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JNMM

JOURNAL OF
THE INSTITUTE OF
NUCLEAR MATERIALS MANAGEMENT

FORUM: Second Annual Safeguards Roundtable

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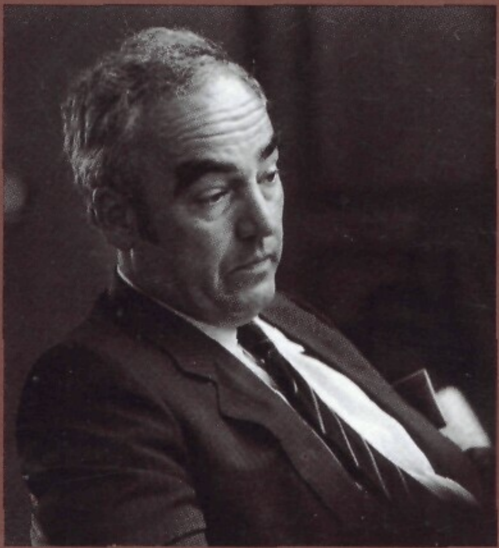

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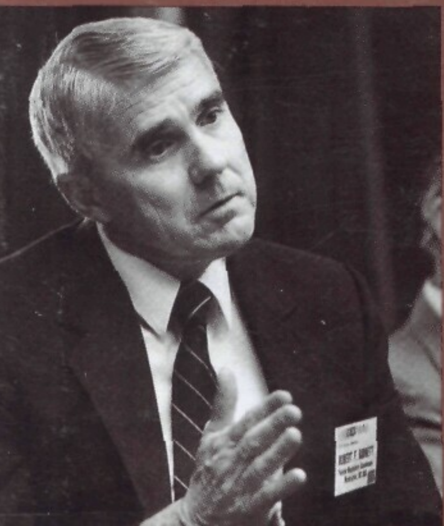
October 1987



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On the Cover:
The Second Annual INMM Safeguards Roundtable was held July 13, in conjunction with the INMM Annual Meeting in Newport Beach, Calif. Pictured are discussion participants (from bottom left) Robert F. Burnett, U.S. Nuclear Regulatory Commission; Dr. Charles E. Till, Argonne National Laboratory; Wilhelm Gmelin, Euratom; Glenn Hammond, U.S. Department of Energy; and Dr. Reinhard Kroebel, ESARDA. *Photographs/Tony Bullard.*

Design and Production
Innovative Design & Graphics
Evanston, Illinois 60202 U.S.A.

Printing
St. Croix Press
New Richmond, Wisconsin 54017 U.S.A.

JNMM is published four times a year by the Institute of Nuclear Materials Management, Inc., a not-for-profit membership organization with the purpose of advancing and promoting efficient management and safeguards of nuclear materials.

SUBSCRIPTION RATES: Annual (U.S., Canada and Mexico) $75.00; annual (other countries) $100.00; (shipped via air mail printed matter); single copy regular issues (U.S. and other countries) $20.00; single copy of the proceedings of the annual meeting (U.S. and other countries) $50.00. Mail subscription requests to JNMM, 60 Revere Drive, Suite 500, Northbrook, Illinois 60062 U.S.A. Make checks payable to INMM.

ADVERTISING, distribution and delivery inquiries should be directed to *JNMM*, 60 Revere Drive, Suite 500, Northbrook, Illinois 60062 U.S.A. or contact Greg Schultz at (312) 480-9573, telex 910-221-5870, telecopy (312) 480-9282. Allow eight weeks for a change of address to be implemented.

ISSN 0893-6188

INMM

Adding Meaning to Maturity

Judging from the figures, this year's annual meeting was a great success. With more than 500 participants and 173 papers, it was the largest in our history. The arrangements were first class: a fine hotel overlooking a harbor and the Pacific Ocean, convenient and efficient meeting rooms and exhibit area, generous coffee breaks, and enjoyable social functions. The technical sessions were well attended, discussions frequently lively, and much of the valuable technical exchanges took place in the halls, at meals, or enjoying the outdoors in small groups. All of this was made possible by a great deal of voluntary effort by the many committee members, and by John Messervey and Beth Perry, our managers.

A subtitle for this meeting was a question: Safeguards — A Mature Technology? It would be helpful to your officers and committees to receive comments from the members of the Institute on their impression of the status of safeguards, on the value of this annual meeting to them, and on how these meetings might be made even more constructive.

To start this process I shall mention some of my reactions and supply a little background information.

Although the meetings have continued to increase in size, the membership has remained at about 700 since 1980, with about 450 living in the U.S., 100 in Japan, and 150 in Canada or Europe. As usual, about half of those attending the meeting were non-members. About 10% of the attendees were from abroad. There were multiple sessions on every subject of interest to the Institute, which contributed to the large attendance. I always find it frustrating when I want to attend two or three sessions which are going on simultaneously. The poster papers are some help in this respect except that they tie down those authors for long periods. The preprinted abstracts are very useful.

This year, the office has managed to put together and to mail the proceedings in record time, so that what one missed or only sketchily absorbed became available while it was still current! With 173 papers this was no simple task. Also, it constitutes a huge volume. Only by using somewhat thinner paper was it possible to keep it at one volume. My suggestion is that we should level off.

The Institute has just announced when and where next year's meeting will take place. There are two possible policies for an organization which requires rather large facilities: One is to plan way ahead and to pay premium prices for the rooms, if not the meeting facilities. The other is to wait until as late as is possible and then get bargain rates for our members at a suitable hotel which has an opening. The latter approach has been quite successful recently. The question is whether the savings for our members compensates for the delay in announcing and preparing for the meeting.

As for maturity, my conclusion is that safeguards, either in the national or international sense, are rather more than a technology. People are the potential adversaries, people are the defenders, and the public is protected. To a considerable extent the technologies employed for materials accounting, containment, and physical protection are relatively mature. Still in the process of evolving are widely accepted agreements as to what should be expected of IAEA safeguards or the safeguards and physical protection to be provided by the United States or other countries with significant nuclear programs. How can the officers of the IAEA or of the U.S. Department of Energy, for example, understand how effective their systems really are and how to explain this to the Board of Governors or the U.S. Congress?

There have been a number of papers on assessment methodologies that were presented in the past, and more papers were presented this year on such matters. Who may be the adversary and what his methods are cannot be predicted with any certainty. The public wants assurance. The resources will always be limited. Given clearly defined objectives it should be possible to design and defend a reasonably effective and efficient system. That, however, may never by possible.

The technologies, it seems to me are maturing. What we all have to keep working on together are the objectives and the means to achieve, evaluate, and explain them.

Dr. William A. Higinbotham
Brookhaven National Laboratory
Upton, New York

To contribute to *JNMM*

Technical manuscripts, news and editorials should be addressed to William A. Higinbotham, *JNMM*, 60 Revere Drive, Suite 500, Northbrook, Ill. 60062 U.S.A. All technical manuscripts will be reviewed before publication.

JNMM welcomes your letters and comments. Please send all correspondence to *JNMM*, 60 Revere Drive, Suite 500, Northbrook, Ill. 60062 U.S.A.

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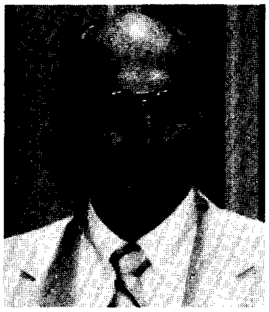
INMM CHAIRMAN'S MESSAGE

Meeting Challenges

Greetings to the members and supporters of INMM. It was good to see so many of you at the annual meeting in Newport Beach, California. The program was outstanding, the facility charming and accommodating, and best of all, we had the opportunity to chat and talk over many issues.

At this point, fiscal 1987 is coming to an end, and planning and preparation for fiscal 1988 is underway. It has been an excellent year. Principally, our accomplishments have been in the areas of the Journal, training and certification, long range planning, and the annual meeting.



The next twelve months pose a unique set of challenges. We will try to implement the plans we made in 1987. Again, our major challenges are the Journal, training, membership and the annual meeting. By the time you read this, the committees will be organized and working on 1988. I encourage any of you who feel you can contribute to any of the Institute's activities to step forward and volunteer. Support your Institute as much as possible.

This is also the proper time of year to plan a technical paper for presentation at the 1988 annual meeting. The meeting will be at Bally's, Las Vegas, Nevada U.S.A. July 26-29, 1988. You can be sure it will be a pleasing setting and an excellent program. Plan now to attend and share with the membership.

Charles M. Vaughan
General Electric Company
Wilmington, North Carolina

JNMM COMMENT

Waste Management Update

In the October 1986 edition of the *Journal of the Institute of Nuclear Materials Management*, Dr. Alvin Weinberg proposed that the state that accepts a monitored retrievable storage (MRS) facility or a geologic repository for disposal of high level radioactive wastes or spent fuel be compensated by a payment of $100-million per year. In late July of this year this proposal took one giant step toward reality in a bill introduced to the Senate (S. 1481) by Senators Johnston, D-La., and McClure, R-Idaho, in which the authors proposed the following payments for affected states, local governments and Indian Tribes:

	MRS	*Repository*
Annual Payment Prior to Receipt of Spent Fuel	$20 million	$ 50 million
Upon Receipt of First Spent Fuel	$50 million	$100 million
Annual Payments Thereafter Until Closure	$50 million	$100 million

Only one set of payments would be made to all parties for a single facility. This means that if it took five years to build a facility after selection of the site, and the facility operated for 25 years, the total payments for a MRS facility would amount to $1.4 billion, and for a repository would amount to $2.85 billion. While this represents a significant cost, it may well prove to be less expensive than the characterization and engineering development of multiple repository sites involving capacity that is not needed at this time, and would appear to offer the prospect of earlier deployment of MRS and repository facilities than might otherwise be possible.

Under any agreement developed by which a jurisdiction(s) could receive the foregoing payments, the jurisdiction(s) involved would be able to participate in the design of facilities and in the development of documents relative to public safety, but would wave its rights to disapprove a recommendation of its site for application for a construction authorization.

The proposed bill also provides for the sequential characterization of repository sites (rather than concurrently characterizing three sites), and the construction of a MRS facility, and prohibits site characterization for a second repository except by the subsequent direction of Congress. This proposed bill was referred to the Committee on Energy and Natural Resources, and was favorably reported out by a 17 — 2 vote. However, there were a number of amendments tacked on to the bill, including requirements that (1) the National Academy of Sciences study the feasibility of spent fuel reprocessing; (2) NRC certify all DOE casks used for spent fuel transport; (3) DOE abide by NRC regulations regarding notification of localities through which high level waste (HLW) or spent fuel was transported; (4) DOE provide technical assistance and training to states through which such materials are transported; (5) NRC fully test packages designed to store or transport such materials; (6) DOE issue a report on the different types of casks and packages used in the U.S. and other countries to transport and store such wastes; (7) a state have oversight rights for a repository located within the state; (8) the DOE Secretary issue a statement declaring that the first repository site poses no threat to national security interests; (9) DOE issue a report on sub-seabed disposal; (10) DOE adopt considerations in any incentive package with the affected state in the 14 areas identified in a recent Nevada resolution regarding mitigation of impacts; (11) public health and safety and cost considerations be incorporated in the choice of a site for detailed characterization; (12) DOE study the need and feasibility of more than one MRS facility; (13) DOE study the desirability of storing waste for 50 years prior to disposal; (14) DOE to consider three sites in no less than two states for a MRS facility; (15) The DOE Secretary give special consideration to siting Federal Research Projects in a state where a repository is located; (16) judicial review for decisions related to the choice of repository sites for characterization to be made by a Temporary Emergency Court of Appeals; (17) adjacent states be granted the right of state veto; (18) DOE issue an environmental evaluation of the factors used in choosing the first repository site for characterization; (19) DOE study dry cask storage technology and issue a report to Congress; (20) DOE consider the presence of site water in site characterization; and (21) other "housekeeping type amendments."

Earlier in July in the House, Congressman Udall, D-Ariz., introduced H.R. 2967 which, among other things, required an 18-month moratorium on DOE spending for site-specific activities related to a waste repository site until after a Nuclear Waste Policy Commission (three persons) reviews the policies underlying the nuclear waste program and recommends (to Congress) changes in the implementation of such policies and the Nuclear Waste Policy Act of 1982 (NWPA) as well as the future role of DOE in implementing the NWPA. The bill also provides for the appointment of a special negotiator who would have the responsibility of finding a state willing to host a repository on reasonable terms, provided there is a satisfactory site within the state.

Just before Congressman Udall announced his bill, Sens. Sasser, D-Tenn., Adams, D-Wash., Mitchell, D-Maine, and Reid, D-W. Va., announced they would offer a floor amendment to the Price Anderson Renewal Act (S. 748) providing, among other things, for stoppage of site-specific work on the first repository, and establishment of a 13-member Nuclear Waste Review Commission to review implementation of NWPA and make appropriate recommendations to Congress. By offering the amendment on the floor, the sponsors of the bill hoped to avoid it being killed in committee by Sens. Johnston and McClure, who oppose the amendment.

Sources in Washington feel that Congressman Udall's bill will remain dominant in any conference committee resolution of differences between it and the amendment proposed by Sen. Sasser *et al.* However, there also appears to be strong support for the Johnston/McClure bill. Moreover, there appears to be some flexibility on the part of Congressman Udall and Sens. Johnston and McClure in their efforts to get implementation of the waste management program on track.

Clearly politics and institutional issues — more than technical issues — have had an adverse impact on the ability of DOE to make the desired progress on deployment of a waste management system since NWPA was enacted. We should all hope that Congress can soon develop a workable system that will permit DOE to get on with its job of implementing a safe and environmentally acceptable waste management system at reasonable cost to the consumers of nuclear-generated electricity.

E.R. Johnson, Chairman
INMM Technical Working Group on Waste Management
E.R. Johnson Associates
Oakton, Virginia, U.S.A.

Pacific Northwest

The summer meeting of the Pacific Northwest Chapter of INMM was held Aug. 12, 1987. The evening was devoted to "rest and relaxation" for a change — the usual technical program was omitted. INMM members and their families had a chance to unwind and enjoy an evening picnic and barbecue. This event turned out to be the most highly attended meeting of the year.

The fall meeting will be held Oct. 28, 1987. Ken Byers of Battelle, Pacific Northwest Laboratories will present a paper entitled, "The MBA Custodian — Has This Safeguards Program Element Been Neglected?" The paper was presented at the INMM annual meeting this summer, and it raises several important issues surrounding selection and training of MBA custodians.

The Annual Hanford Safeguards Symposium, previously scheduled for early October, has been moved to February. Activities at the Hanford site this past year have been directed at two major events: (1) an I & E; and (2) a consolidation of operating contractors into a single company. These events have demanded much extra time and energy from the safeguards community. It was felt the February time frame would allow more time for preparation and receive better participation.

Debbie A. Dickman
Secretary-Treasurer
INMM Pacific Northwest Chapter
Battelle Pacific Northwest Laboratories
Richland, Washington

N14 Standards Committee

N14 meetings have been scheduled through 1989. A schedule will appear in the next issue.

N14 Management Committee meetings were held at Newport Beach, Calif. on July 15 and DOE-Germantown on Sept. 15.

The annual N14 meeting will be held at the Holiday Inn, Gaithersburg, on Oct. 23, 1987 following the DOE Packaging and Transportation Workshop.

Standards Highlights:
N14.1 — 1987
Packaging of Uranium Hexafloride for Transport: Draft has been sent to ANSI for approval and publication.

N14.6 — 1986
Special Lifting Devices for Shipping Containers Weighing 10,000 pounds or more for Nuclear Materials: Has been republished with some editorial changes.

N14.30
A New standard, *Truck Transport of Weight-Concentrated Radioactive Loads* has started.

John W. Arendt, Chairman
INMM/ANSI N14 Committee
Consultant
Oak Ridge, Tennessee

N15 Standards Committee

N15 Working Group activities have met varying degrees of success. On the positive side: a couple of standards were revised and approved; revision of two standards is nearing completion; and development of proposed projects is progressing well. Negatives include: inability to replace the Chairman of INMM-9; delays in ANSI approval of proposed projects; ANSI initiated withdrawal of numerous standards; and the lack of progress with proposed standards.

A summary of N15 activities follows. A detailed listing of all N15 standards' status will be printed in the January issue of JNMM.

Approved
N15.10-1987 (B.J. McKerley) and N15.22-1087 (W.W. Rodenburg) were approved and N15.10 has been printed and distributed.

Revisions
N15.18
"Mass Calibration Techniques for Nuclear Material Control." (D.J. McGuire) — needs resolution of a negative ballot by the approved extension date of November 30, 1987.

N15.19
"Volume Calibration Techniques for Nuclear Material Control." (A.M. Liebetrau) — extension to December 31, 1987 was approved and an ambitious completion schedule is underway.

Proposed Projects
P/N15.28
"Criteria and Standards for the Certification of Nuclear Material Professionals," (B.M. Wilt) — fourth draft completed for review.

P/N15.53
"Guide to Mass Spectrometric Measurement Control," (R.E. Perrin) and P/N15.54, "Guide to Measurement Control of Radiometric Calorimetry," (D.L. Jewel) — data sheets approved by ANSI and target dates for drafts established.

INMM-9
N15 Vice Chairman, Ken Byers, has not been able to locate an individual to serve as Chairman for INMM-9.

Delays
Nuclear Standard/Project Initiation Notice and Data Sheet forms (Data Sheets) submitted for proposed standards have experienced delays in receiving ANSI Nuclear Standards Board (NSB) approval. Data Sheets for P/N15.28 (B.M. Wilt) and P/N15.51 (C.E. Pietri) have been through several information exchanges and NSB review. Formal Approval is still pending.

Withdrawal
ANSI has implemented a program to enforce the withdrawal of standards beyond the "10 year rule." As a result, the withdrawal of six N15 standards will be initiated by ANSI in July.

