glass and ceramic nuclear waste forms as they incur damage from their own radioactivity has been developed at Sandia National Laboratories. These glass and ceramic materials are considered by many to be the most effective hosts for immobilizing containerized high-level radioactive wastes in underground repositories.

The simulation technique basically involves implanting lead ions in small disks of borosilicate glass and titanate-based crystalline ceramic containing nonradioactive isotopes of typical wastes. The ion-implanted disks are then compared with unimplanted disks and with naturally-occurring radioactive minerals that have experienced radiation self-damage.

Key to development of the simulation technique was Sandia scientists' ability to prove that implanting lead ions into the waste forms mimics the effects of alpha-recoil nuclei, the primary cause of radiation damage.

When an atom undergoes alpha decay, the alpha particle is ejected and the nucleus of the original atom rebounds in the opposite direction much like the recoil of a rifle. This recoil produces physical and chemical changes in the waste forms.

Electron microscopy and ion beam analyses have shown that ion implantation gradually changes the crystalline ceramic into an amorphous, glassy-like material.

The simulated self-damage also appears to enhance some chemical reactions in both waste form types. For instance, alkali atoms such as cesium and sodium migrate toward the surface of the $3/16$" to $1/2$" diameter specimens during implantation and, when exposed to water, these elements appear more reactive than the alkali atoms in unimplanted samples.

"It is not yet clear whether observed changes in implanted samples can reliably predict waste form behavior many years into the future," says Dr. Clyde Northrup, supervisor of Sandia's Chemical Technology Division. "However, results do clearly suggest that ion implantation produces physical changes in the test samples that closely simulate natural self-damage.

"Although we speculate that ion implantation-induced chemical changes may parallel those caused by natural radiation self-damage, further confirmatory studies will be necessary."

Physical and chemical changes that occur in radioactive waste forms during long periods of time must be well understood so that satisfactory waste packages and disposal procedures can be developed.

Of primary concern is the rate of leaching—dissolution in water over a period of time. Scientists generally agree that the most probable path for escape of radionuclides from a geologic repository would involve dissolution followed by transport via groundwater.

Ceramic waste forms typically mimic natural minerals and are made of the analogs of zirconolite, hollandite, perovskite, and rutile, several of which readily accept waste components into their crystalline lattices. Glass forms are made by melting together nuclear waste component oxides and specially-prepared, pulverized glasses.

During the ion implantation laboratory work, Dr. George Arnold of Sandia's Ion Implantation Physics Division used computer codes developed by Dr. D.K. Brice of the Labs' Ion-Solid Interactions Division to calculate ion energy deposition that simulates different stages of natural radiation self-damage.

Arnold implanted ions up to 800 angstroms deep into the glass waste form samples (PNL 76-68 glass) and up to 500 angstroms deep into the ceramic samples, a waste form developed several years ago at Sandia by Dr. Robet Dosch of the Chemical Technology Division. (The Sandia ceramic resembles a more recently developed nuclear waste form, SYNROC.)

Implantation energies ranged from 40 keV to 250 keV. Some samples received multiple implants at different levels to achieve relatively uniform damage. Others were implanted at single energies, from 207 keV to 250 keV, through cover grids to produce damaged and undamaged zones in the samples. Ion beam analyses of the elemental concentration were then conducted in the near-surface region.

Sandia scientists verified that lead ion implantation does produce structural effects similar to natural radiation self-damage by comparing the amount of damage in ion-implanted samples with damage in naturally occurring, partially metamict minerals of known alpha radiation doses.

Metamict minerals were once crystalline but, because of radiation self-damage, have become amorphous. Partially metamict minerals are partly crystalline and partly amorphous depending on the amount of self-damage.

"Electron microscope photographs clearly reveal the similarity between the laboratory aged (lead-implanted) ceramic waste forms and naturally aged, partially metamict zircon and zirconolite," says Dr. Thomas Headley of Sandia's Electron Optics and X-ray Analysis Division.

"Because a specific ion dose can apparently be equated with a specific alpha dose, we should eventually get a clear picture of what waste forms will be like many years into the future."

The next phase of the Sandia waste form research will involve development of techniques to quantify leach rate changes that can be directly attributable to waste form self-damage.

On February 4, 1982, the *Wall Street Journal* presented a wide ranging review of current IAEA safeguards. Bob Sorenson, Chairman of the Safeguards Committee, presented the *Journal* with the Safeguards Committee and INMM position (below).

February 24, 1982

Mr. Robert L. Bartley, Editor
The Wall Street Journal
22 Cortlandt Street
New York, NY 10007

Dear Mr. Bartley:

Although it represents a considerable research effort by the authors, your February 4, 1982 article on International Atomic Energy Agency (IAEA) safeguards reflects a distorted view of the IAEA. This appears to be, in part, the result of a lack of understanding of the Agency's charter and function. Similar misconceptions are reflected in the criticism of IAEA safeguards that have erupted in the past few months.

A basic misunderstanding is that the IAEA should somehow provide a "burglar alarm" that could immediately detect the diversion of a small quantity of nuclear material from the hundreds of tons that are in peaceful use around the world, and that action can be taken within a few days to prevent the assembly of an explosive nuclear device. Acceptance of such unreasonable expectations is unfortunate. The IAEA has probably failed to adequately convey to the public the distinction between the role of international inspection and the technical design of its operating procedures and analyses.

IAEA safeguards are essentially technical means of verifying the fulfillment of political obligations undertaken by member nations in concluding international agreements related to the peaceful uses of nuclear energy. Today most of these obligations flow from the Non-proliferation Treaty (NPT) and similar agreements. The purpose of IAEA safeguards is:

- To assure the international community that member nations are complying with their non-proliferation commitments and other peaceful uses of their nuclear material, and
- To deter both the diversion of safeguarded nuclear materials to the production of nuclear explosives, and the misuse of safeguarded facilities with the aim of producing undeclared nuclear material.

To provide that assurance, all but a handful of nations have submitted voluntarily to an unprecedented degree of international inspection covering all their nuclear activities. IAEA safeguards should be judged in terms of in-country inspection related to arms control, not as a police agency backed by the force of law.

IAEA safeguards have gained such wide acceptance because both supplier and recipient countries have direct interests: the former to obtain assurance against misuse, and the latter to provide a *quid pro quo* for receiving benefits. There is a corresponding difference in interests between the IAEA and the safeguarded, and hence the details of safeguards operations must be negotiated. In spite of such differences the IAEA system is a remarkable example of international cooperation and good-faith compliance. We must remind ourselves that the IAEA is an international agency representing over 100 sovereign nations and is not an extension of the U.S. government.

The *Journal* article makes much of the apparent illogic of safeguards in weapon states. When the NPT was negotiated under the leadership of the U.S. and the USSR, non-weapon states were suspicious that the burdens of safeguards were intended to put them at a commercial disadvantage. To show good faith, President Johnson offered to accept safeguards on all U.S. non-defense activities, at the IAEA's option. That offer was reaffirmed by Presidents Nixon, Ford, and Carter, and similar offers were made by the UK and France. Only a few percent of the Agency's resources are applied to weapon states. Besides the demonstration of good faith, these efforts provide useful information on safeguards technical operations and assistance in developing improved safeguards techniques.

The technical limitations of IAEA safeguards that are recited at length in the article are largely due to the limitations of Agency resources. The U.S. contributes the largest single share to the IAEA, but even our annual contribution is not large. To put our contribution in perspective, it is considerably less than the cost of a single fighter aircraft. Considering the importance of the IAEA to international security, this seems like a modest sum. It also puts into perspective the resources available to the IAEA. The Agency can have better safeguards if its members want to pay for them; if not, expectations should not exceed support. Criticisms based on mistaken perceptions can only lead to loss of confidence and decreased effectiveness of the IAEA.

Sincerely,

Robert J. Sorenson

Robert J. Sorenson
Chairman, Safeguards Committee

SAFEGUARDS COMMITTEE REPORT

ROBERT J. SORENSON, CHAIRMAN
Battelle Pacific Northwest Laboratories
Richland, Washington

During the Spring of 1981, a subcommittee was established to act as liaison between the INMM and government agencies engaged in international nuclear safeguards activities. While many of the national laboratories were already interacting with the government agencies, the U.S. commercial/private sector did not have a means of effectively influencing what the government agencies were preparing in the area of international nuclear affairs.

To meet this need, Dick Duda from Westinghouse established a Subcommittee on Government Liaison. Dick met with members of the State Department, Arms Control and Disarmament Agency, Department of Energy, Nuclear Regulatory Commission, and the AIF Committee on Safeguards. Based on these meetings there seemed to be adequate interest in establishing this subcommittee. A letter from the State Department supporting the ideas of the subcommittee noted, among other things, that they welcomed "...this as a significant opportunity to bring a broad spectrum of expertise and experience to bear on the pressing international safeguards issues confronting us today."

At one of their early meetings, the subcommittee developed the following objectives:

- Make available to the U.S. government technical, operational, and commercial inputs for matters relating to international safeguards issues and policies.
- Provide the private sector nuclear community, nuclear steam supply vendors, fuel suppliers, consultants, A/Es, and the utilities with information and insights into government activities in the international safeguards area and the opportunity for private sector comment before final policies and agreements have been firmly established.

One of the activities being discussed is an international regime of plutonium storage (IPS). Information on buffer storage, R&D usage of plutonium, and the levels of plutonium use has been transmitted to the State Department. A representative of the subcommittee (Dick Schneider) attended meetings of the Expert and Working Groups on buffer storage in Vienna.

The State Department and ACDA have requested the subcommittee's views on whether the U.S. should continue its support for an IPS and the form such a regime should take. Papers describing a wide range of matters pertinent to an IPS are currently being reviewed. The group's preliminary views will be presented to the State Department on April 16, 1982 by Dick Duda and the subcommittee.

New initiatives now underway by the subcommittee include determining measures of IAEA effectiveness, ideas for improving the IAEA safeguards system, and a review of international reprocessing and fuel fabrication safeguards.

Dick Duda and his subcommittee are to be congratulated for an outstanding effort. They are excellent representatives of our professional society.

Charlie Vaughan led a working group which met on April 16 at the NUSAC, Inc. office in Washington, DC. The purpose of the meeting was to discuss alternative methods of evaluating inventory differences (IDs). The full committee will be reviewing their recommendations in the very near future.

On March 9, the Safeguards Committee held another meeting with Mr. Robert F. Burnett and his staff at the NRC to discuss a number of topics of interest to the NRC and INMM. We plan to continue these meetings on about a quarterly basis.

I would like to express my thanks and appreciation to all the members of the Safeguards Committee. Its my good fortune to be able to work with such a stimulating and hard working group of people.

MAYER JOINS NUSAC

Richard F. Mayer

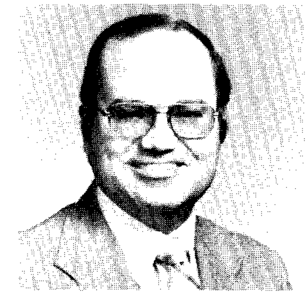
Richard F. Mayer, CPP, Has joined the firm of NUSAC, Incorporated as Project Manager and Senior Analyst in the Security Programs Division. Mr. Mayer is a graduate of the University of Virginia and holds a J.D. degree from the University of Baltimore. He comes to NUSAC, Incorporated from the Baltimore Gas and Electric Company where he held the position of Supervisor, (Nuclear) Security Screening Unit. His background contains extensive legal, security and law enforcement experience including employment with the International Association of Chiefs of Police as Assistant Director.

Mr. Mayer is admitted to the practice of law before the state and federal courts of Maryland and the United States Supreme Court. He has lectured extensively throughout the law enforcement community and at the FBI National Academy in the distinguished lectures series. Mr. Mayer is a member of the American Society for Industrial Security and serves on that organization's Law Enforcement Liaison Council. As an Associate Member of the International Association of Chiefs of Police, he serves on the Private Security Committee of that body.

Mr. Mayer's new responsibilities will include the supervision and development of comments for clients; response to proposed regulatory rulemakings, as well as a range of security personnel screening, training contingency and emergency plans and procedures.

MEMBERSHIP COMMITTEE REPORT

JOHN E. BARRY, CHAIRMAN
Gulf States Utilities
Beaumont, Texas



IT'S BEEN A LONG WINTER

Since my last report, the optimism of the dawning new year has faded somewhat. The long, cold winter, it appears, persists though the spring, we still hope, must inevitably come. So far in 1982, as many power reactors have been cancelled in the United States as were in all of 1981. An internal NRC report surfaced which speculates on 19 more United States cancellations. Self-fulfilling prophecies? True or not, the NRC's philosophy can be portrayed as elimination of immediate backlog by forcing more cancellations and further delays rather than expeditious licensing of plants to be constructed and operate safely. Of the ten power units which on paper have been awaiting construction permits for three years, only three are considered "serious." By the end of 1982, these may get their CPs or be cancelled.

The U.S. Senate, by passage of a particular amendment to the NRC authorization bill (S.1207), calls for licensing restrictions on domestic nuclear units to limit foreign uranium use to 20 percent over plant life. This is the wrong path to take in attempting to help the ailing United States uranium industry. It merely would further complicate our already disastrous licensing process (e.g., 80 percent of zero future uranium use would still be zero). Hopefully, this amendment will fall in conference committee before you read this.

More positively, Congress does seem ready to deal with fuel cycle backend issues through passage of some form of S.1662/HR 3809 which may address off-site spent fuel storage/reprocessing and waste disposal via federal contract, being funded through a charge on nuclear-generated electricity.

US-IAEA Treaty implementation also continues. By the end of 1982, all United States commercial fuel fabrication facilities will be under direct inspection or the protocol.