Progress
Numerous proposed standards have had very little, if any, effort expanded on them in the last couple of years.

Proposed standards which have been inactive should be completed or dropped. A review and resolution of each needs to be completed in the near future. Recent interest (last two years) in standards development appears to be on an encouraging upswing. Effort needs to be expended to ensure completion of the projects.

Maintenance (five year review) of standards is another issue. Detailed consideration needs to be covered to improve the situation. The continued functioning of writing groups, after standard development, is essential to timely maintenance. Development of a defined approach to maintenance will be pursued in the coming year.

Obie P. Amacker, Jr., Chairman
INMM/ANSI N15 Committee
Pacific Northwest Laboratory
Richland, Washington

Secretary's Report – Election Results

According to Article III, Section 6, of the INMM Bylaws, "The Secretary shall notify each member in good standing the results of the election by October 1 of each year." This notice in the Journal shall be construed as having met that obligation.

In accordance with Article III, Section 4 of the INMM Bylaws, the Nominating Committee selected and properly submitted to the Secretary the following candidates for officers and members-at-large for the Executive Committee of the INMM:

For Chairman
Charles Vaughan

For Vice Chairman
John Lemming

For Secretary
Vince DeVito

For Treasurer
Bob Curl

For Members-At-Large
Gary Carnival
Lewis Casabona
Ralph Caudle
Dennis Mangan
Barbara Wilt

In accordance with article III, Section 5, a ballot was mailed to each of the Institute's 689 members, of which 287 returned ballots.

There were no petitions for candidates to be added to the ballot; however there were write-ins.*

As a result of the balloting, the officers and members-at-large of the Executive Committee beginning Oct. 1, 1988 are as follows:

Chairman
Charles Vaughan

Vice Chairman
John Lemming

Secretary
Vince DeVito

Treasurer
Bob Curl

Members-At-Large (to Sept. 30, 1989)
Dennis Mangan
Barbara Wilt
Joerg Menzel
Darryl Smith

Past Chairman
Yvonne Ferris

*Write-ins

Chairman
Roy Cardwell

Member-at-Large
Patricia Baird

Vice Chairman
Lewis Casabona

Secretary
David Camp

Proposed Changes to the Bylaws of the Institute of Nuclear Materials Management

Article I, Section 6. Emeritus Members
(Add that which is italicized)

Any Regular Member in good standing who is no longer gainfully employed through retirement or other cause may, upon *proper* approval of the Executive Committee, be granted Emeritus membership in the Institute. *Such applicants shall be regular members in good standing at the time of application and shall have completed several continuous years of active membership in the organization. In addition, they shall have, in the judgement of the Executive Committee, rendered significant unremunerated services to the Institute and its programs during the period of their membership.* Emeritus Members shall be assessed dues substantially lower than those assessed regular members.

Vote: 160 for; 20 against.

Article II, Section 6. Emeritus Members
(Strike out that which is shown as bold and add that which is italicized)

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** *submitting a proper application furnished by 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.

Vote 170 for; 9 against.

Vincent J. DeVito
Martin Marietta Energy Systems, Inc.
Piketon, Ohio

Education and Training

A recent informal survey of the Executive Committee and Committee Chairmen of the INMM indicated a need for a course in statistics for nuclear materials accounting. Readers with ideas regarding the course content, and even more importantly volunteers willing to participate in the development and delivery of such a course are encouraged to contact Jim Tape at the address listed below. Ideas and help in organizing other courses related to INMM activities are also most welcome.

The training and education committee of the INMM is gathering information regarding courses that are offered in the nuclear community that might be of interest to INMM members. If you are aware of education and training opportunities related to INMM activities, please contact:

Jim Tape
MS E-541
Los Alamos National Laboratory
Los Alamos, N.M. 87545
(505) 667-7777, FTS 843-7777

We will include the information in this section of the Journal provided it is still timely.

Course Listings:

The Central Training Academy

The DOE Central Training Academy (CTA) provides security-related training at its facilities in Albuquerque, N.M. For general information regarding specific courses and schedules call (505) 844-5170, FTS 844-5170, for student enrollment call (505) 846-3830 FTS 846-3830, or write: Central Training Academy, P.O. Box 18041 KAFB, Albuquerque, N.M. 87185

Los Alamos Safeguards Training

Fundamentals of Nondestructive Assay of Nuclear Material Sept. 28-Oct. 2, 1987.

Gamma-Ray Assay of Nuclear Material Jan. 25-29, 1988

Materials Accounting for Nuclear Safeguards April 11-15, 1988

Fundamentals of Nondestructive Assay of Nuclear Material Oct. 1988

Gamma Ray Assay of Nuclear Material Dec. 1988

For additional information regarding Los Alamos courses in nondestructive assay techniques contact: Linda Robinson, MS E-540, Los Alamos National Laboratory, Los Alamos, N.M. 87545, (505) 667-5258, FTS 843-5258

For additional information regarding the Los Alamos course in materials accounting contact: Charlene McHale, MS E-541, Los Alamos National Laboratory, Los Alamos N.M. 87545, (505) 667-7777, FTS 843-7777,

Jim Tape, Chairman
INMM Education Committee
Los Alamos National Laboratory
Los Alamos, New Mexico

Safeguards

The Safeguards Committee met at the annual INMM meeting in Newport Beach, Calif. on July 14, 1987.

Topics of discussions included:

- Category I Material Subcommittee Report
- Update Status on DOE MC&A Activities
- Update Status on NRC Activities
- Computer Security.

In the first area, Larry K. Trent, B&W Navy, presented a report on the Category I Material Subcommittee activities. The resulting plans required by this reform amendment are due to the Nuclear Regulatory Commission (NRC) by September 25, 1987.

Glenn Hammond, Director of Safeguards, U.S. Department of Energy (DOE), discussed safeguards activities involving standards and criteria requirements in the series of 5600 orders. DOE is also looking at the safeguards and security design criteria in DOE order 6430. Glenn indicated there would be increased emphasis on training and the interfaces between physical protection (PP) and materials control and accounting (MC&A). DOE is trying to speed up the clearance delay problems. International topics and activities were also discussed.

Don Emon, U.S. DOE, provided

updates on current activities in the MC&A area. A comprehensive review of DOE order 5630 is being conducted. A graded safeguards table concerning attractiveness levels has been developed. These levels are consistent with the IAEA values. Requirements of MC&A and PP will be keyed to this table. Performance guides will be produced, along with performance criteria for MC&A and PP will be integrated into performance criteria.

Robert Burnett, Director, Division of Safeguards, U.S. NRC, presented a summary of the reorganization in the NRC. He is no longer responsible for any reactor licensing. He now has the added responsibility for transportation. The Category I, II, and III material and inspection function are still in his charter. The Office of Nuclear Reactor Regulation is responsible for all reactor activities. NRC is increasing the level of protection at certain facilities to include double fencing, night qualification, increased threat and force-on-force excercises, armed guards at portals, and increased search requirements. There is now a schedule to convert non-power reactors to low enriched status.

Other NRC activities: The insider rule has been converted to a policy statement; Transportation licensing is the most current topic with up to 200 licenses per year being required; A modification to NRC rule 10/CFR Part 75 which makes licensee's information available to the IAEA is in progress; and a change in the transportation rule affecting security is also in progress.

An action to initiate a session on Computer Security was suggested. L. Chapman will work with Bill Hunteman, Los Alamos National Laboratory, to set up a session.

Leon D. Chapman, Chairman
INMM Safeguards Committee
BDM Corporation
Albuquerque, New Mexico

Membership

As we go into the 1988 Fiscal Year, the membership of the INMM stands as follows:

- 547 U.S. Members
- 101 Japan Chapter Members
- 91 Vienna Chapter Members
- 66 Other Members (outside the U.S., Vienna, Japan)

for a total membership of 805.

Our membership continues to lack representatives from the nuclear utilities, although this segment of the industry represents a major piece of the action. We are beginning a new campaign this fall to recruit utility members. Over the last few years, we have significantly increased our efforts in security, waste management and transportation; and our program now has a great deal more to offer our utility members than in the past. If you have business or personal contacts with any utility people, encourage them to look into membership in INMM. *We need the utility people in our organization . . . and they need us!*

The change in the Bylaws concerning Emeritus Members was approved by ballot of the membership in June. An application for Emeritus status will be available after the first of the INMM fiscal year. Until that time, any applications should be in the form of a letter to Beth Perry, Administrative Director, Institute of Nuclear Materials Management, 60 Revere Drive, Suite 500, Northbrook, Ill. 60062, U.S.A. Please give the date you first joined INMM and whether or not your membership has been continuous, offices and/or committees on which you have served and the length of service, and the name of your last employer.

Since there are currently no dues for Emeritus membership, you need also certify that you are no longer gainfully employed and that you will notify the INMM should your employment situation change. Your letter will be treated as an official application and referred to the Membership and Executive Committees for action.

In Memoriam: Robert E. Tharp

Robert E. Tharp, a 25-year member of INMM, died July 19, in Oak Ridge, Tenn.

Mr. Tharp spent his early years in Colorado and Texas where he graduated from High School in Fort Worth with honors. His college education was interrupted at the University of Denver when he enlisted in the Army in 1942, but was completed at George Washington University in later years.

In 1943, he was commissioned a 2nd Lieutenant and, after a few months as an instructor in Louisiana, was asigned to the OSS in Washington and subsequently to the Central Intelligence Corps in Japan as head of their Second Region.

Upon leaving the Army in 1948, he joined the Atomic Energy Commission as Chief of the Personnel Clearance Branch in Oak Ridge Operations. In 1953 he was promoted to Chief of that branch in AEC Headquarters and continued to move up through several positions with the Agency until he retired in 1976 as Deputy Director of the Office of Safeguards and Security of ERDA.

On retirement, he moved back to Oak Ridge to accept the position as Manager of Security for the Oak Ridge Gaseous Diffusion Plant. Most recently, he was a Senior Security Officer and Y-12 Department Head.

Mr. Tharp is survived by his wife Lorena Jane, two daughters, Sheryl Ann Miller and Sandralee Taylor of the Washington, D.C. area, a brother, Raymond L. Tharp of Texas, and three grandchildren.

Physical Protection

Scheduled and planned activities of the Technical Working Group on Physical Protection are as follows:

- Workshop: "Integrating the Elements of Delay, Intrusion Detection, and Entry Control into Physical Protection Systems; and Detecting Insider Activities." The workshop will be held at the Y-O Ranch Hilton, Kerrville, Texas, Nov. 3-6, 1987.

A special feature on the opening day of the workshop will be an in-depth presentation of fiber optic technology by Mr. John E. Donovan, Head, Fiber Optics Technology Program Office, Naval Research Laboratory. Other topics to be covered at the workshop include early warning detection and portable detection equipment. Jim Hamilton, Martin Marietta Energy Systems, (614) 289-2331 EXT. 2204, FTS 975-2204, is the workshop chairman. *Registrations ($225 for INMM members and $275 for non-members) will be accepted at the workshop.*

- Workshop: "Security Personnel Training." The workshop will be held at the Marriott Hotel, Albuquerque, N.M., April 11-14, 1988.

Fred Crane, International Energy Associates, Ltd., (703) 246-0499, is the workshop chairman. Please contact him if you would like to be a session moderator or if you have suggestions for topics to be covered.

Workshops on other subjects of interest to physical protection personnel will be considered if enough interest is expressed.

The Physical Protection TWG had a very well-attended and successful series of technical presentations at the 28th Annual Meeting of the INMM in Newport Beach. A Working Group Steering Committee Meeting was held at the close of one of the Sessions. Items discussed were:

1) Next year's annual meeting. Attendees were encouraged to start planning to present papers.
2) A session on computer security to be planned for the next annual meeting.
3) Is the Physical Protection Working Group serving the needs of its members?
4) More papers from the Physical Protection Working Group are needed for publication in the INMM Journal.
5) Future workshops.

A workshop on the Use of Computers in Security was held in Oak Ridge, Tenn., March 16-20, 1987. There were more than 60 attendees, and although this was the first time a workshop on this topic was presented, it was received enthusiastically and many suggested that it be repeated. R.G. Cardwell and G.W. Morrison, Martin Marietta Energy Systems, Y-12 Plant, Oak Ridge, Tenn., were co-chairman for the workshop. Input regarding a place and time for another workshop on the Use of Computers in Security would be appreciated.

James D. Williams, Chairman
INMM Technical Working Group
on Physical Protection
Sandia National Laboratories
Albuquerque, New Mexico

Materials Control and Accounting

The MC&A Technical Working Group is sponsoring an INMM Workshop on Process Holdup of Special Nuclear Material. The workshop will be held March 2-4, 1988, at the Ramada Hotel Rockville, Rockville, Md. U.S.A.

The workshop will provide a forum for the timely exchange of ideas and information among persons concerned with problems associated with holdup of special nuclear materials (SNM). The program will include talks on measurements, experiences with holdup, and unresolved issues involved with the problem of holdup.

The workshop will consist of five technical sessions. Individuals with an interest in SNM holdup or holdup measurements, nuclear materials control and/or accounting, or regulatory issues should attend. Further information and registration information is included in this issue of *JNMM*, or call Co-Chairmen Sam Pillay, Los Alamos National Laboratory (505) 667-7777, FTS 843-7777 or Tom Brumfield, Oak Ridge Y-12 Plant (615) 574-2561, FTS 624-2561.

Darryl B. Smith, Former Chairman
INMM Technical Working Group
on Materials Control
and Accounting
Los Alamos National Laboratory
Los Alamos, New Mexico

Waste Management

The Waste Management TWG will hold the Fifth INMM Spent Fuel Storage Seminar Jan. 20-22, 1988, at Loew's L'Enfant Plaza, Washington, D.C. U.S.A. For details contact Beth Perry, INMM, 60 Revere Drive, Suite 500, Northbrook, Ill. 60062 U.S.A., Telephone (312) 480-9573. Copies of the proceedings of INMM Spent Fuel Storage Seminar IV are also available from INMM Headquarters.

E.R. Johnson, Chairman
INMM Technical Working Group
on Waste Management
E.R. Johnson Associates, Inc.
Reston, Virginia

INMM Shines in California

More than 600 safeguards professionals — more than ever before — participated in the 28th Annual Meeting of the Institute of Nuclear Materials Management. The meeting, "Safeguards — A Mature Technology?" was held July 12-15, 1987 in Newport Beach, Calif., U.S.A.

Attendees representing nine countries (including a representative group from the INMM Japan Chapter) heard and saw a wide range of presentations covering measurement technology, safeguards performance, physical protection, international safeguards, waste management, materials control and accountability, material packaging and transportation, the insider threat, and statistics and error propagation. The technical program featured a total of 172 papers.

The Institute's Second Annual Safeguards Roundtable was held at the meeting immediately following Monday's Plenary Session. Plenary Session speakers Robert F. Burnett, U.S. Nuclear Regulatory Commission; Wilhelm Gmelin, Commission of European Communities; Reinhard Kroebel, European Safeguards Research and Development Association; Glenn A. Hammond, U.S. Department of Energy; and Charles E. Till, Argonne National Laboratory spent more than two hours in discussion with *Journal* Technical Editor William A. Higinbotham, Brookhaven National Laboratory; Book Review Editor Eugene V. Weinstock, Brookhaven National Laboratory; then-INMM Member at Large Nancy M. Trahey, Argonne National Laboratory; INMM Technical Program Committee Chairman Charles E. Pietri, U.S. Department of Energy; INMM Chairman Charles M. Vaughan, General Electric Company; and INMM Vice Chairman John F. Lemming, Monsanto Research Corporation. The edited text of that discussion appears in this issue of *JNMM.*

Social highlights at the meeting included dinner on board the Queen Mary followed by a fireworks display and dessert under the wings of Howard Hughes' Spruce Goose, the largest wooden airplane ever built. The Spruce Goose is housed in the world's largest geodesic dome.

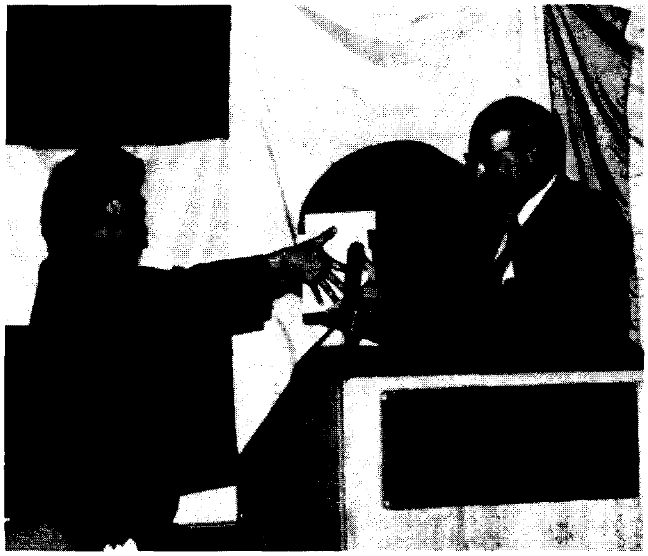
The conference was again considered a success in attendance, in the quality of the presentations, and in the affirmation of the commitment of a dedicated group of national and international government, utility and industry safeguards professionals in a difficult nuclear environment. Plans are underway for next year's conference to be held June 26-29 at Bally's Hotel, Las Vegas, Nev. U.S.A.

Awards

Twenty-three individuals were awarded certification status in the INMM Certification Program. "To strive for and achieve the certification status is indicative of a strong commitment and dedication to the safeguards profession," said Barbara Wilt, then-chairman of the INMM Certification Committee. "It is an honor and award not easily attained, and it is given and accepted with great pride," she said.

Awarded the designation "Safeguards Intern" were Norman S. Beyer, Clarence Breskovic, Richard P. Brownewell, Rickie E. Byrd, William

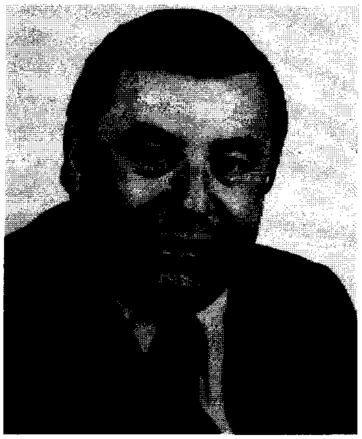
Twenty-four exhibitors displayed their products and services at the meeting.



Japan Chapter Chairman Dr. Mitsuha Hirata presents INMM Chairman Charles Vaughan with a gift from the Chapter.

Roy G. Cardwell

A. William DeMerschman



Vincent J. DeVito

B. Cheney III, Jack R. Craig, Bobby L. Hatcher, Robert E. Kellam, Thomas J. Lewis, Roger R. Miller, Billy S. Moore, Jack L. Paris, Perry A. Patton, Ben Romero, Jr., John Stuart Schork, Donald Ray Stallions, Arnold V. Wieder, T. Preston Winslow, and Joseph D. Woods. Four individuals were awarded the "Safeguards Specialist" designation: William H. Hopwood, Jr., Bruce Wadsworth Moran, Ronald B. Perry, and Nicholas J. Roberts.

Three Fellowship Awards were made at the Meeting. The INMM Fellowship Awards are given to senior members actively engaged in the profession of safeguards. They must have distinguished records of sustained contributions to their profession in the development or exposition of the theory, principles, or techniques of nuclear materials management or of significant work in an allied field. They must also have a minimum of 15 years of active experience in nuclear materials management.

Roy G. Cardwell, Martin Marietta Energy Systems, Oak Ridge, Tenn.; A. William DeMerschman, Westinghouse Hanford Company, Richland, Wash.; and Vincent J. DeVito, Martin Marietta Energy Systems, Piketon, Ohio were named Fellows of the Institute.

Three members of the Institute were also awarded the Distinguished Service Award given in recognition of significant contributions to nuclear materials management. Recognized for distinguished service were Raymond Gunnink, Lawrence Livermore Laboratory, for his "major contributions to safeguards through the development of gamma ray spectrometry for special nuclear materials;" James D. Williams, Sandia National Laboratories, for "his world renowned recognition as a security expert through the development and application of intrusion sensor technology and for his many professional contributions to the Institute;" and E.R. Johnson, E.R. Johnson Associates, for his "outstanding and continued contribution to the fields of nuclear materials management safeguards and nuclear energy programs for 35 years."

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Multi-Level Attributes Sampling Schemes for Material Accountancy Verification

Jonathan B. Sanborn
Brookhaven National Laboratory
Upton, New York, U.S.A.

ABSTRACT

In order to verify the declared material accountancy values of a facility, a safeguards authority such as the International Atomic Energy Agency makes its own independent measurements of the contents of items in the material balance on a sampling basis. Because of advances in non-destructive assay technology, a number of alternative measurement methods may be available to make such verification measurements, each with its own level of accuracy and required measurement effort. It is shown how an arbitrary number of such techniques can be combined in an attributes sampling scheme that will guarantee a given probability of detecting a missing goal quantity.

INTRODUCTION

This paper deals with attributes sampling schemes for material accountancy verification. These schemes are aimed at detecting relatively large discrepancies or falsifications in operator-declared values for material balance quantities by evaluating the difference between operator declarations and inspector-measured values for individual items. The present paper is an extension of previous work[1-2] by this author which dealt with a situation where the inspector had two verification measurement techniques at his disposal. A number of papers relating to the same problem — that of minimizing sampling effort — have appeared[3-7], some using very different approaches than that described here.

The purpose of the verification scheme described below is to detect, with a well-defined probability, the existence of discrepancies (defects) between declared and actual values for the contents of items in a material balance. The discrepancies are assumed to total a "goal quantity" G. The items in the material balance are divided into subsets called "strata" composed of similar items. The total discrepancy or defect can be divided in any manner among the strata.

Within a stratum the amount of the discrepancies (defects) for all items whose declared values are false (defected items) are assumed to be the same; the total defect D for the stratum is therefore spread evenly among m items, each of which has defect s (D = ms; no "error" per se is assumed in the declared values). The defect per item s can be arbitrarily small but may not be greater than the total contents of the item.

In the scheme described here, a series of measurement techniques is available to the inspector for measuring the items in each stratum, each more accurate (and requiring more effort) than the previous one. Each such technique has a critical value or rejection limit (e.g. twice the standard deviation of the measurement error); if the difference between the measured and declared value exceeds the rejection limit, the measured value is judged to be anomalous. Associated with each measurement technique is a sample size n; n items are randomly selected from the stratum for measurement using that technique. Each technique has a known measurement-error distribution, assumed here to be normal (although the derivations do not depend on the details of the normal distribution). Independence is assumed between one technique and the next, but no assumptions are made regarding the statistical dependence of errors from item to item measured by the same technique.

Detection occurs if a defected item is selected for measurement by any technique and the result is anomalous. Only one such detection is required to conclude that falsification exists. The question of "alpha" or false alarm probability will not be addressed explicitly in this paper; it is assumed that the critical values are given, and that an item producing an anomalous result will be remeasured by a more accurate device as necessary to reduce the false alarm probability.

The problem then is: given the number of items in a stratum (N), a goal quantity (G), a target detection probability ($1-\beta_0$), and a sequence of techniques ($k = 1,2,3,\ldots K$) with known standard deviations (σ_k) and critical values (p_k), to find a sequence of sample sizes (n_k) so that falsification of the amount G will be detected with probability greater than $1-\beta_0$. The solution of this problem is essentially given as equations (4) and (5) in the next section: a simple formula is given for each sample size (n_k) in terms of the parameters of the previous technique (p_{k-1}, σ_{k-1}).

This paper draws heavily upon previously published work[2] which provides a more detailed description of the context of the problem and addresses the case where two techniques $(K=2)$ are available.

In practice, of course, only a few techniques would be available, and their standard deviations would have some lower bound; in some circumstances this means that the problem posed here would not have a solution, unless some lower bound is put on the value of s. In other words, in some realistic circumstances the verification schemes of the type described here are vulnerable to strategies in which a large number of very small defects are used. These problems may have other solutions (addressed elsewhere in the literature, but beyond the scope of this paper) or they may not. These problems are avoided here by assuming that the final (best) measurement technique is perfect (zero standard deviation). In reality this will not be the case, and strategies involving defects of approximately the same size as or smaller than the actual smallest standard deviation (strategies which may or may not be feasible) will not be detectable by the means described here. All other strategies, however, will be covered.

It is of course easy to achieve high detection probabilities by making large numbers of very accurate (and costly) measurements. The scheme here minimizes the number of the more accurate measurements in favor of the less accurate measurements. The next section provides the mathematical basis for equations (4) and (5); an example illustrating the use of the sampling scheme is given in the last section.

Statistical Theory

1. Required Characteristics of the Stratum Non-Detection Function

The scheme adopted here is applied to each stratum, independently of the characteristics of other strata. It is pointed out in reference (2) that if $\beta(D)$ is the non-detection probability for a stratum (i.e. one minus the probability of any anomalous result on a detected item in a stratum) as a function of the total defect D in the stratum, then it is desirable that

$$\beta(D) \leq \beta_0^{D/G} \tag{1}$$

This of course guarantees that if $D=G$, the non-detection probability will not exceed the desired non-detection probability β_0. It is easy to show also[2] that if the detection schemes for all strata obey (1), and are independent, and if the total of defects in all strata is G, then the *overall* non-detection probability will be no greater than β_0. Thus it is desirable to prove condition (1) for all D less than G, rather than the weaker condition $\beta(G) \leq \beta_0$.

2. The Sequence of Verification Schemes and the Choice of Sample Sizes

A verification scheme as discussed in this paper is defined by a set of triples

$$(\sigma_1, p_1, n_1),\ (\sigma_2, p_2, n_2), \ldots\ (\sigma_K, p_K, n_K)$$

This indicates that K sets of samples (of size n_k, $k=1\ldots K$) are drawn independently from the stratum and measured with error standard deviations σ_k and with critical values p_k. The symbol $(0,n)$ will designate a sample of size n measured with $\sigma=0$. In the sequences of schemes under discussion, the last technique K will have $\sigma_k=0$. Specifically, it will be shown that if a scheme

$$(\sigma_1, p_1, n_1), \ldots (\sigma_{K-1}, p_{K-1}, n_{K-1}),\ (0, n_K) \tag{2}$$

satisfies (1), then n_{k+1} can be selected so that

$$(\sigma_1, p_1, n_1), \ldots (\sigma_K, p_K, n_K),\ (0, n_{K+1}) \tag{3}$$

also satisfies (1). The methods for determining the n_k are quite simple:

$$n_1 \geq N(1 - \beta_0^{A/G}) \tag{4}$$

$$n_{k+1} \geq (N\sigma_k/G)\ g(\beta_0, p_k) \qquad k = 1,2,3,\ldots. \tag{5}$$

(here the inequalities imply that the n's are integers greater than or equal to the right-hand sides. In these equations,

N is the number of items in the stratum

β_0 is the desired non-detection probability

A is the amount of material in an item (in kilograms of plutonium)

G is the goal quantity (in Kgs)

n_k is the sample size for technique k

σ_k is the standard deviation for technique k (in kgs)

p_k is the critical value of measurement k (in dimensionless multiples of σ_k)

g is a computed function (see table 1), specifically

$$g(\beta, p) = \max\ \{c[\ln(1-(1-\beta)\phi(c-p)) - \ln\beta]\} \tag{6}$$

(where the maximum is taken over $c>o$)

ϕ is the cumulative normal distribution

ϕ_k as shorthand for the function

$$\phi_k(s) = \phi(s/\sigma_k - p_k)$$

3. Proof that the Proposed Sampling Scheme Satisfies the Non-Detection Condition

Proof that the sampling scheme, for $K=1$

$$(0, n_1)$$

satisfies (1) is given in reference 2 (here detection occurs if the sample of size n_1 includes a defected item).

We now show that if the scheme (2) satisfies (1), then scheme (3) satisfies (1), provided that n_{k+1} is given by (5).

Let

a_{1k} = probability of detection for the scheme

$$(\sigma_1, p_1, n_1), \ldots (\sigma_{k-1}, p_{k-1}, n_{k-1}), (0, n_k)$$

a_{2k} = probability of detection for the scheme

$$(\sigma_1, p_1, n_1) \ldots\ (\sigma_k, p_k, n_k)$$

a_{3k} = probability of detection for the scheme

$$(0, n_k)$$

a_{4k} = probability of detection for the scheme

$$(\sigma_k, p_k, n_k)$$

and let $b_{ik} = 1 - a_{ik}$. Each of these quantities are functions of D and s. We wish to show that

$$b_{1,k+1}(s, D) \le \beta_0^{D/G}$$

for all $0 < s \le D$

and $0 < D \le G$

under the assumption that $b_{1,k} \le \beta_0^{D/G}$

Using the independence of the verification techniques, we have, from the standard formula for Pr(A or B)

$$a_{2,k} = a_{2,k-1} + a_{4,k} - a_{2,k-1}\, a_{4,k}$$

using lemma 3 (proved in the next section)

$$a_{2,k} \ge a_{2,k-1} + \phi_k\, a_{3k} - a_{2,k-1}\, \phi_k\, a_{3k}$$

$$\ge \phi_k\, (a_{2,k-1} + a_{3k} - a_{2,k-1}\, a_{3k})$$

from the independence of the verification techniques

$$a_{2,k} \ge \phi_k\, a_{1,k} \qquad (7)$$

Again using the independence of the techniques

$$b_{1,k+1} = b_{3,k+1}\, b_{2,k}$$

$$= b_{3,k+1}\, (1 - a_{2,k})$$

from equation (7)

$$\le b_{3,k+1}(1 - \phi_k\, a_{1k})$$

$$= b_{3,k+1}(1 - \phi_k\, (1 - b_{1,k}))$$

$$\le (1 - n_{k+1}/N)^{D/s}\, (1 - \phi_k + \phi_k b_{1,k})$$

by assumption, and since D/s = m,

$$\le (1 - n_{k+1}/N)^{D/s}(1 - \phi_k + \phi_k \beta_o^{D/G})$$

from lemma 2

$$\le (1 - n_{k+1}/N)^{D/s}\ \ (1 - \phi_k + \phi_k \beta_o{}^{D/G})$$

$$= \exp\{D/(Gs)\ [G \ln(1 - n_{k+1}/n) + s \ln(1 + \phi_k + \phi_k \beta_o)]\}$$

using

$$-x \ge \ln(1-x),$$

$$\le \exp\{D/(Gs)[-(Gn_{k+1}/N) + s \ln(1 + \phi_k - \phi_k \beta_o)$$

$$+ s \ln\beta_o - s \ln \beta_o)]$$

using lemma 1, for all s,

$$\le \exp[-(D/Gs)(-s \ln \beta_0)]$$

finally

$$\beta_{1,k+1} \le \beta_o^{D/G}\ .$$

4. Supporting results

lemma 1. if (5) holds, then for all s>o,

$$0 \ge -(Gn_{k+1}/N) + s \ln(1 - \phi_k + \phi_k \beta_o) + s \ln \beta_o$$

Proof. Substitution of (6) into (5) and straightforward algebraic manipulation yields

$$0 \ge -(Gn_{k+1}/N) + \sigma_k \max_c\{c \ln \beta_o - c \ln[1 - \phi(c - p_{k-1})$$

$$\beta_o \phi(c - p_k)]\}$$

Let $s = \sigma_k c$; then $c = s/\sigma_k$; $\phi(c - p_k) = \phi_k(s)$ and the result follows.

lemma 2. If If $0 \le x, y, z \le 1$ then

$$1 - x + xy^z \le (1 - x + xy)^z$$

This result is proved in reference 2.

lemma 3. $a_{4k}(s) \ge \phi_k a_{3k}$

Proof.

$$a_{4k}(s) = \sum{}_{i-1}^{n_k} \Pr(\text{any anomalous result} \mid \text{i defected items are in the sample}) \Pr(\text{i defected items in sample})$$

$$\ge \sum_{i=1}^{n_k} \Pr(\text{any anomalous result} \mid \text{1 defected item in the sample}) \Pr(\text{i defected items in sample})$$

$$= \phi(s/\sigma_k - p_k) \sum_{i=1}^{n_k} \Pr(\text{i defected items in sample})$$

$$= \phi(s/\sigma_k - p_k)\, a_{3k}$$

$$= \phi_k a_{3k}$$

5. *Calculated Values for the Function g(β,p)*

The function (6) may be evaluated numerically. The results are shown below.

Values for $g(\beta,p)$

β	$p=$ 1.5	2.0	2.5	3.0	3.5	4.0
.50	.61	.82	1.06	1.31	1.58	1.86
.40	.84	1.13	1.44	1.78	2.13	2.50
.30	1.17	1.55	1.97	2.41	2.88	3.36
.20	1.68	2.20	2.76	3.36	3.98	4.64
.10	2.69	3.45	4.26	5.12	6.02	6.95
.05	3.85	4.87	5.94	7.06	8.23	9.44

AN EXAMPLE

The example will deal with the verification of 200 cans of PuO_2 powder, each weighing approximately 2.0 kilograms. Three types of verification methods are contemplated for the verification of the operator's declared values for this stratum of material: (1) a neutron measurement with a standard deviation of 10%, (2) a calorimeter measurement, which when combined with gamma spectroscopy data gives a standard deviation of about 2%, and (3) sampling and destructive analysis. The desired detection probability will be 90%. The goal quantity will be 8 kg of plutonium.

Results from the neutron and calorimeter measurements are considered anamalous if the operator-inspector difference exceeds 2.5 standard deviations; i.e., 25% in the case of the neutron measurement and 5% in the case of the calorimeter. These values were chosen arbitrarily as reasonable values. Choosing smaller critical values will decrease calculated sample sizes, but will increase the number of false alarms that have to be remeasured by the next level of measurement. In theory, this parameter can be varied to minimize the total number of measurements made by each technique; this process is described in reference 2.

In the notation used in the text,

$N =$ number of items $= 200$
$A =$ nuclear material per item $= 2 \times 0.88 = 1.76$ kg of Pu
$\beta_0 =$ desired non-detection probability $= 1 - 0.9 = 0.1$
$G =$ goal quantity of nuclear material $= 8$ kg of Pu
$\sigma_1 =$ standard deviation of neutron technique $= 1.76 \times 10\% = .176$ kg Pu
$\sigma_2 =$ standard deviation of the calorimeter technique $= 1.76 \times 2\% = 0.035$ kg Pu
$P_1 = P_2 =$ Number of standard deviations that define an anomalous inspector/operator difference for the neutron (1) and calorimeter (2) measurements $= 2.5$

Using formulas (4) and (5), and tabled values for "g" above,

$$n_1 = N(1-\beta_0^{A/G}) = 79$$

$$n_2 = (N\sigma_1/G)g(0.1,2.5) = 19$$

$$n_3 = (N\sigma_2/G)g(0.1,2.5) = 4$$

Thus 79 cans would be measured by the neutron method, 19 would be placed in the calorimeter, and 4 would be sampled for destructive analysis.

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Jonathan B. Sanborn received a Ph.D. in Applied Mathematics from State University of New York at Stonybrook in 1975. He then assumed the position of assistant professor at the Harriman College of Urban and Policy Science at the University. In 1977 he joined the Technical Services Organization at Brookhaven National Laboratory. In 1979 he served as a cost-free expert with the International Atomic Energy Agency in Vienna. His primary interests are in the areas of statistics, materials control and accounting, and measurement control.