The following 24 individuals have been reinstated or accepted for membership during the period, January 1, 1982 through March 31, 1982. To each the INMM Executive Committee extends its welcome and congratulations. New members not mentioned in this issue will be listed in the Summer, 1982 issue (Volume XI, No. 2).

Patrick C. Adams, Manager, Security, Monsanto Research Corporation, Mound Facility, P.O. Box 32, Miamisburg, Ohio 45342, (513) 865-4282

Robert L. Armstrong, Chief of Security, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510, (312) 840-3494

Francisco V. Blay, Physical Security Coordinator, Comision Federal de Electricidad, Laguna Verde, Veracruz, Mexico

Steven K. Clark, Lead Fuel Contract Engineer, Kansas Gas and Electric Company, P.O. Box 208, Wichita, Kansas 67201, (316) 261-6657

Charles Robert Conner, Manager, Nuclear Materials Management and Criticality Control, Westinghouse Electric Corporation, Bettis Atomic Power Laboratory, P.O. Box 79, Pittsburgh, Pennsylvania 15155, (412) 462-5000, Ext. 7524

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John Reginald Hall II, Senior Systems Engineer, Analytical Systems Engineering Corporation, 175 The Great Road, Bedford, Massachusetts 01730, (617) 275-2500

James C. Hamilton, Senior Engineer, Goodyear Atomic Corporation, 10776 Rt. 50 E., Hillsboro, Ohio 45133, (614) 289-2331, Ext. 2204

Martin Hershkowitz, Policy and Planning Analyst, Office of Safeguards & Security, U.S. Department of Energy, 1805 Billman Lane, Silver Spring, Maryland 20902, (301) 353-5394

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Francis Gerard Spranza, President, Security Consulting Services, 721 E. 16th Street, Cheyenne, Wyoming 82001, (307) 637-8756

Luciano A. Stanchi, Esarda Scientific Secretary, Commission of the European Communities, Joint Research Center, 1-21020 Ispra, Italy

William I. Winters, Staff Chemist, Rockwell Hanford, 91 Waldron, Richland, Washington 90352

BOOK REVIEW

JAMES DE MONTMOLLIN
Sandia National Laboratories
Albuquerque, New Mexico

Nuclear Proliferation—Breaking the Chain
Edited by George Quester
The University of Wisconsin Press (1981). 240 pp.
$6.95 (paperback)

It is often noted that the problem of nuclear proliferation has many aspects, impacting in the areas of energy policy, economics, foreign trade, national sovereignty, international institutions, national security, arms control, fuel-cycle operations, and technical safeguards. Few of us, or few who are specialists in any of those fields, have a clear and balanced understanding of how all those factors intermesh. Technical people see it as a political problem; political leaders seek technical solutions; nuclear opponents see it only as a consequence of nuclear power; and in foreign policy, non-proliferation policy often seems to have an isolated existence out of context with other issues.

This little book, a reprint of the winter 1981 issue of *International Organization* (Vol. 35, No. 1), sponsored by the World Peace Foundation, is a collection of ten individual essays by prominent specialists in political science and international relations. The selection presents in-depth reviews and analyses of various facets of the problem, with a range of differing and sometimes conflicting viewpoints. The book provides, in a short and readable form, a broader understanding of the context in which international safeguards operate, which Journal readers should find enlightening.

In the introductory chapter George Quester summarizes each of the ten essays, reviews the forces that drive and inhibit proliferation, and offers the cautiously-optimistic view that the inhibiting forces are gradually gaining ground. In the last essay in the book he notes that the slower rate of additions to the weapons club is accompanied by a gradually-developing consensus against further spread. He offers some hope that situations like India/Pakistan, if they develop, will be self-contained. He cautions that attempts at major new initiatives aimed at total solutions would probably be counter-productive; instead, we should continually respond to changing situations with small steps and improvisations.

Chapters by Joseph Nye and Pierre Lellouche present the conflicting positions of the U.S. and the West Europeans. Prof. Nye's views are well-known, and as usual, well-articulated. He makes a rather unconvincing effort to disassociate the Carter position from the viewpoints of nuclear opponents. European reaction to U.S. policy is recounted in detail by Mr. Lellouche.

Irvin Bupp provides a chapter projecting a pessimistic future for the world nuclear industry. From the proliferation standpoint, that matters little: his projections for 1990 still range from about 2½ times to almost 4 times the 1979 installed capacity. However it may relate to the proliferation problem, nuclear power will still be around.

In the next chapter Lawrence Scheinman advocates multinational fuel-cycle facilities as an anti-proliferation measure. That approach was discussed widely, especially in the U.S., following 1974. There seems now to be little serious consideration of such sweeping measures; perhaps it has always been unrealistic to think that such basic structuring of the world nuclear economy would be undertaken for proliferation-control reasons.

The chapter on the Tlatelolco regime in Latin America, by John Redick, is perhaps the most informative one in the book. Too little attention has been given the one example of a regional nuclear-free arrangement, one that is a model of Third-World cooperation. We have failed to appreciate the leadership Mexico has provided in drafting the Treaty and gaining its wide acceptance. Mexico's non-proliferation credentials are second to none, and they deserve better support. U.S. policies, including delay in accepting Protocols I and II, which deal with peripheral weapon-state interests, and opposition to Mexico's nuclear program have generated hostility and suspicion. If further progress is to be made toward international arrangements and cooperation, Mexico should be encouraged rather than alienated.

Other Latin-American countries have been less positive, but Tlatelolco has provided a mechanism that has enhanced cooperation and a commonality of interests, especially between Argentina and Brazil. Redick covers in considerable detail the nuclear activities of each country and their interactions. Particularly significant is the horizontal spread of nuclear technology, mainly from Argentina and Brazil to such countries as Venezuela, Peru, and others beyond Latin America. The assumption that the Third World will continue to be dependent on present suppliers becomes increasingly dubious as nuclear programs mature; more cooperative approaches must be sought.

Robert Harkavy's chapter on pariah states addresses the proliferation dangers associated particularly with Israel, South Africa, Taiwan, and South Korea. Pariah states are defined as regimes winning little or no support from the outside world, while being threatened with imminent military conquest by neighbors. Onkar Marwah's paper discusses India/Pakistan from a non-western viewpoint. Lewis Dunn explores the "Dove's Dilemma"—increased supply of conventional arms to reduce incentives for nuclear weapons, which risks dangers of having the opposite effect. Finally, Michael Nacht's paper on proliferation and American security policy looks at possible U.S. and Soviet responses, including frighteningly-casual mention of pre-emptive nuclear strikes.

In reading this book one is impressed by the complexities of the problem, which go far beyond the narrow confines of technical safeguards and export controls that have dominated U.S. policy. We who are involved in safeguards should know something about that broad context, so that we can better understand the role and limitations of safeguards. This book is a good source.

INMM CONSTITUTION AND BYLAWS

In September, 1981, INMM members overwhelmingly approved changes in the Institute Bylaws. A copy of the new Constitution and Bylaws is presented below. We thank Bylaws Committee Chairman Roy Cardwell.

CONSTITUTION

Article I—Name

Section 1. The name of this membership organization shall be the "Institute of Nuclear Materials Management."

Article II—Purpose

Section 1. In consideration of the high value of nuclear materials and the necessity which this value imposes for efficient management and safeguards of such materials, this Institute is formed to encourage, in the broadest manner:

a. The advancement of nuclear materials management in all its aspects.
b. The promotion of research in the field of nuclear materials management.
c. The establishment of standards, consistent with existing professional norms.
d. The improvement of the qualifications and usefulness of those engaged in nuclear materials management and safeguards through high standards of professional ethics, education, and attainments, and the recognition of those who meet such standards.
e. The increase and dissemination of information through meetings, professional contacts, reports, papers, discussions, and publications.

Article III—Membership

Section 1. Membership in the organization shall be open to qualified individuals who are active in nuclear materials management and related fields and who have an interest in advancing the objectives of the organization.

Section 2. Any reputable firm, association, institution, or corporation, or subdivision of any such, may become a sustaining member of the Institute under the conditions and with the rights specified in the Bylaws.

Article IV—Officers

Section 1. The officers shall be a Chairman, Vice Chairman, Secretary and Treasurer, all of whom shall hold membership in the Institute.

Section 2. There shall be an Executive Committee which shall be composed of the officers of the Institute, the immediate past Chairman of the Institute, and four (4) members-at-large elected from the membership of the Institute. The Chairman of the Institute shall be Chairman of the Executive Committee.

Article V—Meetings

Section 1. There shall be at least one meeting of the Institute each year. The Executive Committee shall determine the date and place of meetings. The operating and fiscal year of the Institute shall begin on October 1, and end on September 30.

Section 2. The Secretary shall send a notice of each meeting to every member at least four (4) weeks in advance of such meeting.

Article VI—Amendments

Section 1. This Constitution may be amended by the consent of two-thirds of those members voting on a ballot mailed by the Secretary to each member in good standing at least four (4) weeks before the date specified for the receipt by the Secretary of the returned marked, sealed ballot. The Secretary shall supply with the ballot an envelope within which the marked ballot shall be sealed and returned to the Secretary in an outer envelope bearing the member's signature.

Section 2. Proposed amendments may be originated by:

a. The Executive Committee upon approval of the proposed amendment by a majority of the members of that Committee.
b. Fifteen (15) members in good standing who submit a proposed amendment in writing over their signatures to the Executive Committee through the Chairman of that Committee.

Section 3. The Secretary shall mail to each member in good standing a copy of the proposed amendment along with the ballot referred to in Section 1 of this Article.

Section 4. The Secretary shall notify each member of the results of the voting on a proposed amendment.

BYLAWS

Article I—Membership

Section 1. *Grades.* The constituted membership of the Institute shall consist of Regular Members, Student Members, Emeritus Members, Sustaining Members, and Honorary Members. The Regular Members shall have the particular designations of Members, Senior Members, or Fellows. Except as otherwise provided in these Bylaws, Regular Members shall be equally entitled to all rights and privileges of the Institute. Student Members, Emeritus Members, and Honorary Members shall have all rights and privileges of Institute membership except that they shall have no voting privileges in matters affecting the Institute as a whole, nor may they hold governing offices of the Institute. Sustaining Members will not have voting privileges.

Section 2. *Members.*

a. A member, at the time of admission or advancement to that grade, shall be at least twenty-one (21) years of age and of good character and:
   (1) Shall have a bachelor's or higher degree in a subject relevant to safeguards and be employed in or related to the management of nuclear materials or nuclear safeguards, or
   (2) Have been engaged in the practice of safeguards or nuclear materials management long enough to have demonstrated competence and understanding of a professional nature.

b. In addition to meeting all of the requirements of Section 2.a, a Member, before admission or advancement to that grade, shall be:
   (1) Qualified, under instruction and supervision, to undertake the planning and carrying out of work involving application of the principles of nuclear materials management; or
   (2) Qualified, under supervision, to teach subjects relating to nuclear materials management approved by the Executive Committee.

c. A Student Member who:
   (1) Completes fulfillment of the requirements of Section 2.a (1) of these Bylaws; or
   (2) During membership of at least two (2) years in that grade, completes fulfillment of the experience requirement of Section 2.a (2), shall be considered as having met qualification (1) or (2) of Section 2.b of these Bylaws, and as eligible for advancement to the grade of Member.

Section 3. *Senior Members.*

a. A Senior Member, at the time of advancement to that grade, shall be at least thirty (30) years of age, and shall be a Member actively engaged professionally in nuclear materials management whether the involvement be technical, administrative, consultative, or pedagogic (temporary unemployment excepted); and shall have had a least ten (10) years of active experience in one or in a combination of nuclear materials management fields indicative of growth in competence and achievement. Graduation in an appropriate curriculum of an accredited educational institution approved by the Membership Committee shall be considered the equivalent of four (4) years of the requisite ten (10) years of professional experience.

b. In addition to meeting all of the requirements of Section 3.a of these Bylaws, a Member shall, in order to be advanced to the grade of Senior Member:
   (1) Be professionally engaged in nuclear materials management and in that capacity shall have had responsible charge for at least two (2) years of work requiring application of nuclear materials management principles, or
   (2) Be a teacher of a subject or subjects related directly to the nuclear materials management field and, as such, be capable of teaching a major course in one or more branches of that field, and shall have had responsible charge for at least two (2) years in a field approved by the Examining Committee, or
   (3) Be a person engaged in nuclear materials management (or in a closely allied field) who by the development of nuclear materials management principles or procedures, or by proficiency in nuclear engineering or in closely allied subjects, or as an executive of a technical or operating enterprise of large scope, or as an executive with major responsibility for physical protection of nuclear materials, has attained a standing equivalent to that required for the Senior Member grade under Section 3.b (1) and (2) of these Bylaws, or
   (4) Be a person who holds, in good standing, in a cognate professional engineering, technical, or scientific society of national scope in any country, a grade of membership for which the qualifications indicate a standing equivalent to that required for Senior Member under Section 3.b (1) and (2) of these Bylaws.

c. Senior Members of the Institute shall be assessed nominally higher dues than those assessed Members.