Calibration and Error Reduction in Neutron Coincidence Counting

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ABSTRACT

The accuracy in measuring the plutonium content by means of neutron coincidence counting can be improved by setting up sample categories and analyzing the categories differently. Four categories of materials are defined, and calibration procedures are recommended for each of the categories. Methods are given to identify which category a sample belongs in and techniques are described to reduce the measurement errors. New data are presented to establish the validity of multiplication corrections, and the application of the correction to induced fissions in uranium as well as plutonium is investigated. Methods are outlined to solve the more general problem of plutonium assay when the (α,n) yield is unknown.

I. INTRODUCTION

Neutron coincidence counting has been used extensively for the nondestructive assay (NDA) of plutonium. Time-correlated neutrons emitted in the spontaneous fission of the even mass number plutonium isotopes are counted to measure the plutonium mass. Electronic circuitry[1] is used to count the total neutron rate (T) and the coincidence rate (R). In most applications, the value of R is related to the mass of ^{240}Pu-effective (^{240}Pu-effective = 2.52 ^{238}Pu + ^{240}Pu + 1.68 ^{242}Pu) to give a calibration curve.

For higher mass loadings of plutonium, this calibration function is nonlinear because of neutron-induced fission or multiplication in the sample. A theoretical procedure to correct for this multiplication was developed by K. Böhnel[2] and N. Ensslin.[3] This correction procedure requires information on the ratio of (α,n) neutrons/spontaneous-fission neutrons (α). For an accurate multiplication correction using R and T, it is essential that the neutron counting efficiency (ε) remain constant and that the deadtime corrections are accurate over the entire sample range. For most historical coincidence counter applications,[4,5] these assumptions were only partially valid, and this led to a larger error in the results than otherwise would have been the case.

Recent detector designs[6-8] and electronic improvements[9] have essentially corrected the problems of variable efficiency and erroneous deadtimes. This has resulted in more accurate multiplication corrections, but the basic problem remains that there are more unknowns (M_{240}, M, and α) than knowns (R and T), where M_{240} is the g ^{240}Pu-eff and M is the sample multiplication. The most popular method to deal with the above dilemma is to calculate α from the plutonium isotopics, ^{241}Am content, and (α,n) yields in oxides. However, this last factor requires knowledge of the sample's chemical composition.

Some calibration work[10] has been done by assuming M is known and using T to eliminate the need to know α. This approach works fairly well when the sample density and shape are matched to the calibration standards, but it fails when M is not a unique function of the mass.

Several technical approaches are being evaluated to solve the more general problem of three unknowns vs. two knowns. These approaches include counting higher neutron moments[11-13] add-a-source[14] such as ^{252}Cf, reflectivity or albedo change,[15] and using the measured mass and size to calculate M with Monte Carlo computer codes.

The purpose of this report is to recommend the technical approaches for different types of samples. Data reduction algorithms and calibration functions are recommended to reduce assay errors based on currently available hardware.

II. PLUTONIUM SAMPLE CATEGORIES

Several sample categories are required to cover the large diversity of plutonium samples found in the nuclear fuel cycle and plutonium processing.

These include the following:

Category A
Small samples of plutonium where variations in the neutron multiplication are small or negligible.

Category B
Medium-to-large samples that are free of impurities and that have a low moisture content.

Category C
Medium-to-large samples that are impure or have a large moisture content.

Category D
Medium-to-large samples that have a very high (α,n) activity so that the induced-fission rate dominates the spontaneous-fission rate.

Table I

Plutonium Sample Categories for Calibration of Neutron Coincidence Counters

Category A (Low Mass)

MOX pellets	(≤5 pellets)
PuO_2 powders	(≤20 g plutonium)
MOX powders	(<40 g plutonium)
Metals	(<10 g plutonium)
Nitrates	(<5 g plutonium)

Category B (Pure Samples)

Bulk Pellets
Pure feed PuO_2 powder
Pure feed MOX powder
LMFBR fuel pins
LMFBR fuel assemblies
LWR MOX fuel pins
LWR MOX fuel assemblies
Pin and pellet storage trays
Plutonium metal buttons
Plutonium metal coupons (trays and birdcages)
Scrap reject pellets

Category C (Impure and Moist Samples)

Impure or moist PuO_2 powder
Impure or moist MOX powder
PuO_2 with unknown ^{241}Am content
Plutonium in low-Z matrix or alloy
Plutonium in scrap or waste

Category D (High α,n Activity Samples)

PuF_4
Plutonium salts
High ^{241}Am activity salts and alloys

Some examples of samples that fall into the four categories are listed in Table I.

III. SMALL SAMPLES – CATEGORY A

For sample Category A, where the multiplication is small or negligible, the purity, moisture content, shape, and density make little difference, because the neutrons escape from the sample before causing induced-fission reactions. The calibration curve is practically a straight line. The calibrations of any two detectors are related simply by the ratio of their responses for a ^{252}Cf reference source.

A recommended calibration function is

$$R = aM_{240} + bM_{240}^2$$

$$\text{where } aM_{240} >> bM_{240}^2$$

A typically small sample calibration curve for PuO_2 and MOX pellets is shown in Fig. 1.

The precision for measuring these types of small samples is generally limited by the counting statistics. Figure 2 shows the expected precision as a function of counting time for typical samples in the inventory sample counter (INVS).[16] This counter has a high efficiency (35%), and it was designed for a small sample assay. With careful packaging, the assay accuracy should be the same as the statistical precision down to a value of ~0.5%. Better accuracy than 0.5% will require a good match between standards and unknowns.

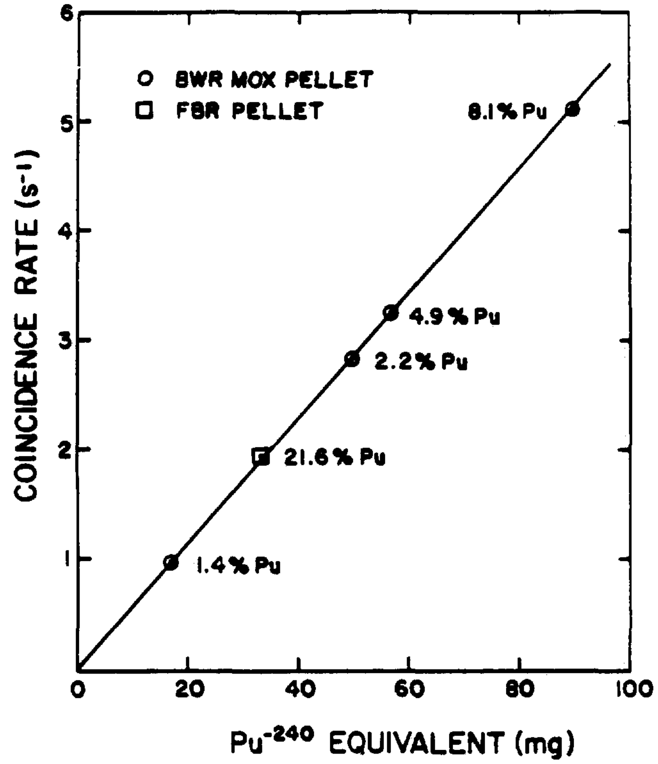

Figure 1. Linear calibration curve for Category A plutonium and MOX pellets in the INVS.

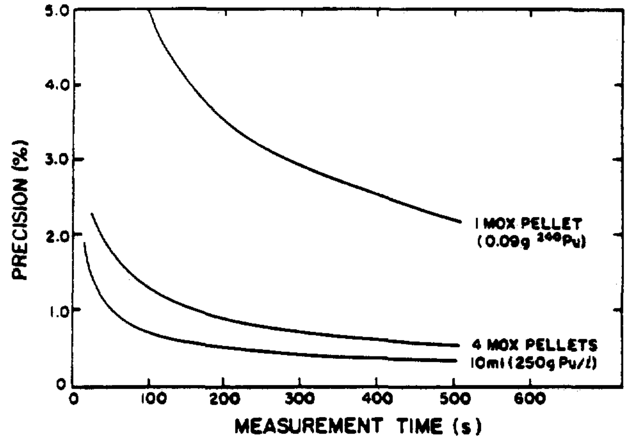

Figure 2. Assay precision as a function of measurement time for typical samples using the INVS.

A potentially useful application of an INVS type system is to resolve discrepancies in bulk sample NDA. Errors in the neutron assay of large samples are often caused by

$$R_{mc} = \frac{R}{CF} \ ,$$

$$CF \equiv M \cdot r \ ,$$

$$r \equiv \frac{\left(\frac{R}{T}\right)}{\rho_0} (1 + \alpha) \ ,$$

$$\rho_0 = \left(\frac{R}{T}\right)_0 (1 + \alpha_0) \quad (\rho_0 \text{corresponds to the rates from a nonmultiplying sample}) \ ,$$

$$M = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \ ,$$

$$A = 2.074(1 + \alpha) \ ,$$

$$B = -(2.074\alpha + 1.074) \ ,$$

$$C = -r \ ,$$

$$\alpha = \frac{134\ f_{238} + 0.381\ f_{239} + 1.41\ f_{240} + 0.013\ f_{241} + 0.02\ f_{242} + 26.9\ f_{241Am}}{10.2(2.54\ f_{238} + f_{240} + 1.69\ f_{242})} \ , \qquad \text{Equation A}$$

impurities or moisture in the sample, giving an unexpected induced-fission component. If the large sample is subdivided into smaller samples, they can be measured in the INVS with negligible multiplication errors.

The use of R and T to make multiplication corrections should *not* be done, because T from the sample is usually smaller than T from the room background that varies with time. The large uncertainty in T translates to a large uncertainty in the multiplication-corrected reals (R_{mc}). Also, the uncertainty in actual multiplication correction is negligible.

IV. PURE SAMPLES — CATEGORY B

Category B includes the majority of cases where neutron coincidence counting has been used successfully for plutonium assay. These samples include much of the primary feed material for fuel fabrication as well as the final product in the form of pellets, pins, assemblies, and buttons. These materials are generally pure and free of moisture.

The primary requirement for accurate assay in Category B is that the *calculated* α is accurate. This is true for pure mixed oxide (MOX), where the (α,n) reaction probability is essentially the same in UO_2 as in PuO_2. Plutonium metal has the desirable feature that there are no (α,n) reactions so $\alpha = 0$.

Multiplication corrections *should always* be made for Category B samples to reduce assay errors from density, size, and shape variations. Also, induced-fission differences from varying plutonium fissile fractions and ^{235}U mixtures are accurately corrected using the new multiplication corrections given by Ensslin.[3]

This correction is: *(See Equation A at top of this page.)*

where the f_m values are the weight fractions of the plutonium isotopes with mass number m.

If the correct value of ρ_0 is used in the above equations, M is the actual leakage multiplication that can be compared with independent Monte Carlo code computer calculations. This was recently done in Refs. 17 and 18 with good agreement.

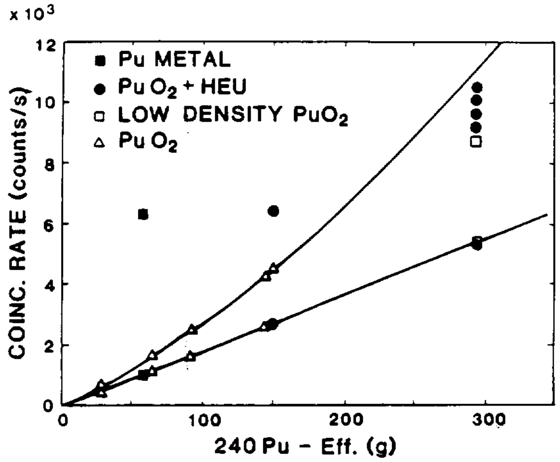

Figure 3. Coincidence rate vs M_{240} for different combinations of PuO_2, plutonium metal, and HEU measured in the HLNC-II.

When the value of M is measured by R and T, then agreement with the expected value of M from calibration standards and/or Monte Carlo calculations gives an effective verification of the fissile content in the sample. Thus, the passive neutron count gives not only the ^{240}Pu-effective confirmation but also the total plutonium verification by the induced-fission component. The measured value of M should always be compared with the expected value as a consistency check.

A. Multiplication Results

Some impressive examples of the accuracy of the multiplication correction are given in Table II. Several different

Table II

Neutron Coincidence Counting Results Using the HLNC-II (November 5, 1986)

Sample No.	M_{240} (g)	T (s^{-1})	R (s^{-1})	R_{mc} (s^{-1})	$\frac{R_{mc}}{240}$	M
Cf (CR-5)	—	6 539	1 264	—	—	—
Plutonium Powder						
LAO 251C10	29.32	7 717	680.2	538.7	18.37	1.050
LAO 256C10	65.18	17 376	1 698	1 185	18.18	1.079
LAO 255C10	92.2	24 872	2 503	1 669	18.09	1.090
LAO 261C10	144.50	39 623	4 264	2 637	18.25	1.109
LAO 261C11	149.27	41 165	4 510	2 725	18.26	1.115
PEO 447	81.44	25 644	2 342	1 516	18.61	1.090
261C11+261C10 (stacked)	293.77	80 864	8 995	5 329	18.14	1.120
261C11+261C10 (14 cm apart)	293.77	80 621	8 699	5 360	18.25	1.110
Plutonium Powder						
261C11+6 HEU	149.27	44 600	6 385	2 722	18.24	1.209
261C11+261C10 (0 HEU)	293.77	80 672	8 772	5 352	18.22	1.112
261C11+261C10 (1 HEU)	293.77	81 063	9 092	5 330	18.14	1.123
261C11+261C10 (2 HEU)	293.77	81 451	9 259	5 334	18.16	1.127
261C11+261C10 (3 HEU)	293.77	81 859	9 666	5 301	18.04	1.140
261C11+261C10 (4 HEU)	293.77	82 256	9 859	5 302	18.05	1.145
261C11+261C10 (5 HEU)	293.77	82 747	10 222	5 285	17.99	1.155
261C11+261C10 (6 HEU)	293.77	83 215	10 659	5 258	17.90	1.168
261C11+261C10 (7 HEU)	293.77	83 545	10 999	5 234	17.82	1.178
Plutonium Metal plus HEU						
STD 621	57.9	16 523	6 290	1 051	18.15	1.619
STD 621+(1 HEU)	57.9	17 458	7 469	1 059	18.29	1.698
STD 621+(2 HEU)	57.9	18 128	8 329	1 068	18.44	1.748
STD 621+(3 HEU)	57.9	18 572	9 076	1 067	18.43	1.793
STD 621+(4 HEU)	57.9	18.866	9 538	1 068	18.44	1.819

Table III

Plutonium Sample Specifications (Data updated to November 5, 1986

Sample ID	Pu (g)	^{240}Pu-eff (%)	^{238}Pu (%)	^{239}Pu (%)	^{240}Pu (%)	^{241}Pu (%)	^{242}Pu (%)	^{241}Am (%)	α
LAO 251C10	171.7	29.32	0.064	82.08	16.38	1.14	0.35	0.296	0.405
LAO 256C10	384.4	65.19	0.059	82.22	16.28	1.11	0.34	0.269	0.400
LAO 255C10	543.1	92.28	0.069	82.19	16.29	1.11	0.34	0.281	0.408
LAO 261C10	847.6	144.50	0.059	82.09	16.37	1.14	0.34	0.256	0.396
LAO 261C11	875.6	149.27	0.059	82.09	16.37	1.14	0.34	0.256	0.396
261C11+261C10	1 723.2	293.77	0.059	82.09	16.37	1.14	0.34	0.256	0.396
PEO 447	777.2	81.44	0.035	89.05	10.14	0.62	0.16	0.416	0.598
STD 621-000[a] (Metal Disk)[b]	999.2	57.9	(0.01)	(93.96)	5.7	(0.5)	(0.3)	—	—

[a] Isotopic fractions estimated from the ^{240}Pu fraction.

[b] The plutonium metal disk is 4.9-cm-diam by 2.31-cm-thick contained in a can that is 6.9-cm-diam by 4.6 cm high

Category B samples were measured to evaluate the correction procedure. The sample specifications are listed in Table III. The high-enrichment uranium (HEU) standards are metal disks 1-cm-thick by 6-cm-diam with a uranium mass of 500 g (93.15% enriched in ^{235}U).

For the experiments, each sample was measured in the HLNC-II in the normal way. Then the samples were modified by changing the density or high-enrichment uranium (HEU) content to significantly change the neutron multiplication. The increase in the multiplication significantly increased the measured R rate, but the change in R_{mc} was always <1%.

Figure 3 shows the results for the different sample categories in Table III. The calibration curve is a quadratic fit through the pure PuO_2 powders (LAO series). The HEU metal disks were added to the outside of the cans to increase M (the multiplication).

The following cases were evaluated:

(a) Pure PuO_2 powder,
(b) PuO_2 powder plus HEU metal,
(c) Low-density PuO_2 (stacked cans),
(d) Plutonium metal, and
(e) Plutonium metal plus HEU metal.

The R values were the greatest when the HEU metal disks were added on the bottom of the can in close proximity to the PuO_2. However, the R_{mc} values were the same regardless of whether the HEU was added to the bottom, sides, or top of the can.

1. *Plutonium Metal plus HEU Metal.* Of particular interest was the result that the R value for plutonium metal was a factor of ~5 above the PuO_2 calibration curve, but the R_{mc} value for the plutonium metal fell on the same line (0.3% mass residual) as the PuO_2 samples.

The greatest multiplication M was obtained when the 1-kg plutonium metal button was combined with 2 kg of HEU metal. In this case, the value of M was 1.82 calculated by the R to T ratio. The corrected R_{mc} value was the same (absolute mass residual of 1.0%) as for the PuO_2 powders.