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Section 4. *Fellows.*

a. A Fellow, at the time of advancement to that grade, shall be a Senior Member actively engaged professionally in nuclear materials management whether this involvement be technical, administrative, consultative, pedagogic, or other (temporary unemployment excepted); shall have established a specific record of contribution to the profession, had at least fifteen (15) years of active experience in the profession, and have been in good standing in the grade of Senior Member for at least five (5) consecutive years immediately prior to the date of his proposal for advancement to the grade of Fellow. A person who, at the time he/she became a Senior Member, held in good standing in a cognate professional engineering, technical, or scientific society of national scope in any country, a grade of membership for which the qualifications indicate a standing equivalent to that required for the grade of Senior Member herein, may have such years of prior membership in that equivalent grade, to a maximum of four (4), considered as part of the five (5) years in the Senior Member grade requisite to advancement to the grade of Fellow. Members proposed for the grade of Fellow during the period in which the grade of Senior Member had not existed for five (5) years may be considered for admission to this grade provided the requirements of Section 4.b are met. The total of the number of Fellows shall never exceed five percent (5%) of the regular membership at the time of their advancement. Fellows of the Institute shall be assessed the same dues as Senior Members.

b. In addition to meeting all of the requirements of Section 4.a of these Bylaws, a Senior Member shall, in order to be advanced to the grade of Fellow:
   (1) Have attained distinction in the planning or operation of nuclear materials management work, or of work in a related technical, administrative, consultative, or pedagogic field; and shall have been in full and responsible charge of the work involved for at least five (5) years; or
   (2) Have attained distinction by reason of original work in the development or exposition of the theory, principles, or techniques of nuclear materials management or of significant work in an allied technical, administrative, consultative, or pedagogic field; or as an alternative, shall have attained distinction as an executive in charge of nuclear materials management work of large scope, or in charge of the application of nuclear materials management principles in important projects.

Section 5. *Student Members.* A Student Member, at the time of admission to that grade, shall be a least eighteen (18) years of age and of good character; shall be engaged in or interested in nuclear materials management, or in an allied field of a technical or administrative nature; and shall be enrolled as a student at the college level in an accredited educational institution approved by the Membership Committee. In exceptional cases and on recommendation of the Membership Committee, the minimum age requirement may be waived by action of the Executive Committee. Student Members shall be assessed dues substantially lower than those assessed Members.

Section 6. *Emeritus Members.* Any Regular Member in good standing who is no longer gainfully employed through retirement or other cause may, upon approval of the Executive Committee, be granted Emeritus membership in the Institute. Emeritus Members shall be assessed dues substantially lower than those assessed Members.

Section 7. *Sustaining Members.* Since many private corporations or divisions thereof, governmental agencies, and other collective groups share the objectives outlined in Article II of the Institute of Nuclear Materials Management Constitution and may wish to make financial contributions on a regular basis to encourage and assist the endeavors involved in meeting these objectives, such contributing groups, upon their application, may be recognized by designation as Sustaining Members. Sustaining Members shall be entitled to receive, without additional charge, one copy of each technical publication issued by the Institute during each fiscal year of their membership. The monies collected from these dues shall be restricted for use in technical activities of the Institute such as standards, technical committees, technical staff, and special publications. Sustaining Members shall be privileged to send a number of their personnel to the national meetings of the Institute at the membership rate. The amount of a Sustaining Member's dues shall be based on the number of such attending personnel selected by the Sustaining Member but on an incremental scale to be determined by the Executive Committee.

Section 8. *Honorary Members.* An Honorary Member shall be one who has rendered acknowledged eminent service to nuclear materials management or to the allied arts and sciences. The number of Honorary Members shall never exceed one percent (1%) of the regular membership. Honorary Members should be prominent political, governmental, scientific, academic, or other figures chiefly from outside of the Institute membership and shall not be assessed dues by the Institute.

Article II—Admission, Advancement, Transfer, Resignation, Reinstatement, and Expulsion of Members

Section 1. *Admission.*

a. Admission to the Institute, except as an Honorary Member, shall be only to the grade of Member, Student Member, or Sustaining Member. Fellowship and Senior Membership may be attained only by advancement, and Emeritus Membership only by transfer, in accordance with Sections 4, 5, and 6 of this Article.

b. A candidate for admission to the Institute must file with the Secretary a completed application form as issued by the Institute designating the type of membership applied for, accompanied by the membership fee as established by the Executive Committee. Upon finding the application in conformance with the requirements for membership, the Secretary shall indicate acceptance of the application, or will note deficiencies, and will forward the application to the Treasurer who will perform a similar review and forward it to the Chairman of the Membership Committee. Upon a unanimous acceptance of the application by the Membership Committee, the applicant shall be declared to be a Member, shall be so advised by the Membership Chairman, and shall have his/her name recorded into the roll of Members by the Secretary. The membership fee submitted with the application shall be considered as payment of dues for the year during which the application was accepted. In the event the application was accepted between July 1 and September 30, the fee shall be considered as payment of dues for the remainder of the current year and for the year following.

Section 2. *Rejection.* If an application fails to have the approval of all members of the Membership Committee, it shall be declared as rejected by the Membership Chairman who shall then forward it, with the noted deficiencies, to the Executive Committee through its Chairman. The Executive Committee shall review the application and the reasons for rejection and make such other examination of the applicant's qualifications as it may deem advisable. If, then, a majority of the members of the Executive Committee sustain the rejection, the Chairman of the Executive Committee shall direct the Treasurer to notify the applicant of the rejection and to return the originally submitted membership fee to the applicant along with the notice of rejection. If, after the review by the executive Committee of the application, the reasons for rejection, and such other examination of the applicant's qualifications as it may deem advisable, a majority of the members shall sustain the application, the applicant shall be declared to be a member and shall be so advised by the Membership Chairman as provided in Section 1 of this Article.

Section 3. *Dues.* Membership dues for each Institute year beginning on October 1 shall be due and payable on the July 1 preceding and shall become delinquent on October 1. The Treasurer shall issue an invoice for dues to each member on July 1. A second, final notice shall be issued to unpaid members on October 1 at which time their member services shall be suspended until their current dues are received. Dues for the various grades of membership shall be established by the Executive Committee.

Section 4. *Senior Members.* Any member of this Institute who is eligible for Senior Membership, may apply for advancement to that grade at any time. Each such applicant shall certify that the requirements of Article I, Section 3 of these Bylaws have been met and shall provide such additional information as prescribed by the Examining Committee. The Examining Committee shall consider each application for advancement to Senior Membership submitted to it under the provisions of Article I, Section 3; and if, following the above consideration, the Committee shall approve said application, then, upon payment of the application of any transfer fee, increase in dues, or other charges prescribed in the Bylaws, the Secretary shall enroll said applicant as a Senior Member of the Institute.

Section 5. *Fellows.*

a. The grade of Fellow may be attained only by advancement from the grade of Senior Member, and may not be attained by application. A proposal for the advancement of a Senior Member to the grade of Fellow shall be originated by five (5) or more Members of the Institute who shall provide data sufficient in their judgment to substantiate the qualifications of their candidate with respect to the requirements of Article I, Section 4 of these Bylaws. Such proposals shall be submitted to the Secretary who shall transmit them to the Examining Board for its consideration.

b. If the Examining Committee finds the subject candidate fully qualified for the grade of Fellow, and that advancement to that grade would be in the best interest of the Institute, it shall so certify the proposal and forward its recommendation to the Executive Committee. If, upon subsequent consideration of the matter the proposal receives the favorable vote of two-thirds of the members of the Executive Committee, the Secretary shall enroll the candidate as a Fellow of the Institute.

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Section 6. *Emeritus Members.* Any member in any grade who is eligible for Emeritus Membership under Article I, Section 6 of these Bylaws may apply for transfer to that classification by written request to the Secretary. The Secretary shall then present such request to the Executive Committee which may act directly to approve or disapprove it or refer it to the Membership Committee for report and recommendation. The Secretary shall notify the applicant of the final action by the Executive Committee and, if approved, the effective date of the transfer shall normally be October 1 of the operating year in which such transfer was approved.

Section 7. *Resignation.* A member of any grade in the Institute may resign their membership by a written communication to the Secretary. If all dues and other indebtedness have been paid, the resignation in good standing shall be accepted unless charges have been preferred in accordance with Section 9 of this Article. A member who has failed to remit his current dues by January 1 of the Institute year shall be considered as having resigned from the Institute. The Executive Committee may grant such temporary dues relief as they deem proper due to prolonged unemployment or other appropriate reason.

Section 8. *Reinstatement.* A member of the Institute in any grade, who has resigned in good standing, may be reinstated by the Membership Committee upon review of that member's professional record, Such member may then renew all membership privileges by paying the required dues for the fiscal year in which the reinstatement occurs. A member in any grade who has been considered to have resigned because of failure to remit current dues may be reinstated in the same manner provided all indebtedness, such as services and materials previously received but not paid for, has been paid.

Section 9. *Expulsion.* Upon written request of ten (10) or more Regular Members that, for cause stated therein, a member of the Institute in any grade be expelled, the Executive Committee shall consider the matter and, if there appears to be sufficient reason, shall notify the accused of the charges by mailing a communication to his/her address as it appears in the Institute records. The accused shall then have the right to present a written defense and to appear for hearing, in person or by duly authorized representative, before a meeting of the Executive Committee, of which meeting the accused shall be notified at least twenty (20) days in advance. The Executive Committee shall then finally consider the case in the light of their findings and if, in the opinion of a two-thirds majority of the entire Committee, the accused has been engaged in conduct prejudicial to the interests or welfare of the Institute, he/she may be expelled, or suspended for such period as they may determine, or be permitted to resign.

Article III—Election of Officers

Section 1. All officers of the Institute and the four members-at-large of the Executive Committee elected from the membership of the Institute shall be elected by ballot mailed to each member of the Institute. The candidate for each elective position receiving the vote of a majority of those voting shall be elected. If votes are cast for more than two candidates for a given elective position and if no candidate receives a majority of the votes, then a special election shall be held in which the two candidates who received the highest number of votes in the first election shall be the candidates for the special election and the candidate receiving the vote of a majority of those voting in the special election shall be elected.

Section 2. Elected officers shall serve for a term of one year beginning October 1 of each year, or in the event of a delayed election, until their successors are elected. In the event of a delayed election, the newly elected officers shall serve until September 30 of the year following their election or until their successors are elected. The Chairman and Vice Chairman shall be eligible for re-election to their respective offices for the succeeding year but thereafter shall not be eligible to serve in their respective offices until after expiration of one year. The Secretary and Treasurer shall be eligible for re-election to their respective offices for successive terms.

Section 3. The four members of the Executive Committee elected from the membership shall each serve for a term of two years. Each year the terms for which two of these members were elected expire and two other members shall be elected to fill those positions. The retiring members of the Executive Committee shall not be eligible to serve as members-at-large of the Executive Committee until the expiration of one year. In the event that a vacancy occurs in these four positions of the Executive Committee, the Executive Committee shall appoint a successor to fill the unexpired term in which the vacancy occurs.

Section 4. The Nominating Committee shall furnish to the Secretary by April 1 of each year the names of at least two members as candidates for each of the elective positions on the Executive Committee for which members are to be elected. The Nominating Committee shall also furnish to the Secretary by April 1 of each year the names of one or more members as candidates for each of the offices of Chairman, Vice Chairman, Secretary, and Treasurer. No individual member shall be nominated for more than one elective office or position at any one election. Candidates may also be named for any of the elective offices or positions by fifteen (15) members who submit to the Secretary in writing over their signatures a petition naming the candidate and the office or position to which that candidate is thus nominated. Such petitions shall be submitted to the Secretary on or before April 1 preceding the election.

Section 5. The Secretary shall mail a ballot listing the names of the candidates and the offices or positions to which they have been nominated to each member in good standing not later than May 1 of each year. The ballot shall bear a notice to the effect that the marked ballot shall be returned to the Secretary before June 1. The Secretary shall supply with the ballot an envelope within which the marked ballot shall be sealed. The sealed ballot shall be returned to the Secretary in an outer envelope bearing the member's signature. In marking the ballot the member may write in the name of a candidate for an office or position for which he wishes to vote if that name is not listed on the ballot forwarded by the Secretary to the member.

Section 6. The Secretary shall notify each member in good standing of the results of the election before October 1 of each year.

Section 7. After the election each year the out-going Chairman of the Institute shall call a meeting of the Executive Committee at which time the newly elected members of the Committee shall meet with the out-going members to arrange for the transfer of responsibility for each office and elective position by September 30 of each year.

Section 8. All officers shall serve without remuneration.

Section 9. In the event of a vacancy in the office of Chairman, the Vice Chairman shall vacate his office and become Chairman for the unexpired term of office. All other vacancies of officers may be filled by the Executive Committee by interim appointment for the unexpired term of office.

Article IV—Duties of Officers and Committees

Section 1. The duties of the officers shall be those customarily performed by such officers together with those specifically mentioned in these Bylaws and such other duties as may be assigned from time to time by the Executive Committee.

Section 2. The Chairman shall preside at all general meetings and meetings of the Executive Committee and shall perform all duties customarily pertaining to such an office.

Section 3. The Vice Chairman shall assist the Chairman in all matters referred and shall perform all of the duties of the Chairman in his/her absence.

Section 4. The Secretary shall keep a record of the proceedings of the Institute and shall serve as Secretary of the Executive Committee. The Secretary shall also:

a. Give due advance notice of all meetings of the Institute to each member.
b. Mail to each member ballots for the election of officers and other elective positions and for proposed amendments to the Constitution and Bylaws.
c. Notify each member of the results of elections and of the voting on proposed amendments.
d. Record the names of new members in the roll of members and advise new members of their acceptance into membership by the Institute.
e. Perform such other duties as the office shall require or as shall be assigned by the Executive Committee.
f. Surrender to his successor all books, records, correspondence, and documents of the Institute.

Section 5. The Treasurer shall collect and disburse the funds of the Institute. The Treasurer may make disbursements for non-budgeted expenditures up to and including $50 without prior approval of the Executive Committee. Non-budgeted expenditures over $50 must have such prior approval. Approval of the Institute's budget by the Executive Committee shall constitute authority to the Treasurer to disburse funds up to and including the amount in each line item, provided that such individual disbursements shall have been vouchered by the responsible Chairman or individual designated by the Executive Committee. The Treasurer shall also:

a. Present a financial report to the Executive Committee at the end of each fiscal year and at other times as requested by the Chairman.
b. Receive applications for membership and membership fees from the Secretary and forward applications for membership to the Chairman of the Membership Committee.
c. Advise any rejected applicant for membership of such rejection and return to the applicant the membership fee originally submitted with the application.

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d. Issue to the members notices of dues payable. Such notices shall show the due date on or before which payment is to be made.
e. Perform such other duties as the office may require or as assigned by the Executive Committee.
f. Surrender to his successor all funds and property of the Institute.

Section 6. The Executive Committee shall be the governing body of the Institute and as such, shall have full power to conduct, manage, and direct the business and affairs of the Institute in accordance with the Constitution and Bylaws of the Institute. It shall:

a. Maintain a book of minutes of all proceedings at its meetings. The Secretary of the Institute shall serve as Secretary of the Executive Committee. In the absence of the Secretary, the Chairman shall designate a temporary Secretary to record the proceedings of that meeting.
b. Interpret and execute the provisions of the Constitution and Bylaws.
c. Fill any vacancy in any office of the Institute or Executive Committee except that of Chairman.
d. Select and appoint a Membership Committee composed of the Secretary, Treasurer, and at least one other member-at-large and designate the Chairman of that Committee. Neither the Secretary nor the Treasurer shall be the Chairman.
e. Select and appoint a Program Committee composed of a chairman and at least one other member and designate the Chairman of that Committee.
f. Select and appoint a Nominating Committee composed of a Chairman and at least one other member and designate the Chairman of that Committee.
g. Select and appoint a Certification Board composed of a Chairman and at least two other members who are themselves certified and designate the Chairman of that Board.
h. Select and appoint a Statutory Agent with a business address in the State of Ohio in which the principal office of the Institute is located.
i. Select and appoint an Examining Committee of at least three Senior Members or Fellows and designate the Chairman of that Committee.

Section 7. If the Chairman is temporarily unavailable, he/she may request the Vice Chairman to act as Chairman for the purpose of calling and presiding over an Executive Committee meeting. In the absence of both the Chairman and Vice Chairman at an Executive Committee meeting, the Executive Committee shall elect a temporary Chairman.

Section 8. The Executive Committee shall meet upon due notice to its members at the call of the Chairman or upon the written request of a majority of the members of the Committee directed to the Chairman of the committee. In the absence of a quorum, which shall be five members of the Executive Committee, called meetings of the Executive Committee shall adjourn to a date. The Executive Committee shall meet at least twice in each fiscal year.

Section 9. The Membership Committee shall give due consideration to applications for membership as referred to in Article I of these Bylaws and shall perform such other duties as are customarily referred to such a committee or as are assigned to it by the Executive Committee.

Section 10. The Nominating Committee shall nominate members as candidates for each office and position as referred to in Article III, Section 4, of these Bylaws and shall perform such other duties as may be assigned to it by the Executive Committee.

Section 11. The Program Committee shall submit to the Executive Committee for its approval proposed dates, meeting accommodations, and agenda for general membership technical meetings and shall be responsible for such other arrangements as may be necessary to ensure the orderly conduct of the meeting. It shall perform such other duties as may be assigned to it by the Executive Committee.

Section 12. The Certification Board shall review all applications for certification and recertification and shall evaluate each candidate on the basis of the information contained on his application, professional and personal references, written examination, and other means as it deems appropriate to assure that the candidate meets the high standards of technical and/or managerial competence required.

Section 13. All appointed committees shall maintain a record of all proceedings of their meetings and otherwise provide for their own operation.

Section 14. Members of committees appointed by the Executive Committee shall serve for a term of one year or until their successors have been appointed.

Section 15. The Examining Committee shall review all applications for advancement to the grade of Senior Member or Fellow, shall evaluate each candiate for such advancement to assure that the requirements of Article I, Sections 3 or 4, of these Bylaws are met, and shall recommend such candidates for advancement as they deem appropriate.

Article V—Meetings

Section 1. At regular meetings of the Institute the order of business shall be established by the Chairman. The rules of order in the conduct of meetings not specifically provided in these Bylaws shall be Robert's "Rules of Order." A quorum shall consist of 10 percent of the members and in the absence of a quorum no business shall be transacted.

Article VI—Chapters

Section 1. Upon the written petition over the signatures of seven (7) members submitted to the Executive Committee through the Chairman, the Executive Committee may authorize the formation of a Chapter. Such petitioners shall either reside or be employed within the geographical area for which the Chapter is proposed. After due consideration of the petition by the Executive Committee, that Committee through its Secretary shall advise the petitioners of its decision as to the authorization of the proposed Chapter.

Section 2. Upon notice of favorable action on the petition by the Executive Committee, the Chapter shall prepare its Constitution and Bylaws and submit them to the Executive Committee for approval.

Section 3. The Chapter shall at all times be subject to the Constitution and Bylaws of the Institute and to all rules and regulations prescribed from time to time by the Executive Committee for the conduct of the Institute as a whole.

Section 4. It shall be the function of the Chapter to foster, promote, and further within the geographical area assigned to it by the Executive Committee, the purposes and objectives of the Institute as contained in the Constitution and Bylaws of the Institute and as promulgated by the Executive Committee.

Section 5. The Secretary of the Chapter shall submit a copy of the minutes of each business meeting to the Secretary of the Institute.

Article VII—Amendments

Section 1. These Bylaws may be amended by the same procedure as provided for the amendment of the Constitution as described in Article VII, Sections 1, 2, 3, and 4 of the Constitution of this Institute.

INMM EXECUTIVE COMMITTEE
CHAIRMAN Gary F. Molen
VICE CHAIRMAN John L. Jaech
SECRETARY Vincent J. DeVito
TREASURER Edward Owings
MEMBERS AT LARGE
Carleton D. Bingham
Roy B. Crouch
Glenn A. Hammond
G. Robert Keepin
Charles M. Vaughan

INMM COMMITTEE CHAIRMEN

Annual Meeting Arrangements	Tommy Sellers
Annual Meeting Program	Yvonne Ferris
Awards	Willy Higinbotham
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Membership	John Barry
N-14 Standards	Jim Clark
N-15 Standards	George Huff
Nominating	Bob Keepin
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INMM CALENDAR OF EVENTS

JULY 18-21, 1982
INMM 23rd Annual Meeting
Hyatt Regency Washington on Capitol Hill
Washington, D.C.

OCTOBER 5-8, 1982
Physical Protection Workshop
Sheraton Old Town
Albuquerque, New Mexico

OCTOBER 19-21, 1982
Nuclear Waste Management Seminar
Hyatt Regency Washington on Capitol Hill
Washington, D.C.

JULY 10-13, 1983
INMM 24th Annual Meeting
Denver Marriott City Center
Denver, Colorado

SPECIAL REPORT

USDOE/IAEA INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION OF STATE SYSTEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS

March 15-30, 1982

C.R. HATCHER AND G.R. KEEPIN
Los Alamos National Laboratory
BERNARDINO PONTES
International Atomic Energy Agency

An advanced International Training Course on Implementation of State Systems of Accounting for and Control of Nuclear Materials was held March 15-30, 1982, in Santa Fe and Los Alamos, New Mexico, and Palo Verde, Arizona. The course was sponsored by the U.S. Department of Energy (DOE) in cooperation with the International Atomic Energy Agency (IAEA) and was developed "to provide practical training in the design, implementation, and operation of a national system of accounting for and control of nuclear materials that satisfies both national and IAEA international safeguards objectives." Nations represented at the course included Brazil, Canada, Czechoslovakia, Finland, France, German Democratic Republic, Iraq, Japan, Malaysia, Pakistan, Phillipines, Republic of South Africa, Sweden, Taiwan, Turkey, and Yugloslavia.

The course was conducted by the University of California's Los Alamos National Laboratory and featured a field trip to the Palo Verde Nuclear Generating Station operated by Arizona Public Service Company. A total of 60 people participated in the course, including attendees, lecturers, nondestructive assay (NDA) equipment demonstrators, and plant engineering personnel.

The 1982 course represents the third in the ongoing series of international training courses on State Systems of Accounting and Control (SSAC) that have been arranged through US/IAEA cooperation. The first course, held in 1980 at Santa Fe and Los Alamos, New Mexico, dealt with practical techniques for safeguarding power and research reactors and associated spent-fuel storage. The second course, held in 1981 at Santa Fe and Los Alamos, New Mexico, and Richland, Washington, addressed safeguards practice at bulk-processing facilities, particularly low-enriched uranium conversion and fuel fabrication plants. Exxon Nuclear Company, Inc., and Battelle Pacific Northwest Laboratories joined Los Alamos in presenting the second course, which featured tours of the Exxon fuel fabrication plant in Richland, Washington.

Emphasis for the 1982 course was again on item-dominant facilities, including power reactors, research reactors, and spent-fuel storage facilities. Internationally known authorities were selected as course lecturers from the IAEA (3), Los Alamos (8), U.S. government and industry (4), and foreign countries (6). Table I presents the course outline, showing session titles and names of lecturers, panel chairmen, tour coordinators, and workshop leaders.

In welcoming participants to Santa Fe, John Hopkins, Deputy Associate Director at Los Alamos, said: "Since the bombing of the Tamuz-I reactor last June, there has been a resurgence of intense debate, inquiry, and re-examination of the posture of nuclear safeguards on both the national and international level. All of this has vividly underscored the fact that our present institutional approach must be made to work, since it is all we have, and indeed is all we are likely to get for the foreseeable future."

Tom Isaacs, Deputy Director, DOE/Office of Safeguards and Security, noted that "this course is mandated by the U.S. Nuclear Nonproliferation Act of 1978, which recognizes safeguards to be one of the pillars of nonproliferation."

Course director Bob Keepin then presented an introduction to the material that would be covered during the training course, including a perspective on past and present SSAC courses. Keepin said that "the need for knowledge, mutual understanding, and cooperation on the part of both the inspector and the 'inspected' clearly underscores the importance of safeguards training and technology transfer—at the international, the SSAC, and the facility levels."

Sessions 2 and 3 (see Table I) covered important background material, with John Boright, U.S. Department of State (DOS), tracing the historical development and current trends in international safeguards and Carlos Büchler, IAEA, reviewing IAEA guidelines for SSAC. The next three sessions (4-6) summarized the German Democratic Republic's experience in safeguarding power reactors, Yugoslavia's experience in safeguarding research reactors, and IAEA approaches for verifying nuclear material inventories at both power and research reactors.

In Session 7, one participant from each country gave a short informal talk concerning nuclear activities and safeguards within his or her country. Session Chairman Dr. Hans Grümm, IAEA Deputy Director General for Safeguards, then summarized the main issues raised by participants. These were: (1) legal arrangements for SSACs, (2) voluntary offers by nuclear weapon states, (3) liaison committees between the IAEA and large SSACs, (4) quality and loyalty of IAEA inspectors, (5) computerization of accounting and reporting, (6) detection of dummy fuel elements, (7) reporting and batch matching of international transfers, (8) quality assurance of safeguards measurement systems and containment and surveillance systems, (9) flexibility of key measurement points at research reactor facilities, and (10) updating of design information questionnaires (DIQs).

Grümm's summary was followed by a panel discussion of specific topics and issues raised by the participants. The panel, chaired by John Boright, DOS, included Paul Morrow, NRC; Victor Dimic, J. Stephen Institute, Yugoslavia; Walter Röhnsch, National Board for Nuclear Safety and Radiation Protection, German Democratic Republic; Hideo Kuroi, Japan Atomic Energy Research Institute; and Carlos Büchler and Les Thorne of the IAEA.

Attendees at previous SSAC courses had suggested that future courses provide more detailed coverage of nondestructive assay/verification techniques. Accordingly, in this 1982 course, several lectures (Sessions 9-12, 20, 21) were devoted to NDA and 2 days were spent visiting Los Alamos safeguards laboratories. During the first day at Los Alamos (Sessions 13, 14), course participants performed measurements of fresh fuel material using neutron assay instruments such as the high-level neutron coincidence counter, the active well coincidence counter, and the coincidence collar. They also used gamma-ray assay instruments, including the SAM-II and the portable multichannel analyzer (mini-MCA) developed by Los Alamos for the IAEA. On the second day at Los Alamos (Sessions 23, 24), participants visited the Omega West Reactor and used NDA equipment for verification of spent-fuel characteristics. Included were the Cerenkov detector and other instruments (such as ION-1) based on neutron and gamma-ray assay techniques.

The course also provided attendees with an introduction to two topics closely related to materials accountancy and control: (1)

containment and surveillance and (2) statistics. Jim McKenzie of Sandia National Laboratory lectured on item identification and seals, and demonstrated various types of seals and seal verification hardware (Session 17). Andrew Stirling, Atomic Energy of Canada, Limited, addressed containment and surveillance techniques developed for CANDU power reactor facilities (Session 18). In Sessions 22 and 25, John Jaech of Exxon Nuclear Company, Inc., discussed statistical methods used in nuclear material accounting, with emphasis on applications to reactor facilities.