2. *Low-Density PuO_2.* Low-density PuO_2 was simulated by placing two cans of PuO_2 powder on top of each other. This reduced the measured R by ~30% from the expected value for a single can containing the combined plutonium masses. This case is represented by the highest plutonium mass point in Fig. 3. The R_{mc} fits the standard calibration line with a mass residual of only 0.2%.

3. *Low-Density PuO_2 plus HEU Metal.* The two cans mentioned in the preceding section were separated with lead disk spacers (~7 cm total height) so that HEU metal could be added between the two cans in place of the lead. The separation distance between the cans remained constant by replacing the lead disks by HEU disks one at a time.

The results of this experiment are shown in Table II. For this special case of a fixed geometric coupling between the plutonium and the HEU, we can determine the amount of HEU in the composite mixture. The results are shown in Fig. 4, giving R(U-235,IF)/T vs g ^{235}U, where the induced-fission rate in the ^{235}U is

$$R(U\text{-}235,IF) = R - R(PuO_2)$$

This calibration curve has the same characteristics as the AWCC[19] calibration for HEU metal.

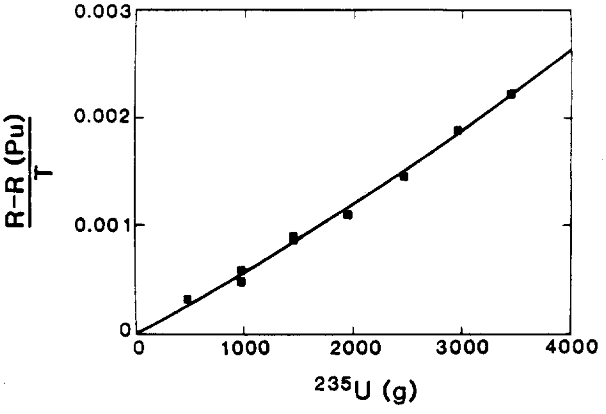

Figure 4. The induced-fission coincidence rate in ^{235}U, R(IF, ^{235}U), normalized by the totals rate vs the ^{235}U mass.

The practical significance of this result relates to the passive coincidence counting of LMFBR and LWR recycle fuel assemblies. If a series of assemblies differs only in its HEU content, then this type of analysis can verify the HEU loading in addition to the plutonium.

A more careful examination of the results for a systematic substitution of one to seven HEU disks for lead disks shows that the R_{mc} values are slowly decreasing (~0.28/disk). Thus, it is likely that the plutonium-based coeffiecients given in the multiplication equations (Sec. IV) are not quite right for induced fission in HEU as would be expected. On the other hand, the addition of HEU on the exterior of the PuO_2 (with no lead disk substitution) gives a slight increase in detector efficiency ϵ, which seems to compensate for the HEU/Pu coefficient mismatch.

B. Baseline Concept

The remarkable result of data shown in Fig. 3 is that a single straight line fits all of the R_{mc} cases listed in Table II, with an average mass residual of only 0.8%.

This leads to the conclusion that the most accurate calibration function for Category B materials is a straight line (or "baseline") through the origin

$$R_{mc} = aM_{240}$$

where a is the slope of the baseline. The value of a $\simeq$ 18.2 counts/s•g ^{240}Pu-eff for the HLNC-II ($\rho_0 = 0.103$). The magnitude of a is proportional to ρ_0. Thus if ρ_0 is increased to 0.108 to match the Monte Carlo calculations, the calibration coefficient a ~19.1.

The reason for introducing the baseline concept is that all legitimate data outliers after multiplication corrections will fall above the baseline. If the sample has (α,n) impurities or a high moisture content, the calculated α and/or ϵ will be too small. This results in an R_{mc} result that is above the calibration curve.

On the other hand, if the measured R_{mc} falls *below* the baseline, then the declared mass or isotopics are in error.

If the measured R_{mc} falls above the calibration line by some present error limit (for example, 2-3σ), then we must treat the sample as Category C material.

C. Calibration Results Before Multiplication Corrections

A typical calibration curve (HLNC-II) for Category B samples is shown in Fig. 5, where the PuO_2 sample masses cover the range from 60 g to 8000g.[20] The top curve corresponds to R and the bottom curve corresponds to R_{mc}.

Several different nonlinear functions were evaluated in fitting the R curve, where the primary figure of merit was the average absolute mass residual (percent) in the least-squares fit. The quality of the fit is very sensitive to the weighting on the individual data points. Typical weighting procedures are to assign equal weights to all points, or the square root of R, or the counting statistical error from the

Table IV

Calibration Functions and Fitting Errors for Category B PuO_2[a]

Calibration Form	*Function*	*Av Absolute Mass Error*[b] *(%)*
Power (zero intercept)	$R = am^b$	6.3
Quadratic (zero intercept	$R = am^2 + bm$	4.3
Quadratic (nonzero intercept)	$R = am^2 + bm + c$	3.6
Cubic (zero intercept)	$R = am^3 + bm^2 + cm$	4.3
Cubic (nonzero intercept)	$R = am^3 + bm^2 + cm + d$	3.6

[a] Data corresponds to the 39 sample set shown in Fig. 5 before multiplication corrections.

[b] The data was weighted with an equal percent error (1%) for all coincidence rates.

measurement. All of these approaches are inadequate because none of them are representative of the primary uncertainty causing the scatter in the data. The counting statistics for all data (39 samples) shown in Fig. 5 was better than 0.7%, whereas the observed scatter is 3-8%. The primary causes for the increased scatter is sample-to-sample differences in density, shape, isotopics, moisture, and ^{241}Am content. A better weighting function is to give all of the R values the same percent error (for example 1 or 2%) so long as the counting statistical error is negligible. When the mass range is large, as in the present case, this makes a considerable difference from the other weighting procedures.

Table IV lists the fitting functions used for the 39-sample data set, together with the absolute mass residuals in percent error. The best fit was obtained with a quadratic function (nonzero intercept). The quadratic would be preferred over the cubic that gave the same mass residual because there are less free parameters in the quadratic. All of the functions fit better with a nonzero intercept for a physical reason related to the mass of the samples and the under moderation in the HLNC-II. As the sample mass gets small, the efficiency of the counter decreases slightly because there is less neutron scattering in the sample. Also, the multiplication M is decreasing faster than would be the case for the change in mass alone because the sample shape is changing from a right cylinder with high multiplication to a pancake that has a very small multiplication. These two factors result in a smaller R than would otherwise be the case for small mass values. When the calibration range is small, the calibration function will adapt to the efficiency shift and the standards and unknowns shift the same. However, for our data set covering the wide mass range, the zero offset was apparent. This zero offset for Category B and C materials does not cause problems because the sample mass cannot go to zero in these categories (low-mass samples are in Category A).

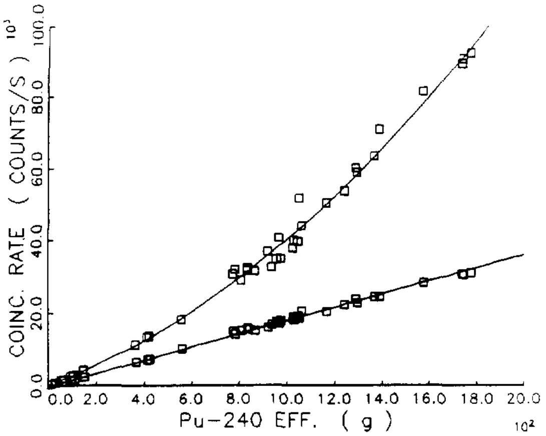

Figure 5. Calibration curves for Category B material (PuO_2) before (top curve) and after (bottom curve) multiplication corrections.

The quadratic calibration function that best fit the R data in Fig. 5 was

$$R = 0.01496\ M_{240}^2 + 25.18\ M_{240} - 52.9$$

so the nonzero offset was -52.9 counts/s on a full scale of 100 000 counts/s. For the data set in Fig. 5, the lowest M_{240} value was 10.1 g so the offset changes the calculated R by ~20% for this small sample.

V. IMPURE SAMPLES — CATEGORY C

When samples fall into Category C (see Table I), then additional information is required to obtain an accurate assay. The simple coincidence measurement gives two knowns (R and T) but there are three unknowns (M_{240}, M, α),

$$R = f(M_{240}, M, \alpha)$$

$$T = h(M_{240}, M, \alpha)$$

In the above equations, we have assumed that the deadtime corrections have been made accurately and that the efficiency ϵ is constant or that R has been corrected for any changes n ϵ. For example, the container wall thickness correction is made to keep ϵ.

In Category B samples, we were able to calculate α from the isotopic ratios and (α,n) neutron yields in oxides. For Category C samples, α is larger than would be the case for pure samples, and we must obtain additional information such as

(1) measurement of higher moments,
(2) the use of ^{252}Cf add-a-source to estimate M,
(3) the use of Monte Carlo calculations and sample parameters to calculate M, and
(4) measurement of the sample both with and without neutron reflectors to change M.

Methods (2)-(4) require an additional measurement on the sample and Method 1 requires improved electronics, data reduction, and detector characteristics. The relative accuracy and convenience of the above methods will be evaluated during the next few years. Work is in progress at Los Alamos on Methods (1)-(3). Method (4) was tried and abandoned after discouraging results.

For the present, Category C data should be fit to both the R and R_{mc} calibration curves obtained from similar standard samples. The calibration functions are the same as for Category B samples. The selection of which curve to use should be made on a case-by-case basis, depending on agreement with declared masses and experience.

A. Higher Moments Technique

In the higher moments approach, the time distribution of coincidence neutrons is evaluated for the multiplicity of the fission neutrons. When neutron multiplication takes place, the induced-fission events occur in the same time window (less than the gate length) as the birth of the original neutron that induced the fission. This multiplicity information can be used to give as many measured parameters (knowns) as unknowns.

Work in this area has been reported by M. Krick at Los Alamos using fast-neutron counting systems, by M. Zucker at Brookhaven,[12] with coincidence electronic modifications to count the third moment, and by Hage and Cifarelli[13] at Ispra, Italy.

B. Californium-252 Add-a-Source

The basis of the ^{252}Cf add-a-source approach is that the multiplication (M) in the sample can be estimated by placing a known source on the exterior of the sample and measuring the incremental multiplication of the ^{252}Cf source.[14] This requires an additional measurement with the source closely coupled to the sample can.

The procedure is to measure the sample in the normal way to obtain R and then to repeat the measurement with the ^{252}Cf source at the bottom of the can to obtain R(Cf plus sample). The totals rates also are obtained and the californium source is measured with no plutonium in the can to obtain R(Cf) from ^{252}Cf.

The parameter that can be related to the multiplication is

$$\frac{R(Cf + sample) - R(sample)}{R(Cf)} \equiv F$$

When multiplication is present, F will be in the range of 1.0-1.3 for PuO_2. In general, F will be less than the reals correction factor (CF) because the multiplication of a source positioned on the exterior of the sample will be less than the multiplication averaged over the volume of the sample.

A more sensitive way to look at F or M is to take the quantities $(F-1)\times 100\%$, and $(M-1)\times 100\%$, which give the percent change from the multiplication process. Figure 6 shows a plot of $(F-1)$ vs $(M-1)$ from a set of PuO_2 powders for masses up to 877 g of plutonium. The M values were obtained from the standard method (see Sec. IV) using R and T. The curve is almost linear until the fill height becomes greater than the diameter in which case the californium source on the bottom of the can is far removed from the added plutonium mass in the top of the can. As the fill height increases, M will increase faster than F because of geometric coupling differences.

This same type of analysis can be performed with the totals rate T rather than R. The T ratios are defined the same as for the reals ratio by

$$\frac{T(Cf + sample) - T(sample)}{T(Cf)} \equiv L$$

where L more closely corresponds to the leakage multiplication M.

The value of $(L-1)$ is about four times less than $(F-1)$ because the coincidence rates amplify the multiplication signal. In general, the T ratios have a very good counting precision, but $(L-1)$ is small and the variation in the totals room-background rates would add uncertainty in the measured L.

The relationship between F and M shown in Fig. 6 is dependent on the geometry of the sample container. Separate calibration curves for M would be required for each can diameter unless corrections are made for the changes in geometric coupling.

To get the plutonium mass, the add-a-source curve (Fig. 6) is used to obtain M, and the equations given in Sec. IV are solved for M_{240} and α.

This add-a-source method of determining M has the desirable feature that sample moisture effects on the multiplication are part of the measurement.

C. Monte Carlo Calculation of M

If the mass and size of the sample are known, Monte Carlo neutronic calculations can be used to determine M. The measured R and T values then can be used to solve for M_{240} and α to determine the total plutonium mass.

The values of M from Monte Carlo calculations[17,18] have been compared with M determined from the measured R and T rates for a large group of PuO_2 powders. A portion of these results[17] are shown in Fig. 7 for the same PuO_2 samples used in Fig. 6. The M values determined from the R and T rates depend on the value of the ρ_0 constant used in the equations in Sec. IV. The value of ρ_0 was increased from the normal value of 0.103 (HLNC-II) to 0.108 to get the agreement with Monte Carlo calculated curve shown in Fig. 7.

Normally, plutonium packages have a known size and shape so M can be calculated, but for powders, the fill height or density is uncertain, and methods are being evaluated to determine the fill height.

For many practical cases of plutonium scrap, the sample size is known but α is unknown and variable. In these cases, the relationship between M and the plutonium mass can be calculated as shown in Fig. 7.

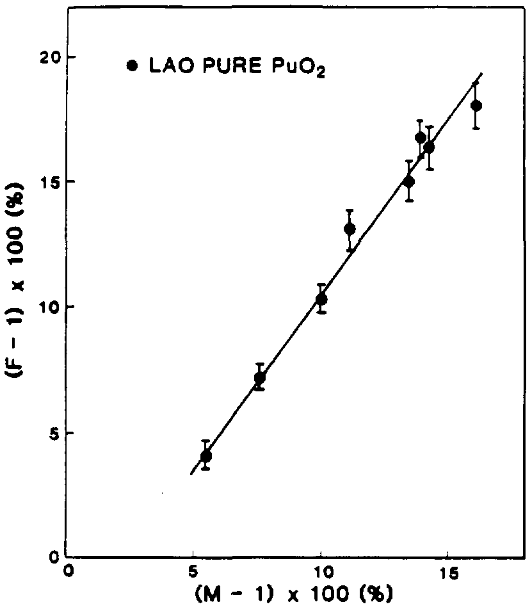

Figure 6. The percent change in the ^{252}Cf source response, (F-1)x100 vs the percent change in multiplication, (M-1)x100, for different PuO_2 masses.

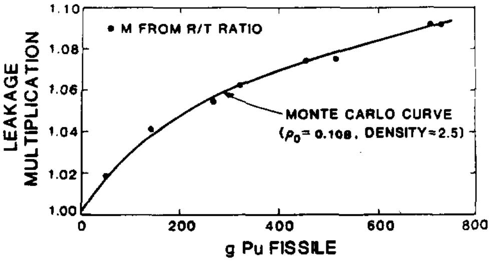

Figure 7. Calculated value of M (solid curve) using Monte Carlo code compared with M values from the R/T ratio (solid points) with $p_0 = 0.108$.

D. *"Known" M Approach to Assay*

Several methods have been outlined to determine M for assay samples. If M is taken as a known from calibration standards or supplemental measurements, then the plutonium mass can be calculated without knowing α.

The multiplication equations can be rewritten as

$$\alpha = \frac{M}{\frac{R/T}{\rho_0} - 2.074(M^2 - M)} - 1 \ , \tag{1}$$

and

$$M_{240} = \frac{\rho_0}{a} \frac{T}{(1 + \alpha)M} \ , \tag{2}$$

where a is the baseline calibration constant defined in Sec. IV.B ($a/\rho_0 = 176$ for the HLNC-II).

Thus, we can treat α as a variable and M as a known for the sample size. Because M is a nonlinear function of the plutonium mass (see Fig. 7), we must assume an initial value of M to solve Eqs. (1) and (2). This gives us a new plutonium mass and M, and the equations are iteratively solved until convergence. If M is set at unity for the first iteration, then convergence was reached in approximately four iterations for several test cases of bulk PuO_2.

This method of using the "known" M to solve for the mass is very attractive for samples with low-plutonium density because M approaches unity. For example, a can containing 0-200 g of plutonium in a 1-*l* volume will have M range from only 1.00 ~1.02 and the uncertainty in M is small.

E. *Reflectivity Change*

The principle of this approach is to change the reflecting boundary around the sample to vary M, R, and T but to keep α fixed. Potentially there are then enough knowns to solve the problem. However, intial experiments at Los Alamos have indicated that the change in M is small and the value of ϵ changes, introducing a new variable. If thermal-neutron reflection is used, then M changes substantially, but the sample surface area becomes an additional variable. This approach has been used successfully for fixed geometry samples such as fuel assemblies.[15]

VI. HIGH-ACTIVITY SAMPLES — CATEGORY D

For samples with very high (α,n) neutron rates, the induced-fission counting rate R(IF) will normally dominate the spontaneous-fission rate R(SF). Typical samples in Category C incude PuF_4 and plutonium salts.

In this case, where essentially all of the induced fissions are from (α,n) neutrons, the measured rate can be expressed as

$$R = R(IF) + R(SF)$$

and

$$T \simeq T(\alpha,n)$$

where T(α,n) is the totals rate from (α,n) neutrons.

The induced-fission rate in the sample is proportional to the neutron flux and the mass of fissionable material in the sample. The ratio of R(IF)/T is proportional to the fissionable mass in the sample.

This self-interrogation approach has been applied to bulk (1-16 kg) UF_6 samples[21] and more recently to high-activity plutonium salts.[22] For the plutonium salts, the precision is about 2-5% for a 1000-s measurement, and for UF_6 cylinders of HEU the precision is better than 1% in 300 s. This self-interrogation approach requires that the calibration standards have a geometry that is similar to the assay samples or that calculated coupling corrections to be made to the data.