Most of the remaining lectures dealt in further detail with materials accountancy and control procedures for power and research reactors. These included the lectures by Paul Ek of the Swedish Nuclear Power Inspectorate, H. Kuroi of Japan Atomic Energy Research Institute, Henry Bliss of Commonwealth Edison Company, and J. Maurel of the French Atomic Energy Commission. These materials accountancy and control sessions led into a 1½-day workshop in which course attendees were divided into four groups. Each group was given the task of designing a safeguards system for a "reference" 1000-MWe pressurized-water-

Participants in international training course were photographed March 17, 1982. Standing on first level, left to right, are: Jasna Bozic, Yugoslavia; Victor Dimic, Yugoslavia; Lilia Palhares, Brazil; Tom Canada, USA; Clarissa Lobo Iskin, Brazil; Iqbal Ahmed, Pakistan; Claude Milet, France; Gloria Mirabal, USA; Virgilio Santiago, Philippines; Ingegaerd Rehn, Sweden; Mauri Riihonen, Finland; Joy Clark, USA; and Charles Hatcher, USA. Sanding on first step (second level) are Roddy Walton, USA, and Toshihide Sugiyama, Japan. The third level starting far left includes Dogan Oner, Turkey; Kenechi Schimizu, Japan; Hideo Kuroi, Japan; George Healy, Canada; Len Watkins, Canada, and Masatoshi Morone, Japan. Fourth row: Johannes Van Wyk, Republic of South Africa; Arif Mumtaz-Ud-Din, Pakistan; Hisato Komatsu, Japan; Teh-Shih Chien, Taiwan; Zdravko Gabrovsek, Yugoslavia. Fifth row: Paul Morrow, USA; Hung-Ming Yu, Taiwan; Ayad Nabi, Iraq; Jaromir Moravec, Czechoslovakia. Sixth row: Carlos Büchler, IAEA; Yazis Yunis, Malaysia; Michael Burmester, German Democratic Republic; Ludek Cermak, Czechoslovakia. Seventh row: Bob Keepin, USA; Hans Grümm, IAEA; Abdul Al-Hani, Iraq; Top row: Bernadino Pontes, IAEA; Walter Röhnsch, German Democratic Republic; and John Boright, USA.

continued on page 26

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reactor facility. Rapporteurs for each group presented their group's system design in a 20-min talk, which was critiqued by workshop coordinators and course participants.

Following the formal sessions in Santa Fe, the group boarded a bus for Phoenix, Arizona, with a weekend visit to the Grand Canyon. On March 29, participants heard briefings on the Palo Verde Nuclear Generating Station (PVNGS) by senior engineering personnel from Arizona Public Service Company (APS) and were given a walking tour through the plant. PVNGS consists of three 1300-MWe reactors with Unit 1 now 96% complete and scheduled to go on-line in May 1983. The Palo Verde tour provided an excellent opportunity to see how modern nuclear power plants are constructed and to follow the path of nuclear fuel during receiving, inspection, temporary storage, transfer through the fuel canal to the reactor core, and eventually to on-site spent-fuel storage ponds. The visit to Palo Verde was arranged through Edwin van Brundt, APS Vice President for Nuclear Services, and William Kellogg, Director of Public Information. On the final day of the course, Leroy Norderhaug and Lou Vorderbrueggen of the U.S. Nuclear Regulatory Commission outlined NRC activities at Palo Verde during construction and operational phases of the plant. Bob Page, Supervisor of Energy Affairs, led a panel of APS technical experts in answering questions relating to the PVNGS tour. Page also presented a talk on APS's program to develop public confidence in nuclear power.

For many, the high point of the 1982 course was the banquet address and presentation of diplomas by Dr. Sigvard Eklund, Director General of the IAEA from 1961 to 1981. This gala event, presided over by Course Director Bob Keepin, took place at the Santa Fe Hilton on March 25, 1982. In his remarks, Eklund said that "international safeguards represents a pioneering step in controlling certain activities in otherwise sovereign states. No sovereign state wants to give away even a minute part of its sovereignty, and IAEA safeguards has had (and will continued to have) to explain to governments that it is of mutual interest to collaborate with—and participate in—and accept—an international safeguards system to insure that nuclear energy is not used for military purposes. Your course, which is approaching its conclusion today, represents a very important attempt to bridge the differences between the inspectees and inspectors."

The differences in perception by people at facility, state, and IAEA levels in safeguards—and the need for better understanding and communication—was a recurrent theme throughout the course. In international safeguards, technology has a very important role, but successful implementation also depends on people—working cooperatively across political, organizational, and cultural barriers. No one expressed this thought better than Hideo Kuroi, who made an analogy between the perception of safeguards and the perception of a 500-yr-old rock garden at the Ryoanji Temple in Kyoto, Japan. According to Mr. Kuroi, if visitors attempt to count the number of rocks in the garden, they will invariably arrive at different answers. The garden is arranged so that some rocks are always hidden, and the number of rocks that are visible depends on your "point of view."

Published proceedings of the 1982 course, including the full text of all lectures, will be available in late 1982 from the U.S. Department of Energy, Office of Safeguards and Security, or from Los Alamos National Laboratory.

Table I Course Outline

	Welcome and Orientation—J. Hopkins, Los Alamos; T. Isaacs, DOE/OSS; B. Pontes, IAEA
Session 1	Introduction to SSAC Training Course—R. Keepin, Los Alamos
Session 2	Historical Development and Current Trends in Nuclear Safeguards—J. Boright, Department of State
Session 3	Overview of IAEA Guidelines for State Systems of Accounting and Control—C. Büchler, IAEA
Session 4	State System Experience with Safeguarding Power Reactors—W. Röhnsch, German Democratic Republic
Session 5	IAEA Safeguards at Reactor Facilities—L. Thorne, IAEA
Session 6	State System Experience with Safeguarding Research Reactors—V. Dimic, Yugoslavia
Session 7	Workshop Seminar on IAEA-State Systems Interface—H. Grümm, IAEA, Chairman
Session 8	Workshop Panel on IAEA-State Systems Interface—J. Boright, Department of State
Session 9	Elements of Nondestructive Assay Technology—C. Hatcher, H. Smith, Los Alamos
Session 10	Gamma-Ray Techniques for Assay/Verification of Unirradiated Uranium and Plutonium Fuels—H. Smith, Los Alamos
Session 11	Neutron Techniques for Assay/Verification of Unirradiated Uranium and Plutonium Fuels—H. Menlove, Los Alamos
Session 12	Elements of In-Plant Nondestructive Assay Instrumentation Design and Implementation—T. Canada, Los Alamos
Sessions 13/14	Tour of Los Alamos Safeguards R&D Laboratories: Demonstration and Use of NDA Instruments and Methods for Assay/Verification of Unirradiated Fuels—D. Reilly, H. Smith, Los Alamos—Tour Coordinators
Session 15	Materials Accountancy and Control for Power Reactors and Associated Spent Fuel Storage—P. Ek, Sweden
Session 16	Materials Accountancy and Control for Research Reactors and Critical Assemblies—H. Kuroi, Japan
Session 17	Item Identification and Seals: Technology and Experience—J. McKenzie, Sandia
Session 18	Containment and Surveillance Techniques at Power Reactors—A. Stirling, Canada
Session 19	Reactor Operation and Spent-Fuel Characteristics—J. Foley, Los Alamos
Session 20	Passive Gamma-Ray Methods for Assay/Verification of Spent Fuel—J. Phillips, Los Alamos
Session 21	Passive and Active Neutron Methods for Assay/Verification of Spent Fuel—D. Lee, Los Alamos
Session 22	Survey of Statistical Methods in Nuclear Material Accounting and Control—J. Jaech, Exxon Nuclear
Session 23/24	Los Alamos Tour and Demonstration of Instruments and Techniques for Assay/Verification of Spent Fuel—J. Phillips, N. Nicholson, Los Alamos—Tour Coordinators
Session 25	Statistical Methods Applicable to Reactor Facilities—J. Jaech, Exxon Nuclear
Session 26	Material Accountancy and Control Practice at an Operating Power Reactor Facility—H. Bliss, Commonwealth Edison
Session 27	Material Accountancy and Control Practice at a Research Reactor Facility—J. Bouchard, J. Maurel, Y. Troneur, France
Sessions 28-32	Workshop on Safeguards System Design for Reactor Facilities—E. Hakkila, J. Sapir, Los Alamos; D. Perricos, IAEA; K. Sanders, NRC—Workshop Coordinators
Sessions 33/34	Briefing, Tour, and Discussion of Palo Verde Nuclear Generating Station—Arizona Public Service Company and NRC staff
Session 35	Course Evaluation, Discussion, and Wrap-up—Course staff and attendees

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CARDWELL SPEAKS AT BOB JONES UNIVERSITY

A seminar on energy was recently presented to the Student Business Association of Bob Jones University in Greenville, South Carolina, by Past INMM Chairman Roy G. Cardwell of the Union Carbide Nuclear Division in Oak Ridge, Tennessee.

The talk, entitled "Nuclear Energy and its Alternatives—How Good Are They?", was attended by 900 members of the SBA and addressed all of the significant energy sources that are contributing to the total U.S. power picture.

In commenting on the seminar, Dean Richard Leiter, of the University, said that he welcomed the presentation because "as a pro-nuclear energy advocate" he felt that "the nuclear community has not been as agressive as it could be in its public relations effort in promoting nuclear energy."

"I feel that nuclear energy is the energy source of the future, but that we are losing the battle because of the high profile that the anti-nuclear people are enjoying and the success they are having in slowing down its progress," he said.

Dean Leiter is a native of Harrisburg, Pennsylvania, near the Three-Mile-Island nuclear power station.

Roy Cardwell, UCC-ND Oak Ridge, presents an art montage of nuclear reactor materials developed over many years at the Oak Ridge National Laboratory to David Rinkliff, President, and Greg Turnage, Vice-President, of the Bob Jones University Student Business Association as Dean Richard Leiter looks on. Nuclear Energy and Its Alternatives was the topic of a recent seminar given by Cardwell at the University.

A METHODOLOGY FOR EVALUATION OF CONTAINMENT AND SURVEILLANCE SAFEGUARDS SYSTEM PERFORMANCE*

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ABSTRACT

A method is presented for evaluating the performance of containment and surveillance safeguards systems in detecting diversion of nuclear material from fuel cycle facilities. System performance is described by a probability of detection calculated as a function of diversion amount and the time over which it takes place. System performance is dependent on the performance of detection instrumentation and the strategy used in the diversion attempt. Instrument performance for each surveillance application is assumed available as input. The identification of diversion strategies is part of the evaluation method. The strategies of greatest interest for purposes of evaluation are those which, for any particular diversion amount and time, maximize the probability that the diversion will go undetected. These strategies are used as the basis for safeguards system evaluation because they provide worst-case bounds for system performance. Protracted diversion strategies involving uniform diversion of material are shown to be optimal for instrument performance of a particular mathematical form. System false alarm rate and instrument reliability are given explicit attention.

INTRODUCTION

Safeguards are employed within the nuclear industry to provide a means of timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown (1). Containment and surveillance (C/S) have increasingly been regarded as an important part of international safeguards for spent nuclear fuel reprocessing plants (2). A particular concern has been the quantification of the assurance provided by C/S systems in providing timely detection of diversion. This paper describes a methodology for evaluation of C/S systems which are based on the definition of containment boundaries coupled with surveillance of all penetrations through these boundaries to detect any undeclared movement of material through them. (See Reference 3 for application of the surveillance of containment boundary penetration concept.) Surveillance of containment boundaries as a safeguards measure is complementary to material accountancy which keeps track of nuclear material by measuring it directly to confirm its presence.

A C/S system is defined by proposing instrumentation for detection of nuclear material transfer through all or some subset of boundary penetrations. The specification of an instrument for application to each penetration (i.e., an instrumented penetration), along with the performance characteristics of this application, provides the empirical input upon which the evaluation is based.

The probability that diversion past a particular instrument will be detected by the system (i.e., cause an alarm) is usually dependent on the amount of material that is being diverted. Furthermore, for a system of instruments, the probability of detection of any diversion attempt is dependent upon such key factors as the specific penetrations used (e.g., one or several) and the time over which the diversion takes place (e.g., abrupt or protracted). Since it is impossible to determine in advance which particular diversion strategy may be used, the performance of a system should be described by consideration of those diversion strategies which are least detectable.

In the methodology described in this paper, these factors are taken into account by determining the diversion strategies which result in worst-case performance and basing system evaluation upon those. The methodology focuses on quantification of system performance by determining a system probability of detection as a

*The research performed by Sandia National Laboratories and Science Applications, Inc. was supported by the U.S. Department of Energy, Office of Safeguards and Security.

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function of diversion amount. The evaluation problem is expressed in the form of a mathematical optimization problem which is similar to that formulated by Gregson and Musto(4), but the methodology used to solve this mathematical problem is different. The current methodology is based upon the use of dynamic programming (5). A key feature of the methodology is the development and application of an analytical test that can be extremely effective in reducing the final size of the optimization problem. It does this by identifying (in advance of the application of dynamic programming) penetrations that will be used, if used at all, uniformly over time. Ensuring computational feasibility when the method is applied to systems of realistic size and complexity was the central goal in development of the evaluation methodology. False alarm rates and instrument reliability are given explicit attention; other important practical factors such as cost, inspector support, and tamper-safing are not considered.

Although the evaluation methodology presented here is described in the context of the C/S evaluation problem, the analytical results presented and the application of the methodology extend to any other safeguard evaluation problem which has a similar mathematical formulation.

SYSTEM MODEL

The system model must represent three facets of the safeguards evaluation problem: the configuration of the facility, the performance of safeguards instrumentation, and the potential action of the diverter. The physical characteristics of the facility that are important to a C/S safeguards system are reflected in the definition of containment boundaries and in the identification of penetrations through these boundaries. The characterization of instrument performance is based upon measurement and test data. The action of the diverter is important because different diversion strategies result in different probabilities of detection. (As will be seen, the probability of detecting a particular diversion strategy is one minus the product of the probability of avoiding detection for all instrumented penetrations each time they are used.)

Each of these three aspects of the problem are considered individually before a mathematical representation of the system model is formulated.

Facility Representation

For this problem, a network provides a compact and visual means of facility representation. A network of the facility is a system of nodes joined by arcs. The area of the facility within each of the containment boundaries is represented by a node. An example network is shown in Figure 1. The node labeled "primary containment zone" refers to the area within a primary containment boundary. The node labeled "secondary containment zone" refers to the area between primary and secondary containment boundaries, and the node labeled "outside" refers to all areas located outside of any containment barrier. The arcs between nodes represent the penetrations through the containment boundary which separates the zones. It should be recognized that most of the arcs of Figure 1 represent entire sets of identical penetrations.