VII. SUMMARY

The primary goal of this paper is to give procedures for reducing errors and extending the range of neutron coincidence assay. A key to accomplishing this error reduction is to separate the samples into Categories A-D, and to apply the standard multiplication correction for Category B. More sophisticated correction procedures are described for Categories C and D, and no multiplication corrections should be made for Category A samples.

Table V

Sample Categories and Calibration for Neutron Coincidence Counting

Fuel Category	*Characterization*	*Calibration Parameters*[a]	*Calibration Function*
A	Small Samples	R vs M_{240}	Near Linear
B	Pure and low moisture samples (variable M, calc. α)	R_{mc} vs M_{240} (primary)	Linear
		R vs M_{240} (secondary)	Quadratic
C	Impure and/or moist (variable α, calc. or measure M)	R vs M_{240} R_{mc} vs M_{240} M vs Pu	Quadratic Linear
D	High-activity salts and ^{241}Am (variable α)	R(IF)/T vs Pu fission	Nonlinear

[a] R_{mc} corresponds to the reals rate after multiplication correction.

Table V lists the materials categories and recommended calibration functions. The traditional approach of calibrating with R vs M_{240} is appropriate for Category A materials, but is inadequate for the other categories. Category B materials can give very accurate results (0.5-1.0%) after multiplication corrections. The data reduction is making use of the totals rate, so more care is required to measure T accurately. A short ($\sim$10 − s) room-background measurement is desirable before and after the sample measurement to improve the accuracy of the room-background subtraction, and for in-plant counters, exterior neutron shielding will help.

Methods to improve the accuracy of Categories C and D materials are under development and progress has been made for specific cases such as PuF_4 and samples with a predictable value of M.

For neutron coincidence counting, the challenge to reduce the biases is great because of the wide range of sample types. The sample masses range from 10^{-3} to 10^4 g of plutonium, and sizes vary from small pellets to crates and barrels. Improvements in electronics and data reduction hardware and software will expedite the transfer of the technology to the plant environment.

ACKNOWLEDGMENTS

The author is grateful to N. Ensslin, M.S. Krick, P. Rinard, and J.E. Stewart for their assistance in the work described in this report. M. Aparo from Cassacia, Italy contributed to the neutron add-a-source method and calculational work and is continuing in this area in Italy.

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Intelligent Knowledge-Based Near-Real-Time Materials Accountancy

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ABSTRACT

An intelligent knowledge-based systems approach to the analysis of near-real time accountancy data is proposed. One of the keys to building a sucessful system is in representing knowledge in an appropriate manner, another is in the merging of the information from statistical tests with that obtained from experience. A multi-layered inference mechanism incorporating the statistical test, a plant simulation and a number of heuristic searches are recommended.

INTRODUCTION

Near-real-time materials accountancy (NRTMA) as applied to reprocessing facilities involves two major elements, the measurement or estimation of material transfers and the in-process physical inventory at frequent intervals and the evaluation of the resulting sequential material balance data. Various NRTMA systems have been installed at a number of plants over the last decade (e.g. References 1-3) and a large number of statistical tests have been developed to analyze the resulting balance data (Reference 4). Published information as to the performance of these systems is limited although there are indications that sufficient practical experience has been gained to encourage the revision of the "untried" statistical tests (References 5-6). In addition the information made available has provided plant management with an increased assurance that the plant is operating to flowsheet.

One undeniable conclusion to date is that operating such systems is resource intensive. Russell et al report in Reference 5.

> "Experience in evolving and operating an NRTMA system on real plant, on a daily basis, shows that it is extremely difficult to produce complete 'same-day' data before the next period is under way. Laboratory analyses may be reported up to 3 days later, small quantities of wastes may only be removed and measured at intervals, operator errors arise in the data collection system which have to be identified and resolved, some irregularity in operation may have occurred requiring investigation etc. A preliminary materials balance will be formed as soon as practicable if necessary making use of quick analyses performed for operational purposes. Simple MUF and CUMUF plots can be very useful, at this point, in monitoring the plant account and in helping to detect and resolve any accountancy or operational problem that may have arisen. The final data and associated materials balance may be derived 2 or 3 balance periods later."

Although it may be argued that a large part of this activity may be automated by installation of an appropriate data acquisition system, the nature of the operation still necessitates the intervention of an experienced analyst. A straightforward data acquisition system which simply collects data, forms materials balances and tests the resulting sequence lacks the flexibility needed to cope with the numerous irregularities that might arise.

A high degree of skill is required to perform a task which could only be described as being both time consuming and monotonous. In addition the arrival of data for subsequent periods and the need for timeliness impresses an immediacy on the situation with the net effect that minor anomalies may be ignored in the hope that they will correct themselves. This is unfortunate because opportunities may be lost to correct systematic errors. For instance there may be sufficient information available to not only suggest that an error exists in the derivation of the physical inventory of a particular plant but also help rectify it.

The question must also be raised as to the safeguards inspector's role in these activities. His objective is the timely detection of diversion of significant quantities of nuclear materials, not the day-to-day operation of the plant. He would prefer not to digress into detailed scrutinies of individual measurements but how can he verify that individual materials balances are being formed correctly? Does the need for timeliness require this anyway?

The intelligent knowledge-based system proposed here could ameliorate these problems. Specifically it should reduce the workload, improve the detection and elimination of anomalies, help to identify and eliminate systematic errors, help clarify the detailed activities of the inspector and to some extent be self-verifying.

Finally, note that the term "intelligent knowledge-based system" has been used as opposed to the term "expert system" which may be more familiar. This is to emphasize that the approach adopted is more flexible than would normally be envisaged for an expert system. The next 2 sections attempt to clarify this point.

GENERAL BACKGROUND

Expert systems are currently attracting a large amount of interest and activity (e.g. Reference 7). Briefly, the purpose of an expert system is to enable the user to emulate some aspects of a single or group of expert's problem-solving behavior within some domain of expertise. The distinguishing feature of an expert system is the requirement that the domain-specific knowledge is represented separately from the programs which carry out the inference.

The knowledge base may therefore be increased incrementally. As more knowledge is acquired it may be added to the knowledge base without disrupting what is already there so long as consistency is maintained. In this way, the knowledge may be refined and tested. This is a particularly useful feature when the plant is complex enough to suffer rare faults i.e. those which occur so infrequently that perhaps only one accountant has encountered that fault before with recollection. Data of the detection and diagnosis of these conditions may be added to the knowledge base, thereby accumulating a very valuable record of expensive and probably time-consuming occurences.

An expert system can therefore readily capture one expert's knowledge or experiences from one campaign, combine it with the total knowledge accumulated over previous campaigns and make it available to perhaps a new accountant starting on the subsequent campaign. The odd peculiarity within a particular campaign can then be retained and made available when required. This should be particularly useful to the various nuclear safeguards inspectorates who may have a relatively high turn-over of plant-based staff.

Another very important feature of expert systems is the ability to explain their own reasoning, thereby justifying their conclusions. The simplest form of explanation is to provide a listing of all the rules that have been triggered on the way to a conclusion. Again this information will be of particular interest to the inspector who would require such a justification before taking any action.

The content and complexity of the domain which is to be represented within the expert system influences the inference methods and the knowledge representation techniques which are appropriate. The simplest and most widely proposed method for representing knowledge is with If-Then production rules, for example

> "If the accountancy tank has just been emptied then the level in the plant feed tank should be greater than 1m."

A large number of these rules can be strung together to relate observed signals to implied underlying causes and faults. Such systems tend to lack depth because although terms like "empty" and "full" can be quantified the relationships between the various plant components do not represent the mechanism by which these rules are obtained; the underlying physical relationships have been eliminated from the description. Such rules are often called "surface heuristics."

Figure 1 shows an example of a number of surface heuristics that have been strung together. These are based on the well known NRTMA heuristic,

> "if there are approximately equal but opposite signed MUF's on two consecutive balance periods then there is probably an error in the physical inventory balance data on the first period or a transfer may be attributed to the wrong period."

KNOWLEDGE-BASED SYSTEMS FOR NRTMA

NRTMA on the other hand is firmly based on something which is both quantifiable and physically meaningful, the materials balance (MUF) statistic X_n:

$$\text{measured MUF} = \hat{X}_n = \text{Book Inventory} - \text{Physical Inventory}$$

$$= (\hat{Y}_{n-1} + \hat{U}_n) - \hat{Y}_n \quad \text{\_\_\_\_\_\_\_\_\_\_}(1)$$

where $\hat{U}_n$ - measured net transfer during period n

$\hat{Y}_n$ - measured total inventory during period n

All measurements, whether they are made for purposes of conventional accountancy or not, are subject to 3 basic types of error, random, systematic and transcription; in addition, plant measurements may be erroneous because of operational constraints or other types of error which tend to be plant specific. The problem of inferring whether

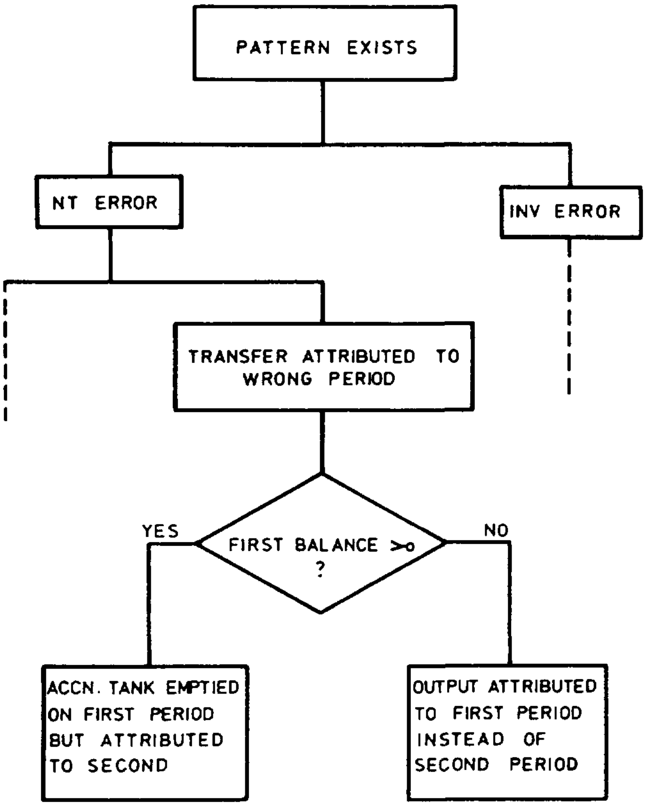

Figure 1. Some typical rules.

an MUF has arisen and if so, of diagnosing whether it is explainable in terms of plant operations or whether a diversion has actually occurred must therefore be based on information which is both quantitative and highly structured.

That is not to say that the surface heuristics described previously are now of no use, but that they can be augmented by something else. Research into the application of Artificial Intelligence techniques to such structured problems is now well-established (References 8-10) with theories of, for example, qualitative modelling and disrepancy detection being propounded. A central feature of such theories is simulation and in particular quantitative simulation. The conventional problem solving approach is to analyze a mathematical model of the physical process assuming that it is correct (or bounded in some way); qualitative simulation attempts induce if-then type rules from the same mathematical model. For instance the "equal but opposite" rule described previously is derived from the materials balance given by Equation 1.

There are few pre-defined objectives as to what the simulation is to achieve. The system may first want to examine the flow of material through a particular MBA on a particular period. It may then want to examine a sub-MBA or 2 MBA's together or the calculation of the physical inventory of a particular plant component in detail and so on. The system therefore requires a sufficiently flexible plant representation to achieve this. One approach to providing this flexibility is known as object oriented programming (Reference 11).

The flexibility of such systems is often denoted by reserving for them the term Intelligent Knowledge-Based System. Their "intelligence" is derived from the flexible way in which the knowledge may be manipulated. With the aid of different inference mechanisms and different parts of the knowledge, such systems can be developed to cope with a whole spectrum of tasks. In addition, the entirety of the plant may be kept in perspective, so that the propagation of a fault throughout a plant may be detected.

CENTRAL CONCERNS

Before embarking on a general description of the system it is worth specifying its main concerns.

The intelligent knowledge-based system should be developed on the basis of a number of fundamental principles:

The system must NOT be able to update the NRTMA database.

The purpose of the system is simply to alarm that an anomaly has arisen and advise the accountant of its whereabouts. A thorough investigation will be required before the database is updated.

By definition the system must make as much use as possible of the current way of doing things.

The accountant combines an analytic approached based on statistical tests like MUF and CUMUF with a more heuristic approach which includes a mental simulation of plant activity during the period in question. One of his main objectives is to check for consistency. He does not work solely at one level; he may simultaneously infer something by applying the statistical tests, mentally checking that the plant has been operated in a particular way, examining the measurements being collected from a "suspect" tank and so on. He may resort to back-of envelope techniques, heuristics or even complicated mathematical models. An important aspect in the design of an intelligent knowledge-based system is therefore to ensure that such a picture may be built-up, contradictions can be explained and information can be properly weighed-up. A great deal of hard facts like calibration tables must be incorporated into the system as must heuristics like

> "if a particular physical inventory is in error on period i but that inventory is not taken until r periods later then the reflection anticipated on the MUF plot will not occur until r periods later."

Candidate generation must be carried out at various levels.

An anomaly may first be detected by applying one of the statistical tests. Alternatively a discrepancy may be found between various pieces of information gathered. The symptoms could indicate a bias in the net transfers or a positive/negative error in the physical inventory of a particular plant component or even an individual measurement could be singled out. Indeed more than one option may be possible.

If an individual measurement is not isolated then the system must analyze the information that has been gathered so that possible candidates can be generated to explain the phenomena observed. Initially it may not be possible to pin-point one or more particular measurements, for instance the measurements from one or more plant components may be thought suspect. These components must then be analyzed in detail to generate possible measurement candidates.

The system should seek a minimal amount of additional information.

The purpose of the system is to save the accountant effort. It will not be very popular if it asks the accountant to check the analysis of some obscure tank which is obviously irrelevant to the investigation. The first request for information must be close to the final solution.

The problem of complexity versus completeness must be overcome.

To be effective, all plant components must be considered. If each component is given the same weighting then candidate generation will become indiscriminate; this will result in a large number of requests for additional information. Yet omitting any component could have a greater effect on the system's capability than would outwardly seem possible. One technique for dealing with this dilemma is enumerating and layering the categories of anomaly. As experienced accountants know, some things are more likely to go wrong than others. A list of "categories of anomaly" can be drawn-up and the most likely can be assessed first, the less likely categories only being applied in the face of contradictions.

The system must learn.

One of the main justifications for developing such a system is so that the experience gained in any campaign can be stored for posterity. The system must therefore be able to communicate with the accountant in a reasonable manner so that this experience can be induced into the knowledge base. This poses considerable problems if the earlier problem of complexity versus completeness is to be overcome.

The conclusions reached at the end of one campaign should be made available to the system at the start of the next campaign. For instance it is quite possible that information during more than one campaign may be needed to confirm a particular systematic error. Statements like

> "we had this feeling that the technique for determining the volume in tank 22 was in error but couldn't be more precise"

can be quantified and tests designed to focus on this particular issue. The system must therefore be able to adapt to the needs of the day!

The system must be able to cope with random errors.

The above approach would be relatively straightforward if it were not for the additional problem of random errors. Such errors are largely irrelevant during the initial analysis of the data; the MUF's that the accountant is trying to investigate are usually in excess of 2x the standard deviation of the random error. The system should therefore initially tolerate large margins; these can be reduced during the later stages of the analysis.

INFERENCE

The current statistical approach to the analysis of NRTMA data defines the net transfer and total MBA physical inventory data as being the base information. (The measurement errors associated with this data may be multiplicative in nature and hence require information pertaining to the individual components but this is secondary to the issue here.) A great deal more information than this is required to isolate a particular problem. Information about both the structure and behavior of the plant must be represented and all the individual plant measurements may be of interest. The term structure is used to refer to information about the interconnection of the plant components both in the plant proper and in the laboratory facilities supporting it; behavior relates to the black box description of a component e.g. given a task with analysis a, and change in volume, ΔV and with x kg/period of material M flowing into it what is its output during the period?

As explained previously, there are a number of levels of decision making which can be carried out both concurrently and sequentially:

level 1 — apply various statistical tests to the sequential material balance data to alarm the incident. If an alarm does arise then attempt to resolve whether a problem really exists or whether, for instance, a plant measurement is missing. If there is cause for concern, try to decide whether the problem is with the key measurement points or with the physical inventories. If possible identify a particular plant component.

level 2 — detect any discrepancies by performing a simple plant simulation.

level 3 — carry out a detailed investigation into the individual plant components and laboratory instruments.

A different form of inference mechanism is required at each of the 3 levels and some possible approaches will not be considered. For clarity it will usually be assumed that only single losses/operational errors can occur and that only the MUF test is available to detect these occurences. The same mechanisms would be used for other incidents, the knowledge base would just be larger.

LEVEL 1: APPLICATION OF STATISTICAL TESTS

The various statistical tests can be applied to the sequential balance data on each period up to and including the current period. As each period (n) is evaluated, the following list of information can be written on what is known as the blackboard

$$(n\ \hat{Y}_n\ \hat{U}_n\ \hat{X}_n\ S_n\ T_n\ G_n)$$

where

S_n is the score obtained by applying the various tests on period n

T_n is a boolean which indicates whether the data for that period is complete

G_n is the generation of the data collected during period n (this is used to indicate whether or not the data for that period is identical to that in the NRTMA database; the system may wish to look at e.g. a case with a loss scenario being hypothesized instead).

The score is a device invented to enable the candidates to be ordered so that either the most serious or the most likely possibility can be considered first. The scale of the score must be the same at all levels. The choice of scoring system is one of the key issues in building expert/intelligent knowledge based systems. If the scale of the score at level 1 is chosen on the assumption that the accountant intuitively resolves to $0.5\sigma_n$ and if only the simple MUF test is applied,

then letting $S_n = 2.\dfrac{X_n}{\sigma_n}$

will result in an alarm for $|S_n| > 4$

(σ_n is the standard deviation of the random measurement error associated with X_n).