The above discussion centers on the spatial representation of the facility. Another feature that requires representation is its use over time. To reflect the temporal aspect of facility characterization, we increase the number of arcs in the network. This is done by first determining the time horizon to be considered in the safeguards evaluation and then replicating each arc as many times as the penetration can be used by the diverter during this time. For example, for a personnel portal, the usage depends on the number of personnel normally expected to pass through it within the time horizon. For a penetration that can be used continuously, such as a pipe instrumented with a radiation monitor, the number of discrete time increments of use are obtained by dividing the time horizon by the length of the instrument counting interval.

Thus, when both space and time are fully represented, the number of arcs expands considerably from those shown in Figure 1. Each arc shown in Figure 1 is a representation of a collection of identical arcs whose number corresponds to the product of the number of identical penetrations represented times the

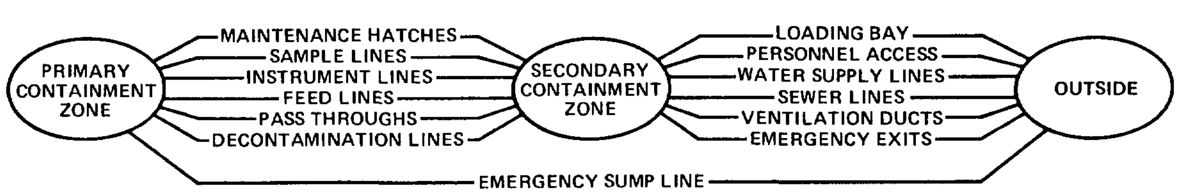

Figure 1. Aggregate Facility Network.

number of time increments contained within the desired evaluation time horizon. Clearly, the large number of arcs representing a network of realistic size threatens computational practicality. Fortunately, as will be seen, an effective means exists for taking computational advantage of the fact that many arcs are identical in the sense that they represent a single type of penetration replicated in space and time. This will result in a mathematically-equivalent problem of much smaller size.

Instrument Performance

A primary input to evaluation of system performance is the performance of the individual instrument. Instrument performance in a particular C/S application is characterized by quantifying, as a probability, the ability of the instrument in detecting diversion of various amounts of nuclear material during each incremental use of the penetration. Instrument performance against diversions involving several penetrations over several time increments of use is based on this single-time-increment performance.

In one time increment, it is possible to divert various amounts of nuclear material through an instrumented penetration. Performance as a function of the amount of nuclear material diversion is described through a function of the form shown in Figure 2. The detection avoidance function provides a more useful representation than the probability of detection when considering the problem from the diverter's point of view, which we subsequently do. There are no methodology-induced restrictions on the shape of the detection avoidance functions, whether available as a continuous function, as shown, or as a discrete function representing a limited number of data points.

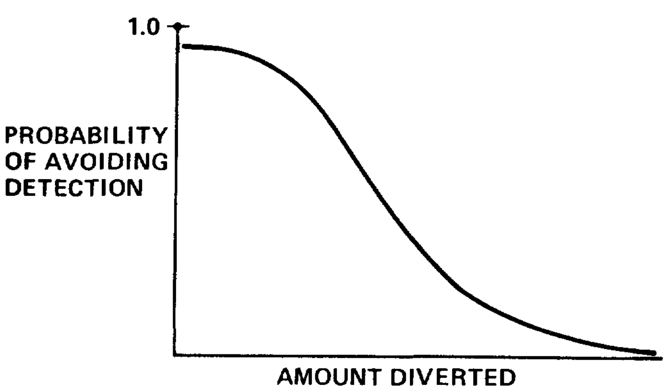

Figure 2. Detection Avoidance Function.

To illustrate the form of a specific detection avoidance function, consider the instrumentation of a penetration with a radiation detector. In a typical application, the detector would be set to sound an alarm if the number of counts it registers within any counting period exceeds a preset threshold. (A non-zero threshold is set to avoid false alarms due to background radiation.) It is well known that the number of counts produced by a radioactive material within a certain time interval can be represented by a Poisson probability mass function, and that, for a sufficiently large mean number of counts, this function can be adequately approximated by a normal density function with variance equal to mean, both of which equal the mean of the Poisson distribution. Thus, normal densities can be used to represent the number of counts produced by the background radiation and by a diversion. The probability of avoiding detection is then the probability that the number of counts represented by the sum of the two density functions will not exceed the instrument threshold. (The summation follows from an assumption that the number of counts produced by the background are independent of those produced by any diversion of material.) If we consider a background radiation level with mean counts α per counting interval and an alarm threshold of T counts, then the probability of avoiding detection of a diversion amount x is

$$f(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{T-\alpha-\beta x}{\sqrt{\alpha+\beta x}}} e^{-n^2/2}\, dn, \quad x > 0$$

$$f(0) = 1.0,$$

where βx is the mean number of counts produced by a diversion of x. (β is a constant representing factors associated with the performance of the measuring instrument.) When calculating f(x) only those diversion paths (arcs) along which material is actually diverted are considered. Therefore f(0) = 1., since no diversion paths are used when no material is diverted. This should not be confused with the calculation of false alarm probability, which is dealt with later in the paper, i.e., the false alarm probability is not equal to 1.-f(0).

Diversion Strategy

The third major facet in the formulation of the system model is a strategy to divert a particular amount of material within some particular time horizon. This requires specification of the penetrations to be used and the amount to be taken through each penetration at each opportunity in time. Clearly, a large number of possible diversion strategies exist.

As already noted, one measure of safeguard system performance is its effectiveness against diversion strategies which are least likely to be detected. These strategies are called optimal diversion strategies. They provide worst-case evaluations of system performance and facilitate the identification of system weaknesses. Although the determination of optimal diversion strategies increases the complexity of the system evaluation task, this determination is essential to an evaluation scheme based on diversion detection probabilities. This is particularly important in an international safeguards setting, where the diverter (the State) may know not only the facility configuration but also the performance of each C/S instrument.

We now proceed to formulate the mathematical optimization problem facing the diverter in a given safeguarded facility. After that, the determination of optimal diversion strategies will be presented.

Mathematical Representation

Consider the system of parallel penetrations represented by the network of Figure 3. Three indices are used to distinguish each arc: two are used to reflect the physical features of the instrumented penetrations and one for time. The first identifies the instrumented penetration type (e.g., sample line radiation monitor), the second the time increment, and the third the individual instrumented penetration within each type. For the example shown there are n instrumented penetration types, where each type $i = 1,2,\ldots,n$ involves m_i time increments and q_i individual, identical instrumented penetrations. The network has a total of $m_1q_1 + m_2q_2 + \ldots + m_nq_n$ arcs.

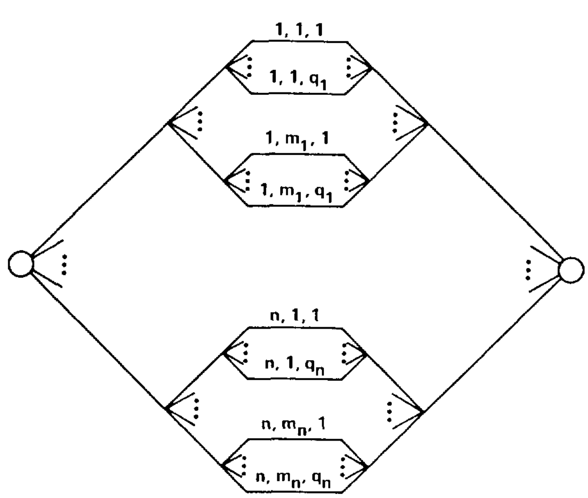

Figure 3. Parallel Network System.

Let $f_{i,t}$ for $i = 1,2,\ldots,n$ and $t = 1,2,\ldots,m_i$ represent detection avoidance functions for the instrumented penetrations of this system. Each $f_{i,t}(x_{i,t,r})$ represents the probability of avoiding detection when $x_{i,t,r}$ units are diverted through the r-th penetration of type i during time increment t. If d units are to be diverted through the system, these d units may be spread among the penetrations and time increments to maximize the probability of avoiding detection. The probability of avoiding detection for the entire system is the product of the probability of avoiding detection over all penetrations and all time increments available within the time horizon T. This suggests the following optimization problem:

$$\text{maximize} \quad \prod_{i=1}^{n}\left[\prod_{t=1}^{m_i}\left[\prod_{r=1}^{q_i} f_{i,t}(x_{i,t,r})\right]\right] \qquad \text{(A)}$$

$$\text{subject to} \quad \sum_{i=1}^{n}\sum_{t=1}^{m_i}\sum_{r=1}^{q_i} x_{i,t,r} = d,$$

$$x_{i,t,r} \geq 0.$$

This mathematical formulation represents a determination of a diversion strategy $x_{i,t,r}$ for $i = 1,2,\ldots,n$, $t = 1,2,\ldots,m_i$, and $r = 1,2,\ldots,q_i$ such that the product of the values of the detection avoidance functions $f_{i,t}$ associated with this diversion strategy is maximized. Thus, the solution to problem (A) provides the optimal diversion strategy and the composite probability of avoiding detection for this strategy. Changing the value of d will change the solution to problem (A). By solving problem (A) for different values of d, a composite detection avoidance function for the entire set of instrumented penetrations can be constructed.

The network representation of an actual facility is expected to include penetrations in series as well as in parallel. For example, consider the network represented by Figure 1. This network describes a section of a reprocessing facility with penetrations between the primary containment zone (P) and the secondary containment zone (S), between S and the outside (O), and also directly between P and O.

This network can be analyzed by decomposing it into four steps involving repeated solution of problem (A):

1. Solve problem (A) for the penetrations from P to S for all practical diversion levels to obtain a composite detection avoidance function.

2. Solve problem (A) for the penetrations from S to O for all practical diversion levels to obtain a composite detection avoidance function.

3. Form a composite detection avoidance function for the series system P to S to O by multiplying the two detection avoidance functions obtained from Steps 1 and 2.

4. Solve problem (A) for a single equivalent network detection avoidance function by using the avoidance function of Step 3 in parallel with the penetrations directly from P to O.

The detection avoidance function which results from Step 4 is the detection avoidance function for the entire facility.

The practicality of this decomposition approach depends on being able to solve the optimization problem (A) for all diversion amounts d in an efficient manner.

EVALUATION METHODOLOGY

The presentation of the solution methodology is notationally less cumbersome if we reformulate problem (A). The formulation of problem (A) requires three indices to uniquely refer to a specific arc. Without loss of generality, we can use only a single index if we let n refer to the total number of actual arcs in the network rather than to the number of arc subsets corresponding to the number of different penetration types. This redefinition yields the equivalent problem

$$\text{maximize} \quad \prod_{i=1}^{n} f_i(x_i) \qquad \text{(A')}$$

$$\text{subject to} \quad \sum_{i=1}^{n} x_i = d,$$

$$x_i \geq 0.$$

In this formulation, $f_i(x)$ represents the probability of avoiding detection when x units are diverted across arc i. Unlike formulation (A), where the index i referred to a penetration type, here the index i refers to a single arc that represents an individual penetration during some single time increment.

Dynamic programming will be used to solve problem (A'). Unlike some other methods for solving problem (A'), dynamic programming does not require derivatives, and it is guaranteed to find a globally optimal strategy. Also, solution of the problem for a particular value of d yields solutions for lower values.

Solution Methodology

The basic observation underlying dynamic programming is the principle of optimality which allows us to break a complex problem into subproblems. The principle of optimality for our problem can be stated as follows: if we are considering an optimal strategy for the network of Figure 3, and know that as part of this strategy some amount of material will be diverted across certain arcs, then the diversion of the remaining amount over the remaining arcs as defined by this strategy will also be optimal for the diversion problem (A') defined by that amount and those remaining arcs. The principle of optimality allows us to view the problem as a sequence of decisions to be made. The diverter must decide how much to divert via arc 1, how much via arc 2, and so on. If we make these decisions moving backward from arc n, we build up a composite probability of avoiding detection. Upon reaching arc 1, we will have the optimal values of the objective function of problem (A').

If we are about to make the decision for arc n (the last decision) with k units left to divert via arc n out of an original d units to be diverted, our decision is easy: we allocate all k units to penetration n. If we let V_i denote the composite detection avoidance function for optimal allocation decisions associated with arcs i,...,n, then for the arc n decision

$$V_n(k) = f_n(k), \qquad k = 0,1,\ldots,u_n.$$

That is, the composite detection avoidance function at arc n is simply the individual detection avoidance function for arc n evaluated at k. All possibilities for the number of units left to divert via arc n are considered by letting k vary between 0 and u_n, where u_i is a value such that $f_i(x)$ is, for all practical purposes, equal to zero for $x > u_i$.

When k units remain at the (n-1)-th step, these units must be split between penetrations n-1 and n. The composite detection avoidance function at arc n-1 is found by taking the product of the composite function at arc n and the individual detection avoidance function for arc n-1 for all possible splits of k. The split which produces the maximum composite function is the one retained for use in consideration of subsequent arcs. Mathematically, this is

$$V_{n-1}(k) = \max_{\substack{0 \leq x \leq u_{n-1} \\ 0 \leq k-x \leq u_n}} \left| f_{n-1}(x) * V_n(k-x) \right|,$$

$$k = 0,1,\ldots,u_{n-1}+u_n.$$

In general,

$$V_i(k) = \max_{\substack{0 \leq x \leq u_i \\ 0 \leq k-x \leq \sum_{j=i+1}^{n} u_j}} \left| f_i(x) * V_{i+1}(k-x) \right|,$$

$$k = 0,1,\ldots,\sum_{j=i}^{n} u_j.$$

The function V_1 then consists of the optimal values for the detection avoidance function for the entire system. By saving the optimal x's at each step for each k, the optimal diversion strategies can be recovered.

It should be noted that the individual detection avoidance functions f_i must be step functions with steps at integer values in order for this procedure to work. However, this is not a severe restriction in practice, because the problem can be rescaled and any particular detection avoidance function can be approximated arbitrarily well by a step function. In fact, for complex instrumentation where the theoretical form of the detection avoidance function is not well understood, a few experimentally-obtained data points may have to suffice for the characterization of instrument performance. The solution method outlined here is suitable for any form of function as long as the step function restriction is met.

One other important consideration in the development of a solution methodology for any problem is the computational effort required. A favorable computational characteristic is that problem (A') can be solved with dynamic programming for all diversion amounts, d, at the same time. Also, it can be shown that the dynamic programming algorithm described above requires no more than

$$\sum_{i=1}^{n-1} \left[u_i+1\right] \left[1+\text{MAX}(u_i, \sum_{j=i+1}^{n} u_j)\right]$$

multiplications. In fact, the number of multiplications increases only quadratically (not exponentially) as n or the u_i's increase.

Log-Concave Avoidance Functions

When some arcs are identical, or at least can be realistically assumed so, an important simplification exists. Arcs can be identical because they represent identical penetrations or, if the performance of the instrumented penetration is not time dependent, because they represent different time increments for the same penetration. As shown in the Appendix, when the logarithm of the detection avoidance function for identical arcs is concave (except perhaps at $x = 0$), and if these arcs are used as part of an optimal diversion strategy, the same amount of material will be diverted over each arc. This enables us to replace a set of, say, q identical arcs with a single composite arc that has the detection avoidance function $f_{\text{composite}}(d) = f(d/q)^q$.

Any reduction in the number of arcs that must be explicitly considered by the dynamic programming methodology will result in a corresponding reduction in computational effort, as noted in the previous section. Since most, if not all, detection avoidance functions are expected to be log-concave, a significant amount of problem simplification and reduction in computational effort should be realizable. The maximum simplification occurs when all penetrations of a single type are identically instrumented and when the (log-concave) detection avoidance functions can be assumed to be identical from one time increment to another. In this case, a single composite arc is representative of all penetrations falling within a single penetration type. The total number of composite arcs in the entire system would be n, the number of penetration types of problem formulation (A).

False Alarm Probability

All sensors may false alarm. To illustrate the calculation of the false alarm probability, consider a radiation monitor, where a false alarm occurs when the counts produced by the background radiation exceed the preset alarm threshold and no diversion is taking place. The false alarm probability associated with an alarm threshold T is the probability of the counts from background radiation alone exceeding T. If we let α represent the mean number of counts per counting interval due to background radiation, then the probability of a false alarm in the counting interval can be approximated by:

$$P(\alpha,T) = \frac{1}{\sqrt{2\pi}} \int_{\frac{T-\alpha}{\sqrt{\alpha}}}^{\infty} e^{-n^2/2}\, dn.$$

By referring back to Figure 2, the false alarm probability can be visualized graphically by recognizing that it is represented by the distance between the detection avoidance curve as it approaches the vertical axis and the discrete point at (0,1). It can also be observed that the maximum detection avoidance probability for a diverter is reduced from 1.0 by this same amount, representing the false alarm probability, as soon as he begins to divert even the smallest amount feasible. That is, a diversion of an extremely small amount may be "detected" because of what is essentially a false alarm.

Before we can formalize system false alarm probability into a mathematical expression, we must recognize that any reference, as before, to the probability of a false alarm in one counting interval will not be meaningful when different intervals are represented by the system of instruments. We can overcome this discrepancy by considering some time horizon such that every instrument has one or more discrete opportunities to alarm within the time period represented (i.e., for every instrument the time period encompasses one or more complete counting intervals). Following the notation of problem (A), we let m_i represent the integral number of time increments represented for instrument type i. If $\overline{P}_{i,t,r}$ represents the probability of no alarm, given no diversion, for instrument r of type i in time increment t, then the false alarm probability for this instrument within the time horizon is

$$1.- \prod_{t=1}^{m_i} \bar{P}_{i,t,r}.$$

(Although the arguments are dropped, this probability is dependent, as before, on α and T for each instrumented penetration.) Within this same time horizon, the false alarm probability for the entire system is

$$1.- \prod_{i=1}^{n} \left[\prod_{r=1}^{q_i} \left[\prod_{t=1}^{m_i} \bar{P}_{i,t,r} \right] \right].$$

The expected number of system false alarms within the time horizon can be calculated as

$$\sum_{i=1}^{n} \sum_{r=1}^{q_i} \sum_{t=1}^{m_i} \left[1.- \bar{P}_{i,t,r} \right].$$

This value can be used to state a false alarm rate.

Instrument Reliability

The possibility of instrument failure introduces a complicating factor into the analysis. An unreliable instrument will increase the probability of avoiding detection for all values of alarm threshold, background radiation and diversion amounts. The amount of increase in the detection avoidance probability depends on two factors: the failure rate of the instrument and the time elapsed since it was last determined to be functioning.

As in the previous section, let time be indexed for a particular instrument in terms of the number of elapsed counting intervals. The failure rate of an instrument is expressed as the probability of failure in one counting interval conditional on its operating properly in the previous interval. If we let λ represent this probability, then the probability that the instrument is functioning after t time intervals (given that it is functioning initially) is easily shown to be $(1.-\lambda)^t$. It is assumed that the failure rate is constant over the normal operating life of the instrument. The probability of detecting a diversion that takes place in counting interval t is simply the probability of detecting the diversion, given that the instrument is operating (as represented by the detection avoidance function), times the probability that the instrument is operating. This can be expressed as

$$\left| 1.-f(x) \right| \left| (1.-\lambda)^t \right|,$$

where f(x) is the detection avoidance function given that the instrument is operating properly.

To take advantage of possible instrument failure, the diverter will favor counting intervals that take place just before scheduled instrument maintenance. It is assumed that after instrument maintenance the instrument is operating properly. The determination of an optimal diversion strategy is complicated by the fact that instrument performance is not stationary but changes with time. This introduces a significant computational burden in that arcs representing different instrument counting intervals are not identical. For very low instrument failure rates, it should be possible to achieve a sufficiently accurate analysis by breaking the total time horizon into only a few time periods of relatively long length. Each time period will include many counting intervals and instrument performance is approximated as being constant within each period.

SUMMARY AND DISCUSSION

The ability of a C/S system to detect a diversion of nuclear material is influenced by the performance of the individual instrumented penetrations and the strategy used in carrying out the diversion. Instrument performance and the configuration of the instrumented penetraions are the primary inputs to system evaluation. The diversion strategy of greatest interest in evaluation is that strategy which maximizes the probability that the diversion is not detected. System evaluation is based on this optimal diversion strategy, which changes as the amount diverted or the time available for diversion is varied.

The system evaluation problem is formulated as a *discrete mathematical optimization* problem. The special mathematical structure of the resulting optimization problem has made it possible to devise efficient dynamic programming techniques to solve the problem and guarantee that the solution is indeed a global optimum. The analytical procedures outlined have been computerized and applied in the analysis of safeguards for reprocessing plants (6,7). Evaluation results take the form of a multi-dimensional detection avoidance function. This expresses the probability of avoiding detection as a function of diversion amount and the time over which diversion occurs. Included in this function is the influence of particular background radiation levels and instrument alarm thresholds.

The model of system performance as formulated depends on the assumption of independence between measurements from different instruments and between measurements from different time intervals. That is, the instrument measurement and the decision whether to alarm depends only on the level of radiation present (or whatever is being measured) at the time and not on the outcome of any other measurements. Of course, this assumption is not valid if the basis for alarming depended on a series of measurements from either a single or several instruments.

It was shown that, without requiring any change in problem formulation and solution method, it is possible to include explicit consideration of instrument reliability. The penalty associated wth incorporating reliability into the evaluation is an increase in computational effort. Since time is considered as a series of discrete intervals, incorporating a large number of very small intervals for the purposes of reliability analysis can result in a substantial increase in computational effort. An effective reliability analysis can, hopefully, be based on a division of the desired time horizon into only a small number of intervals. Implicit in the reliability analysis was the assumption that an instrument will give no indication that is has failed for otherwise the diverter would simply wait for this signal. We also assumed that instrument failure would be uncovered and repaired during scheduled maintenance.

The Appendix shows how the magnitude of the evaluation problem is greatly simplified when uniform diversion strategies are optimal. The shape of each instrumented penetration's detection avoidance function is tested to determine whether diversion across it will be uniform over time in any optimal diversion strategy. If it can be shown that a penetration will indeed be used uniformly over time, then all that remains to be determined is whether the penetration will be used and, if so, for what amount. Further simplifications of a similar nature exist among identical penetrations that are identically instrumented. In practice, it is expected that these simplifications will hold in many cases of instrumentation.

It should be recognized that the results presented in the Appendix, lacking further generalization, apply only in the case where the composite probability of avoiding detection for a group of penetrations (the objective function which is to be maximized) can be expressed as a product of individual detection avoidance functions. Direct extension of the results to groups of non-identically instrumented penetrations is also not warranted. A necessary condition for optimality is that the first derivatives of the logarithm of the detection avoidance functions are equal when evaluated at the corresponding non-zero diversion levels. For non-identical penetrations, the detection avoidance functions may be such that this condition is satisfied only when the diversion levels are unequal.

There may be system configurations which are too complex to permit the analytical decomposition process described in the "Mathematical Representation" section above. In such cases, the evaluation procedure of this paper cannot identify optimal diversion strategies and will, therefore, be unable to provide a complete analysis. However, it will be able to analyze certain subsystems completely and thereby provide input to safeguard system evaluation.

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APPENDIX:

OPTIMAL k-UNIFORM DIVERSION STRATEGIES

Consider the case of n identical arcs with fixed d and detection avoidance function f. The optimization problem facing the diverter, labeled S_f^n, is

$$\text{maximize} \prod_{i=1}^{n} f(x_i) \qquad (S_f^n)$$

$$\text{subject to} \sum_{i=1}^{n} x_i = d,$$

$$x_i \geq 0, \qquad i = 1,2,\ldots,n.$$

By definition, let a strategy for diverting a total of d units over n identical arcs be called k-uniform if the diversion over each of k of the arcs is d/k units and the diversions over all other arcs are zero. Assume that the logarithm of f is a concave function on $(0,\infty)$. We now show that there is a k such that a k-uniform strategy is optimal for diverting d units in problem S_f^n.

Let $x^* = (x_1^*, x_2^*, \ldots, x_n^*)$ be an optimal strategy. Without loss of generality, suppose $x_i^* > 0$ if and only if $i \le k$, for some k, $1 \le k \le n$. Define a function g by

$$g(x) = f(x), \quad x > 0$$

$$g(0) = \lim_{y \to 0} f(y) \quad \text{(assume this limit exists)}$$

Then, g is log-concave on $[0,\infty)$, and $\hat{x}^* \equiv (x_1^*, x_2^*, \ldots, x_k^*)$ solves the problem (S_g^k). Since

$$\log \prod_{i=1}^{k} g(x_i) = \sum_{i=1}^{k} \log g(x_i),$$

$\hat{x}^*$ also solves the problem

$$\text{maximize} \quad \sum_{i=1}^{k} \log g(x_i)$$

$$\text{subject to} \quad \sum_{i=1}^{k} x_i = d,$$

$$x_i \ge 0, \quad i = 1,2,\ldots,k.$$

We now show that the k-uniform strategy solves this problem. Define

$$h(\hat{x}) = \sum_{i=1}^{k} \log g(x_i).$$

Without loss of generality, assume that $x_1^* \le x_2^* \le \ldots \le x_k^*$, and select α such that

$$\alpha x_1^* + (1-\alpha)x_k^* = d/k, \quad 0 \le \alpha \le 1.$$

The concavity of h (inherited from the concavity of log g) implies that

$$\alpha h(x_1^*, x_2^*, \ldots, x_{k-1}^*, x_k^*) + (1-\alpha)h(x_k^*, x_2^*, \ldots, x_{k-1}^*, x_1^*)$$
$$\le h(\alpha x_1^* + (1-\alpha)x_k^*, x_2^*, \ldots, x_{k-1}^*, \alpha x_k^* + (1-\alpha)x_1^*).$$

By noting that

$$h(x_1^*, x_2^*, \ldots, x_{k-1}^*, x_k^*) = h(x_k^*, x_2^*, \ldots, x_{k-1}^*, x_1^*),$$

it follows that

$$h(\hat{x}^*) = \alpha h(\hat{x}^*) + (1-\alpha)h(\hat{x}^*)$$
$$\le h(d/k, x_2^*, \ldots, x_{k-1}^*, \alpha x_k^* + (1-\alpha)x_1^*).$$

The optimality of $\hat{x}^*$ and the feasibility of the point $(d/k, x_2^*, \ldots, x_{k-1}^*, \alpha x_k^* + (1-\alpha)x_1^*)$ imply that equality holds above. Repeating this process leaving x_1 at d/k, then leaving x_1 and x_2 fixed at d/k, etc., shows that $h(\hat{x}^*) = h(d/k, d/k, \ldots, d/k)$, so that the k-uniform strategy is optimal.

When h is strictly concave and $(x_1^*, x_2^*, \ldots, x_{k-1}^*, x_k^*)$ is not the same point as $(x_k^*, x_2^*, \ldots, x_{k-1}^*, x_1^*)$, i.e., $x_1^* \ne x_k^*$, the inequality $\le$ in the above expression is replaced by the strict inequality $<$ which results in a contradiction to the original supposition that $\hat{x}^*$ is optimal. The k-uniform strategy $x_i = d/k$, $i = 1,2,\ldots,k$, is thus the unique solution when log g is strictly concave.