Note that the tests are applied on *ALL* periods irrespective of whether or not the data is complete. (The system will estimate any measurement that is not available.)

Each of the periods, n: $|S_n|>4$ are examined starting with the period with the largest $|S_n|$. (If $|S_n|$ on the previous period is similar then the order is reversed so that the previous period is investigated first.) The blackboard is first checked to see whether the data for that particular period is complete. If a measurement has had to be estimated, the accountant will be informed and asked to confirm its validity; a revised estimate can be input where necessary. The results obtained by applying the statistical tests are then interpreted. For instance, heuristics that describe the effect of a physical inventory measurement error on the MUF plot can be applied at this time. The application of each heuristic generates a number of scores; for instance they may quantify the possibility of an anomaly arising in those measurements that relate to the net transfer and/or quantify the possibility of an anomaly arising in the total physical inventory for the period in question. In addition scores can be generated for other periods. Again all these scores are written on the blackboard.

It is widely accepted that there is considerably more information in, for instance, the standard MUF or CUMUF plot than just whether the test has alarmed or not. Operators can correlate plant incidents with trends in the plots and so on. These correlations are fairly qualitative; a typical heuristic may be

> "if material only gradually 'disappears' when a particular tank is filling then it is likely that its inventory measurement is at fault!"

Less detailed information is used here than in the plant simulation at level 2. However the flexibility obtained in an IKBS enables any level to access the overally knowledge base so that level 1 will simply use a subset of the knowledge acquired primarily for level 2.

It is important to note that the investigation need not be restricted to the analysis of the sequential balance data for a single MBA. Heuristics pertaining to the movement of material between MBA's can also be applied. For instance, heuristics can be based on the principle that if 3 materials balances are formed for 2 MBA's ordered in sequence (the third balance is across both MBA's) then this information can be used to discriminate between an error in the input and an error in the output of the MBA under scrutiny. The physical layout and operation of the plant may also allow the division of the MBA into sub-MBA's. (Reference 6) It may then be possible to treat a particular plant component as a key measurement point so that a bias in that particular component may be detected.

Statistical correlation techniques may also be applied. For instance, Kalman filter techniques have been developed (References 6 and 12) which can alarm an error in a particular key measurement point provided the plant is operated in an appropriate manner.

LEVEL 2: DISCREPANCY DETECTION

Neither is it possible nor necessary to specify the optimum approach to the detection of discrepancies. One of the main features of such a system is that it must be programmed in such a way so as to be able to adapt with experience. The computer framework is a key to this and this is very much an area of research. The prototype system being developed at the University of Glasgow will be briefly described here to give some insight into the type of system envisaged.

The plant that is currently being simulated is shown in Figure 2. A number of duplicate tanks (e.g. 2 evaporator feed tanks) are included to study the effect of creating separate sub-MBA's. The only other information required is a descripton of operation including details of which tanks were being filled/emptied and so on. At present the simultation does not take measurement errors into account; an inference mechanism capable of dealing with this level of complexity is under development.

It is important to realize that Level 2 can only detect discrepancies within the MBA i.e. it must assume that the material specified as having been transferred into and out of the MBA is correct (within random measurement error tolerances).

Starting with the accountancy tank and working down the plant, the operation of each plant component is examined. The component's closing physical inventories on both the previous and current periods are first confirmed as being reasonable. All individual measurements are checked as well. This is achieved by applying either pre-determined (and therefore conservative) upper and lower bounds or by calculating limits on the basis of heuristic or mathematical models which may take additional plant measurements into account.

Any component specific heuristics either generated from previous campaigns or "commonsense" are now applied.

The amounts of uranium (U) and plutonium (Pu) output from the component during the period in question are then calculated. These two outputs are written on the blackboard and used to calculate the outputs from components further downstream in the plant.

At this stage the outputs are only examined for consistency with the period of operation,

i) if the tank was non-operational then no output should occur

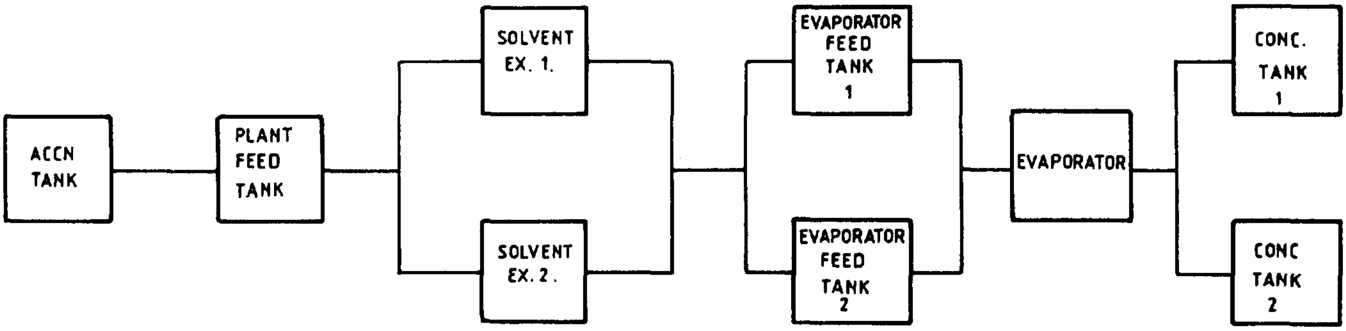

Figure 2. Plant layout.

ii) if the tank was operational throughout the period then an output of between a kg and b kg should have occurred — values for a and b can either be pre-determined (and consequently conservative) or derived from plant data (if available) or based on previous operational experience

iii) the ratio of U to Pu should be consistent

Once each component has been considered the simulation is repeated but this time starting from the concentrate tank end and calculating the inputs to each of the plant components. These alternative estimates for the outputs (from the previous component) are also added to the blackboard.

Tests can now be applied depending on the number and location of the inventory anomalies thought most likely to exist. For instance, a different test will be formed to determine whether there is an anomaly in the laboratory instrument that analyzes liquor from tanks A, B and C. Clearly the simplest fault will be hypothesized first; more complicated scenarios can be hypothesized if necessary.

To give an idea of the type of test that can be applied. Consider the test to detect a single anomaly (e.g. a transcription error) in one of the number of components arranged sequentially. It can be shown that if the physical inventory of each component is calculated on the basis of the inputs and outputs derived above then the only inventory that will be correct (i.e. not erroneous) is for the anomalous component itself. The test therefore reduces to comparing the measured physical inventory with the calculated physical inventory; only the anomalous component should "show a preference" for the calculated value.

LEVEL 3: INVESTIGATION OF INDIVIDUAL PLANT COMPONENTS AND LABORATORY INSTRUMENTS

That plant component or laboratory instrument most likely to be the source of the error is examined first. The component may be chosen on the basis of information obtained at levels 1 and 2 or from previous experience. Indeed it is difficult to separate out level 3 activities from the others. For instance, level 2 could detect that the U analyses for tanks A, B and C are in error on periods n onwards thus indicating that a particular laboratory instrument is operating normally. Level 3 is there to decide whether and why this could happen. To some extent the intention is to mimic the maintenance engineer who would call for re-calibration etc.

VERIFICATION

The considerable number of consistency checks carried out on data collected within the MBA coupled with the system's ability to explain its reasoning for alarming makes it harder to divert material from within the MBA. The system is largely self-verifying. However, it is unlikely that the system will be able to detect a falsification of the data at a key measurement point even if the odd inter-MBA (i.e. shipper/receiver) test can be applied.

The system should result in a considerable reduction in the workload for the safeguards inspector especially if he is the only person authorized to alter the NRTMA database. Then all the anomalies together with the system-generated explanations will have to be screened by him.

INCORPORATING EXPERIENCE

The knowledge-base can be amended in a number of ways. The most obvious way is in the addition/subtraction of heuristics and experiential knowledge. The aim is to program these rules in something approaching natural language so that the accountant can readily alter them.

A more subtle way is to adjust the various scores in the scoring system. At installation, the intention is to initialize the system with a score attributed to each plant measurement and heuristic, the value of which is chosen on the basis of its likelihood to be associated with a problem. These values can then be up-dated on the basis of experience gained during each campaign. By doing this the evidence about, for instance, systematic errors can be seen to accumulate. The means of doing this have been a subject of research for the past 20 years (e.g. in chess playing); however an algorithm has still to be developed specifically for NRTMA.

IMPLEMENTATION

Intelligent knowledge-based systems have been developed in a variety of programming environments but most of the features are most effectively handled by symbolic processing. The system described here is being programmed in VAXLISP (a version of Common Lisp-Reference 13) on a DEC VAX 11/750. However it must be stressed that the primary objective is to demonstrate the feasibility of operating an intelligent knowledge-based near-real-time materials accountancy system. The programming task is essentially just used to generate, focus and clarify ideas.

CONCLUSIONS

It is generally accepted that a high calibre of accountant will be needed if a near-real-time materials accountancy system is to perform effectively in a reprocessing facility. He must be able to build on experience gained in previous campaigns and be prepared to spend a considerable amount of time investigating plant irregularities. The intelligent knowledge-based systems approach proposed here could provide a valuable technique in this situation.

One of the keys to building a successful system is in representing knowledge in an appropriate manner, another is in the merging of the information from statistical tests with that obtained from experience. A multi-layered inference mechanism incorporating the statistical test, a plant simulation and a number of heuristic searches is recommended.

Although in its infancy, the development of such a system appears promising.

ACKNOWLEDGEMENTS

The author would like to thank Mr. F.J. Walford, NMCO, UKAEA Harwell and Mr. T.L. Jones, UKAEA Dounreay for their useful comments.

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John Howell graduated with a B. Eng. in Control Systems in 1975 and subsequently joined the Control and Instrumentation Division of UKAEA. There he spent the next nine years working on various aspects of the Fast Reactor Project, both in power generation and in fuel fabrication and reprocessing. In particular, he was responsible for the development and installation of a near-real-time nuclear materials accountancy system in a fuel reprocessing facility. In 1984 he joined the Department of Mechanical Engineering, University of Glasgow. He is now researching into the application of intelligent knowledge-based systems.

Development of Containment and Surveillance Equipment at JAERI for International Safeguards

■
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■

ABSTRACT

C/S equipments have been developed at JAERI for IAEA use. This paper presents the recent developments in the following equipments:

- *Electronic Verifier of COBRA Seal*
- *Compact CCTV Surveillance System*
- *Portal and Penetration Monitor for FCA.*

The electronic verifier reads and digitizes the seal patterns electronically. Comparisons can be made by calculating correlation coefficients between the digitized patterns, one to be verified and the reference taken when the seal was initially installed. The experimental results obtained with the prototype equipment have demonstrated that the electronic verifier provides a simple and accurate quantitative measures for COBRA seal verification.

The compact CCTV system has been designed as a potential replacement of the Twin Minolta of the current IAEA use. It can store 30,000 video pictures for a three month period by battery driving. The novel one-shot 8mm VTR has been developed for this system.

The FCA portal and penetration monitor is the comprehensive C/S system and has been developed based on an unattended scheme. The system was completed at the end of 1985. The field trial operation jointly by IAEA, the state and JAERI will be started soon to obtain performance data under the actual conditions of facility operation.

1. INTRODUCTION

The number of safeguards-related facilities has been increasing while the IAEA has been facing budgetary limitations. Under these circumstances, containment and surveillance (C/S) measures become increasingly important. While various developments in C/S equipments and techniques have continued in many institutions, some of the conventional devices have become older and need replacement. The development of *in situ* verifiable seal as a replacement for the metal cap seal (Type E and Type X seal), and the video surveillance device as a replacement for the Twin Minolta system are highly requested.

The development of the portal and penetration monitor system for the fast critical facility FCA of Japan Atomic Energy Research Institute (JAERI) has been completed. The field trial operation of the monitor jointly by the IAEA, the state inspection authority and JAERI is to be initiated soon. The developments of the electronic verifier of COBRA seal and the video surveillance device have been started based on the experience obtained in the portal monitor development.

2. ELECTRONIC VERIFIER OF COBRA SEAL

2.1 The COBRA seal

A few ten thousands of metal cap seals (Type E and Type X seals) are in routine IAEA use. These seals are removed during an inspection visit and returned to the IAEA headquarters for verification. This process results in a delay in verification and resolution of anomalies. An *in situ* verifiable seal eliminates this delay and provides timely information for the operator and the inspectors to resolve anomalies during an inspection visit. The *in situ* verification also permits the repeated use of the same seal without its being removed for verification and thus provides a considerable savings in effort as compared with that required for conventional sealing, sampling, replacement and subsequent verification at the IAEA headquarters.

The COBRA seal has been developed at Sandia National Laboratories as the *in situ* verifiable sealing system. The system consists of fiber optic loop with seal body and a seal pattern recorder/verifier. Among the newly developed seals for IAEA use, the COBRA seal is the simplest and the lowest in the cost as a potential replacement for the Type E seal. The details of the COBRA seal are described elsewhere[1]. The seal pattern is photographed by the seal recorder/verifier. Visual verification by photograph overlay comparison is a very effective and accurate method under normal circumstances. However, when the number of seals is large, or the quality of two photographs is different, or the quality itself is poor, as is often the case with film processing, the human eye/brain comparison will be faced with ambiguous judgement. This leaves the inspector a subjective judgement. To solve this problem, development of a simpler and quantitative means for the in situ verification has been desired.

Taking into consideration the appropriate features of the COBRA seal as a replacement for the Type E seal and the necessity of easier approaches of *in situ* verification, development of the electronic verifier of the COBRA seal has been initiated at JAERI. The electronic verifier may also enable the concept of a joint or common seal between the IAEA and the state inspection authority.

2.2 Development of an electronic verifier for the COBRA seal

Prototype Verifier

The design of an electronic verifier is based on the following considerations:

- in situ verification
- Simple and quantitative means for verification
- Low cost and portable equipment

The practical ways of electronic image generation and pattern recognition were investigated using the bread-board unit and a reliable technique was developed. Based on this technique, the prototype unit of an electronic verifier has been built. The prototype electronic verifier is shown in Fig. 1. This equipment consists of the following items:

1. Probe, to view the seal pattern. The seal body is inserted into a viewer receptacle. In the receptacle the one end of the seal loop is illuminated and light traverses uncut fibers to the other end of the loop, then the unique pattern is produced by the uncut fibers. The seal image is transferred to a CCD (charge coupled device) camera via a flexible image fiber guide.

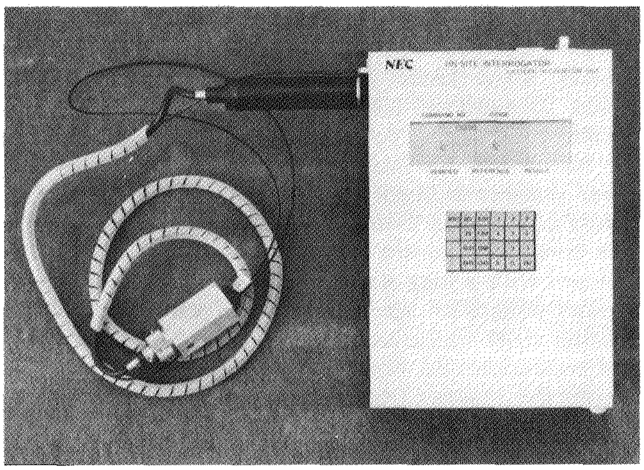
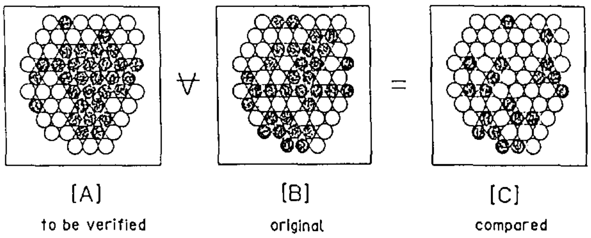


Figure 1. Prototype electronic verifier of COBRA seal.

2. Pattern Detection Part, to generate the image of a seal pattern. The video signal from the CCD camera is sampled (sample points; 48x48) and digitized.
3. Memory, to store the digitized pattern temporarily. Memory (A) stores the digitized pattern to be verified and Memory (B) stores the original patterns which are transferred from the auxiliary memory. The memory capacity is 40 patterns.
4. Auxiliary Memory, to store the digitized reference patterns on a compact floppy disc with the capacity of 200 patterns for later use. Prior to the inspection, the patterns of concerned seals are transferred from the disc to the memory (B), then the disc unit is unplugged.
5. Processor and Comparator, to calculate the correlation coefficients between the digitized patterns.
6. Display, to display the correlation coefficient along with two patterns on the liquid crystal display board.

The concept of the pattern comparison and the calculation of the correlation coefficient is illustrated in Fig. 2.



COMPARISON $A_i \forall B_i = C_i$

i: bit number
$\forall$: exclusive "or"

$C_i = 1$ if A_i or $B_i = 1$
$C_i = 0$ if $A_i = B_i$ (= 1 or 0)

Correlation Coefficient K

$$K = \begin{cases} 1 - \sum_i C_i / \sum_i A_i & \text{if } \sum_i C_i / \sum_i A_i < 1 \\ 0 & \text{if } \sum_i C_i / \sum_i A_i \geqq 1 \end{cases}$$

Figure 2. Comparison of patterns and calculations of correlation coefficients.