From the definition of $g(x_i)$,

$$\sum_{i=1}^{k} \log g(x_i) = \sum_{i=1}^{k} \log f(x_i)$$

when all $x_i > 0$, and

$$\sum_{i=1}^{k} \log f(x_i) = \log \prod_{i=1}^{k} f(x_i);$$

therefore, $x_i = d/k$ is optimal for S_f^k, and

$$x_i = d/k, \quad i = 1,2,\ldots,k,$$

$$x_i = 0, \quad i = k+1,k+2,\ldots,n$$

is optimal for S_f^n.

This result points to a convenient and efficient way to determine k and to form the detection avoidance function for the n-arc system. Denote this composite detection avoidance function by f_n. Since we want that k for which

$$\left[\prod_{i=1}^{k} f(d/k)\right]\left[\prod_{i=k+1}^{n} f(0)\right]$$

is a maximum, it follows that

$$f_n(d) = \max_{k=1,\ldots,n} \left[f(d/k)^k\right].$$

The product over $i = k+1,k+2,\ldots,n$ does not appear since $f(0) = 1$.

AN IN SITU VERIFIABLE SECURITY SEAL SYSTEM FOR INTERNATIONAL SAFEGUARDS

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Summary

The seal system consists of a supply of fiber optic loop material, a number of seal bodies, and a special purpose camera. The seal uses a jacketed, multi-strand plastic fiber optic cable which is cut to length in the field. The two piece, hinged seal body contains a serrated blade which randomly severs a portion of the fibers when the seal is closed. A unique signature, produced by the uncut fibers, is viewed and photographed by the camera system at the loop termination. The camera is designed to operate automatically when the seal is inserted into the viewer receptacle. In situ verification is accomplished by comparing the photograph obtained at inspection with the photograph obtained when the seal was installed. The seal is easily assembled and the signature is destroyed if the seal is opened. Recording and verifying the seal are manageable in awkward conditions by the transfer of the seal image to the camera system via a one meter, flexible fiber optic image guide. The seal recorder/ verifier is field portable, weighs approximately 8 Kg, is self-powered, and has provisions for installing and/or verifying 20 seals. Additional seals, film and loop material are provided in the shipping case to install and/or verify an additional 80 seals.

Discussion

Seals, by basic definition, are devices which are used to verify the integrity of physical containment by ensuring that detectable evidence will result from unauthorized entry through sealed openings. Seal systems consist of the seals and those procedures, techniques and devices necessary to control the procurement, storage and fingerprinting of the seals; the application, removal and identification of the seal; and the inspection of the seal to judge whether entry or tampering has occurred.

Sophisticated modern seals emphasize the unique identification characteristics (fingerprints) of the seal. The ability to verify this uniqueness in the field (in situ) provides a timely assurance of integrity.

Two types of seals are presently used for general application in international safeguards; the metal cup/wire and the label or paper seal. Label seals can provide effective short-term verification of containment, but are inadequate in long-term applications. The cup/wire ("TYPE E") seal is used for all applications that require a wire loop-type seal. The time consuming verification procedure is a serious limitation. Each fingerprinted seal bears identification marks on the inside of the seal. These marks are recorded before the seal is issued. The seals are authenticated when they are returned to Agency Headquarters or field offices from the field by inspectors. In situ verification of the E seal is therefore impractical since in situ inspection can only provide visual evidence of tamper and authenticity of the serial number. The seal must be removed and opened in order to verify that the uniqueness has remained.

Research and development have been underway for about twelve years, both in the U.S. and overseas, to investigate and demonstrate concepts for passive seals that can be verified in situ. Both fiber optic and ultrasonic seals have been considered. Fiber Lock Corp., Harry Diamond Laboratory, Atlantic Research Corp. and ENSCO, Inc. developed seals utilizing fiber optics for the loop material in lieu of wire. A loop of jacketed, multi-strand light guide cable is passed through or around the item to be sealed and the ends of the loop are then captured in a clamping device. These seals require stripping of the cable jacket at the loop ends and the subsequent random mixing and distributing of the fibers to viewing and illuminating ports within the seal clamp. In two of these systems, light passing through the illuminating port produces a unique pattern of illuminated fiber ends at a single viewing port. In the other two systems, each of several viewing ports contain random numbers of fibers which produce a different level of light intensity when light is introduced into the illuminating port(s). Seal recording is accomplished in the one case by photographing the unique pattern, or in the second case by recording the port light levels. Verification is achieved by re-photographing or re-recording the light outputs and comparing these results with data obtained when the seal was installed. Several of these systems were submitted to the International Atomic Energy Agency (IAEA) for evaluation, but were rejected because of anticipated difficulties in using them in the field. The EURATOM Joint Research Center, Ispra, has used ultrasound technology to demonstrate general purpose seals in conjunction with prototype verification equipment. A parallel effort by Sandia National Laboratories (Sandia) investigated a low cost general purpose ultrasonic seal. These seals, similar to cup wire seals, contain random inclusions of mixed density materials within the cup, which when ultrasonically scanned, provide a unique reflection pattern or fingerprint.

In FY 1980, the U.S. Security Seal Program was established by DOE/OSS to develop and establish, for use by the IAEA, a production capability for an in situ verifiable, general purpose seal as a potential replacement for the Type E seal. Furthermore, the system operational characteristics were required to be compatible with current IAEA capabilities and resources. An additional objective was to provide a capability for in situ verification of seals in DOE applications to improve the U.S. seal system and demonstrate feasibility to the international community.

A comprehensive seal development program was initiated by Sandia which included a review of past seal research and development. A committee of experts considered these technologies and selected fiber optics and ultrasonics for further development.

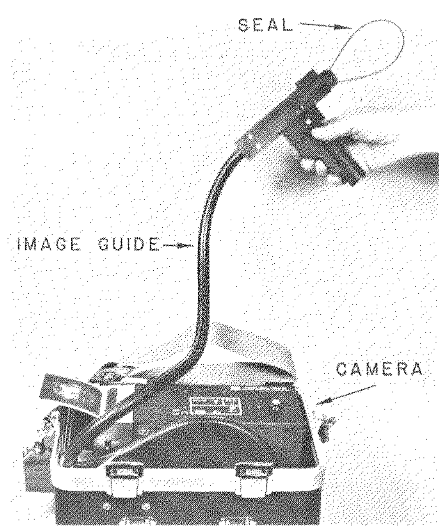
Studies concluded that although the technology was available to develop an ultrasonic seal with in situ verifiable capability, the risk factor involved in near-term production of a prototype system was higher than for a similar fiber optic approach. The development of a prototype fiber optic seal was begun.

Direct visual, electronic, and photographic verification was considered for the fiber optic seal. No practical method was found for direct visual verification. In addition, it was concluded that human factors would degrade the reliability of verification. The technology for a practical photographic verifier was available while the electronic technology would require long-term development. Thus, the development of a photographic verifier was begun. In a longer term parallel effort, a feasibility study was initiated to determine the practicability of verifying the fiber optic seal electronically.

General specifications for the fiber optic seal and photoverifier were established in cooperation with the IAEA. Requests for quotations to produce one prototype verifier and 20 seals, on a six-month contract, were sent to selected suppliers. The proposal from Atlantic Research Corporation, Alexandria, Virginia, presented a conceptual design which met the intent of the specification and which suggested a fresh approach to optical verification. Endorsement of the proposal was received from the IAEA, and in July 1980 a contract was placed with Atlantic Research Corp.

The prototype system developed under the contract was completed in December 1980. The IAEA and EURATOM Safeguards Directorates were favorably impressed during demonstrations at Vienna and Luxembourg in February 1981. The IAEA endorsed the continuation of the program and approval to proceed with fabrication of field evaluation systems was obtained from the DOE/OSS. Three verifiers and 200 seals are to be fabricated and delivered to the IAEA in early 1982.

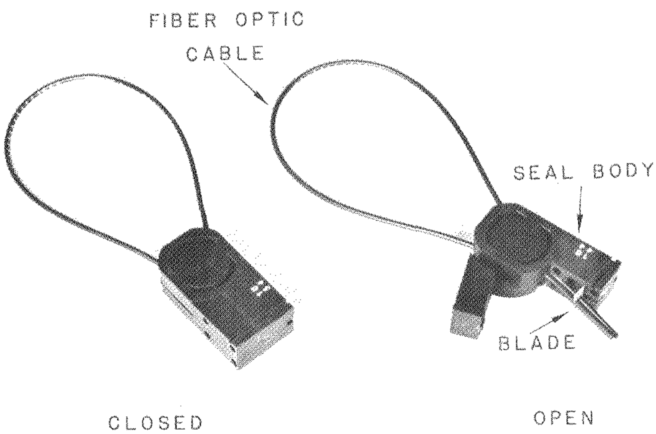
The system was designed to be a field portable unit providing a secure seal that is capable of in situ verification of the integrity and identity of the seal. It consists of seal bodies, fiber optic cable, a seal fingerprint recorder/verifier, and a shipping case. The photographic recorder/verifier (Figure 1) is housed in a portable ABS plastic satchel which carries 20 seal bodies, 15 meters of fiber optic cable, two ten-exposure packs of POLAROID film and seal installation tools. It weighs approximately 8 Kg and is 31.9 x 22.9 x 19.7 cm in dimension. A handle and shoulder strap are provided for carrying. A fiberglass transit case provides space for the satchel, an additional 80 seal bodies, 60 meters of fiber optic cable, eight packs of film and a spare lamp.



Fiber Optic Seal Recorder/Verifier
Figure 1

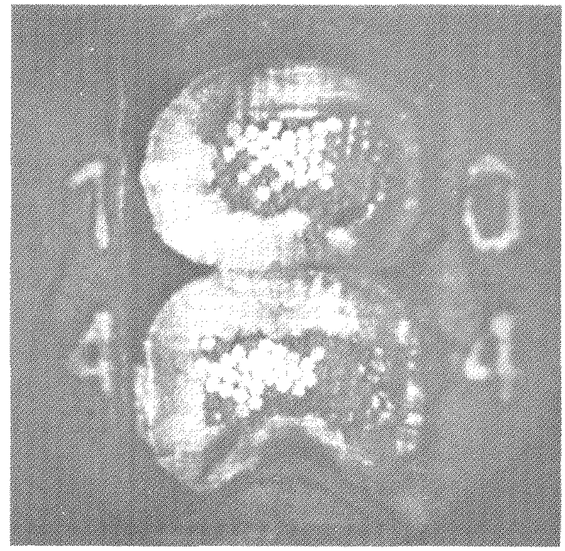
The seal (Figure 2) consists of a loop of multiconductor plastic sheathed, fiber optic light guide terminated in a two piece molded plastic seal body. The fiber optic cable is a commercial DuPont CROFON light guide having the following characteristics:

DuPont Part No.:	1605
Jacket:	Material, black polyethylene Outside dia., 2.21 mm Nominal wall thickness, 0.5 mm
Fibers:	Material, polymethyl methacrylate core, fluorocarbon cladding diameter, 0.127 mm No. of fibers, 64
Attenuation:	3 db/meter (white light)



Fiber Optic Seal
Figure 2

The seal body is injection molded of DUPONT ST801 NYLON resin having excellent dimensional stability and high resistance to organic solvents. The hinge design is such that with the cable in place, the two halves are locked together. A stainless steel serrated blade provides a dual function; the internal teeth sever the cable sheath and a portion of the fibers and the external teeth lock the two halves of the seal together when the seal is closed. The rake of the external teeth prevents the seal from being easily opened. The rake of the internal teeth will destroy the fingerprint if the seal is pried open. Laser engraved serial numbers are applied to the fingerprint viewing window, and to the seal body. The seal body is keyed so that it can be inserted into the verifier receptacle in only one direction. Installation of the seal is accomplished by threading several meters or less of fiber optic cable through the hasp, inserting the ends of the loop into the seal body, and snugging the loop up to the desired tightness. Stripping of the cable jacket is eliminated. The seal is closed finger-tight and locked into place with the closing tool. The surplus ends of the loop are severed with the cut-off tool. The fingerprint, generated by the unsevered fibers (Figure 3), is then ready for recording by the recorder/verifier. Unlike the earlier versions, both ends of the fiber are illuminated.



Typical Seal Signature
Figure 3

The photographic recorder/verifier is basically a custom designed camera which has been provided with convenience features for in situ operation. The seal fingerprint is magnified approximately twelve times. It is photographed through an optic train composed of an objective lens, an iris, 1.2 meters of flexible fiber optic image guide, a beam splitter, a lens, a shutter, and a POLAROID SX-70 camera film back. Other than loading and unloading the film pack and operating the on/off switch, the system is completely automatic. A 12 volt dc battery, rechargeable from a 110/220, 50/60 Hz source, supplies power for the shutter and the light source. LEDs provide the operator with the condition status of the film pack and the system.

The sequence of operation is as follows:

a) The seal is inserted into the verifier receptacle at the end of the image guide and pushed against a switch.

b) The control circuit, sensing the switch action, turns on the lamp, opens the shutter, regulates the exposure time, closes the shutter, extinguishes the lamp and triggers the film ejection mechanism. In this sequence, light from a quartz-halide lamp in the receptacle illuminates the seal window through a beam splitter. The seal image is then transferred to the camera via the image guide. The POLAROID SX-70 film records the seal pattern and the seal serial number. When the seal is to be verified, it is rephotographed and the new photograph is compared with the one taken when the seal was installed. The recorder/verifier is a high cost item; whereas the seal is less costly than the Type E seal when consideration is given to the cost of applying the seal signature to the Type E seal and its recording and verification.

Conclusion

A production capability has been developed and established for an in situ verifiable general purpose seal as a potential replacement for the Type E seal. A prototype seal and recorder/verifier were demonstrated to the international safeguards community (IAEA and EURATOM). The fabrication of preproduction seals and recorders/verifiers is underway. The preproduction (IAEA Class III) material will be furnished to the IAEA in early 1982 for field evaluation.

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