2.3 Experimental results obtained with the prototype verifier

The seal patterns have been compared for 35 seals of various lengths ranging from 10cm to 1m. The results of the measurements are as follows:

1. Uncertainty of the electronic data processing

   Each seal pattern was compared ten times with its reference while the seal was kept inserted into the receptacle. The average correlation coefficient was *0.95 ± 0.02* for the 350 data.
2. Reproducibility of positioning of an image to the CCD camera

   The position of the image focused on the CCD sensor will be changed slightly due to the mechanical looseness at the seal receptacle. Each seal was repeatedly inserted to and ejected from the receptacle and the correlation coefficients were measured. The change of correlation was less than 4% for 350 measurements. The effect of the looseness of the other part of the optics system was found to be about 4%. Combining these uncertainties, the total 6% uncertainty in the correlation coefficients is caused by the looseness of the optical connection.

3. Correlation coefficients measured

A histogram of correlation coefficients obtained by repeated comparisons of the same seal and of the different seals is shown in Fig. 3. The repeated comparisons of the same seal (auto-correlation) are highly correlated while the patterns of the different seals (cross-correlation) show little correlation. The difference in correlation coefficients between auto- and cross-correlation is large enough for inspectors to definitely decide the acceptance or non-acceptance of the seal.

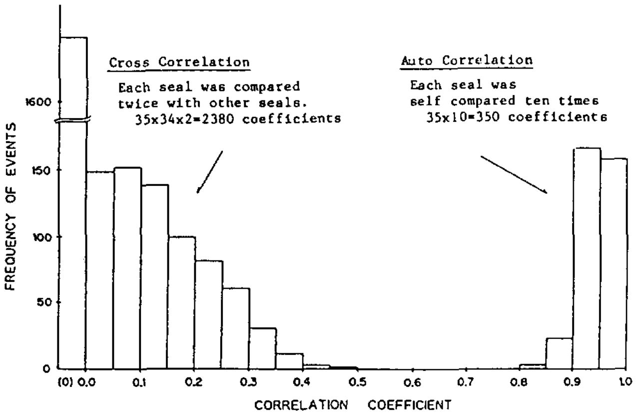


Figure 3. Distribution of correlation coefficients of pairs of patterns for 35 COBRA seals.

2.4 *Summary*

The experimental results have confirmed that the electronic verifier is sufficiently promising and provides a simple but unambiguous quantitative means of COBRA seal *in situ* verification. The digitized patterns can be plotted and this provides the means of visual comparison when it is desirable for redundancy.

The modified model is being designed to improve the reproducibility of an image on the image sensor and to reduce the size and the weight of the verifier body.

3. COMPACT CCTV SURVEILLANCE SYSTEM

The Compact Surveillance Monitoring System (COSMOS) has been designed as the ultimate replacement of the Twin Minolta camera system. The design philosophy is the following:

- Compact and portable configuration
- Ultra low power consumption
- Battery driving for three month period to reduce intrusiveness
- Picture capacity of 30,000
- Low cost

A conceptual drawing of a completed system is shown in Fig. 4. The COSMOS consists of:

1. a charge coupled device (CCD) camera
2. a rotary shutter in front of CCD
3. a time code mixer
4. a modified 8mm video tape recorder
5. a system controller
6. a battery.

A set-up unit and a miniature video monitor are provided for use in initial system installation.

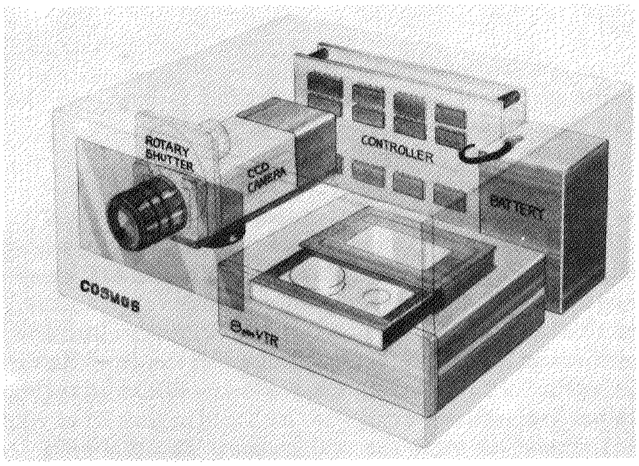


Figure 4. Conceptual drawing of COSMOS (Compact Surveillance Monitoring System).

Since COSMOS is designed as a replacement for Twin Minolta, intrusiveness of its installation to a facility should be equal or less than that of Twin Minolta. Therefore the battery power supply and compactness are key features of COSMOS design. Timeliness goal for power reactors is three months, but for changing the battery and film in Twin Minolta, the inspector visit is once every two months. The application of C/S devices equipped with a long standing battery and large enough capacity of data storage will lead to the reduction of inspection visits which are just for battery replacement or data collection and otherwise are not required. Considering these facts, COSMOS is designed as the system of battery driving for a period of three months.

For a device whose power supply is only a battery of reasonable capacity, power consumption should be very low. The power consumption rate of a conventional time-lapse video tape recorder (VTR) which is used in a video surveillance system is about 50W — too high for our purposes. Consequently, the development of a special VTR has been initiated using a conventional 8mm VTR.

In our new VTR, a video recording head rotates with 1/8 speed of that of a conventional one, and tape speed is also slower. During non-recording period, every component except the system controller is switched off. By the random time interval base, the controller activates the whole system, then the rotary shutter is opened for 1/30 sec. The video recording head of VTR makes only three turns and one still video image on the CCD is slowly read out and recorded on a tape during these three turns. Then the system is switched off within 2 seconds of activation. Time and date are annotated on video signal. Estimated power consumption is 150WH for 30,000 pictures recorded over three months with the application of this novel VTR and the on-off system control.

A good quality picture was demonstrated using the breadboard VTR built to confirm the one-shot VTR concept. A prototype of COSMOS will be built by the end of 1986 and a field test will be carried out to obtain performance data for later improvement.

4. PORTAL AND PENETRATION MONITOR FOR FCA

4.1 FCA from the safeguards viewpoint

The fast critical facility FCA of JAERI possesses a large inventory of fissile material in relatively pure form by experimental requirements. Moreover, the fact that these nuclear materials are clean, virtually unirradiated, accessible and easily handled poses unique safeguards problems. Consequently, it is considered to be among the most sensitive facilities from the safeguards point of view, and thus inspection activities are quite frequent. Manpower and radiation exposure problems accompanied with frequent NDA-based inspections are quite a burden for both the inspectorates and the facility operator. Expecting to alleviate these burdens, the development of C/S measures for FCA was initiated.

4.2 Concept of C/S application to FCA

A portion of the nuclear material is stored in the birdcages, which are placed in fuel storage vaults. The rest of it is loaded in the zero power reactor for experiments. Nuclear material in the birdcages is secured by the inspectorate seals, but that in the reactor is difficult to seal due to the structure of the reactor and the experimental procedures. Then the main effort of inspection is directed to inventory verification of non-sealed material in the reactor by NDA.

The reactor building provides an ideal containment measure because of its explosion-proof and air-tight structure and limited number of penetrations. Most penetrations are seldom opened. Only the personal doorway is frequently used. Therefore, the combination of monitoring for containment boundaries and all the penetrations thereof except the doorway by penetration monitor and monitoring for the doorway by portal monitor provides complete coverage of all realistic diversion routes. The assurance that the integrity of the containment itself remains unimpaired is provided by reviewing the operation record of the monitor.

The concept of the FCA C/S system is shown in Fig. 5.

4.3 Description of FCA portal and penetration monitor

The detailed description of FCA C/S system is given in Refs. 2), 3), 4). The system was designed to meet a number of basic functional requirements and conditions including the following:

- High probability in detecting anomalies
- High reliability and redundancy
- Low false alarm rate
- Unattended operation
- Concealment of data obtained with the system to the facility operator
- Tamper indication
- Good maintainability
- Simple and accurate verification
- Friendly system to inspectors
- Intrusiveness to facility operation.

The system developed consists of the portal monitor and the penetration monitor.

Portal Monitor

The function of the portal monitor, which is built at the exit from the reactor building, is to detect undeclared removal of nuclear material from the reactor building through the doorway. The major characteristics are the following:

1. Walk-through metal detector, to detect metal nuclear material. FCA nuclear materials are in the form of metal plates of several sizes. The metal detector developed has a special coil arrangement to detect a single metal coupon of the size of 2 in.x2 in.x$^1/_{16}$ in. regardless of its orientation relative to the direction of passage.
2. Video surveillance, to support the unattended operation.
3. Tamper indication, to indicate tamper attempts with the system.

The exterior of the portal monitor is shown in Fig. 6. In front of both entrances, one into and the other from the reactor building, operator's metal detectors are placed to detect careless carrying of metals and thus to avoid activating the portal monitor anomaly alarm by careless

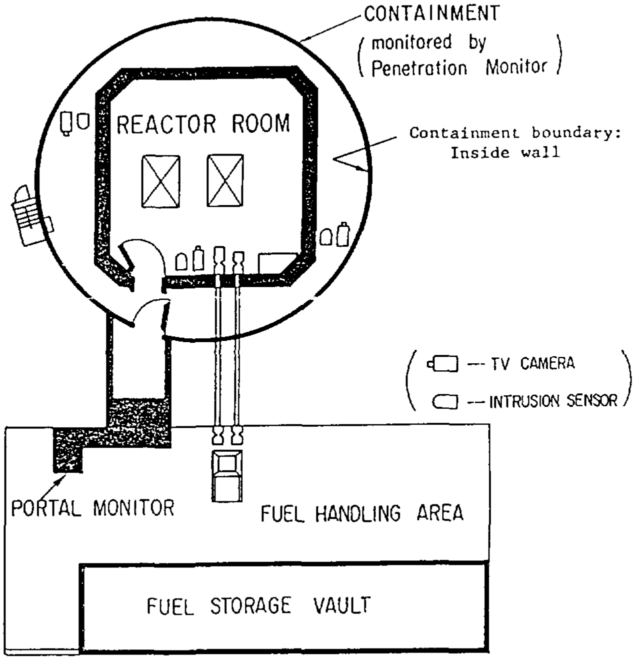


Figure 5. Concept of C/S system at FCA.

action. These metal detectors are completely separated from the portal monitor to secure the concealment of data in the inspectorate devices.

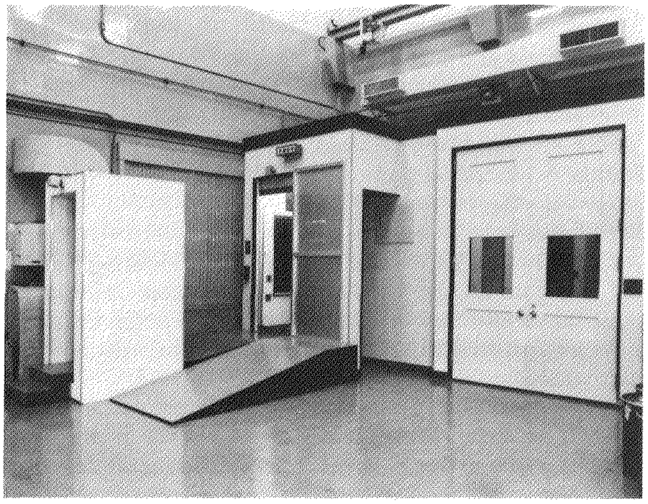


Figure 6. Exterior of FCA portal monitor.

Penetration Monitor

The penetration monitor is designed to provide the surveillance of diversion routes through containment boundaries and of safeguards related activities which involve the resolution of metal nuclear material for bypassing the portal monitor (the detection of metal solution by a metal detector is rarely possible).

The inside wall of the outer building was chosen as the containment boundary (see Fig. 5). A number of TV cameras and infrared motion detectors are distributed in the reactor building to provide complete coverage of all realistic diversion routes. To handle large numbers of video signals from TV cameras, a special video recording device was developed. With the combination of a video switcher and a VTR, video signals from up to four TV cameras can be recorded with one VTR. Thus the required number of VTRs were reduced.

4.4 Operation of the portal and penetration monitor

The portal monitor and the penetration monitor are individually controlled by their own computers (NEC 9801) and specific inspector interactive software. Every event on the monitor is recorded in the bubble cassette memory and also is printed out at a fixed time of a day. The print out contains the time-wise event records and the list of anomalies, if any. The data in the bubble memory is saved during an inspection period. Video recording is initiated by motion detection or anomaly detection and also by random time interval.

The control hardware, including the control circuitries, VTRs, a computer, interfaces, a printer, a floppy disc driving unit (the system control software is loaded from the floppy disc) and a bubble cassette memory unit are accommodated in the tamper resistant cabinet. During a surveillance period, the cabinet door is closed and seals are placed on it.

Upon arrival of inspectors, seals are removed and the cabinet door is opened, then the computer display is switched on. After this, inspectors are asked to follow instructions displayed on the screen to review the data obtained during the previous inspection period. Itemized lists of events during the whole surveillance period are printed out. Video tape review is also a part of data review.

In the case that anomalies are recorded, a list of anomalies is printed out. Inspectors will then find out the information about the type of anomalies, time, and date of anomaly occurrence. They will analyze the data and review the recorded tape of the part of the anomaly. When inspectors conclude that the anomaly is not false, appropriate response procedures will be carried out.

4.5 Present status of the portal and penetration monitor

The FCA C/S system development was basically completed in 1985. Since 1981, several functional and performance tests were performed jointly by the IAEA and JAERI with the final one in February 1986. In 1982, the performance test was carried out for a five-month period. High confidence in the detection capability of nuclear material transfer, tamper indicating performance and low false alarm rate, overall system reliability with redundant functions was demonstrated.

The system was modified several times based on the comments concluded during tests. The system is fully functional now.

The field trial operation by the IAEA and the state authorities will start as soon as the procedures are agreed upon by the IAEA, the state authorities and JAERI.

The field trial operation aims at assessment of both parties of the inspectorates and the facility operator whether the system should be implemented as routine use and trying out the inspection, training, performance monitoring, testing and maintenance procedures required in routine use. Criteria for acceptance or rejection, formulation of appropriate response procedures to anomalies should be agreed upon prior to the field trial test.

Significant alleviation of burdens both on the inspectorates and the operator which arise from NDA inspection is expected when the FCA C/S system is in routine use for international safeguards.

ACKNOWLEDGEMENT

The developments described in this paper have been carried out by the team of Y. Yokota, H. Ogawa, Y. Yamamoto and the author, of JAERI. The author gratefully acknowledges the contributions of K. Onozuka, K. Kita, I. Mitsuya of SONY Corp. for the development of COSMOS, and R. Yoshihara, N. Ohgi, H. Ishikawa, K. Koga of NEC Ltd. for the development of the electronic verifier for the COBRA seal. Thanks are gratefully extended to H. Kuroi for the valuable discussions and encouragement.

This work has been performed within the framework of the Japan Support Program for Agency Safeguards (JASPAS).

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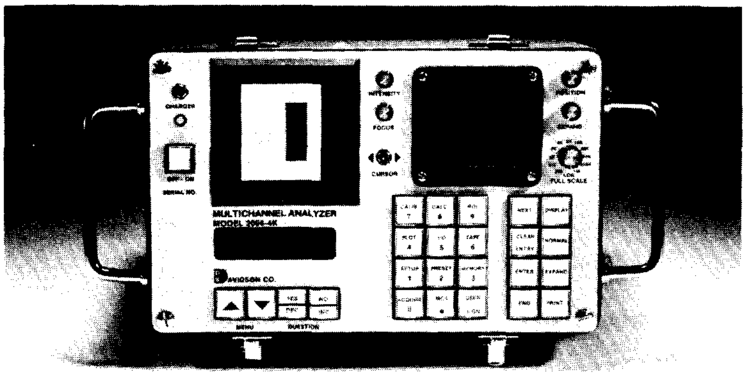
Takehiko Mukaiyama joined the Japan Atomic Energy Research Institute in 1965. From that time he has been involved in the research and development of fast reactor physics. Since 1980, his efforts in this field have been largely concentrated on waste actinide transmutation studies. From 1976-1978 he worked at the laser fusion project at the Laboratory for Laser Energetics, University of Rochester. Since 1979 he has also been involved in the development of containment and surveillance systems for international safeguards. He is a graduate of Tokyo University with a degree in Nuclear Engineering.



Institute of Nuclear Materials Management Second Annual Safeguards Roundtable

July 13, 1987 ▪ Newport Beach, California, U.S.A.
28th Annual Meeting of the Institute of Nuclear Materials Management

The following forum was conducted during the 28th Annual Meeting of the INMM. The Institute is grateful to the five Plenary Session speakers who agreed to further discuss and elaborate on their presentations — and the state of nuclear safeguards. Abstracts of the five papers follow the discussion.

It is the sincere hope of the Institute that this Annual Roundtable with international leaders and representatives of the scientific community might open the door to greater understanding, cooperation and dialogue.

Robert F. Burnett
Director, Division of Safeguards and Transportation,
Office of Nuclear Material Safety and Safeguards,
U.S. Nuclear Regulatory Commission,
Washington, D.C. U.S.A.

Wilhelm Gmelin
Director of Euratom Safeguards, Inspector of the
Commission of the European Communities,
Luxembourg

Glenn A. Hammond
Director, Division of Safeguards,
U.S. Department of Energy,
Washington, D.C. U.S.A.

Dr. Reinhard Kroebel
Chairman, ESARDA,
Nuclear Research Centre
Karlsruhe,
Federal Republic of Germany

Dr. Charles E. Till
Associate Laboratory Director, Engineering Research,
Argonne National Laboratory,
Argonne, Illinois U.S.A.

Nancy M. Trahey
then Member-at-Large, INMM,
New Brunswick Laboratory,
Argonne, Illinois U.S.A.

Eugene V. Weinstock
Book Review Editor, JNMM,
Brookhaven National Laboratory,
Upton, New York U.S.A.

Dr. William A. Higinbotham
Technical Editor, JNMM,
Brookhaven National Laboratory,
Upton, New York U.S.A.

William A. Higinbotham: I think we have to take note of who we have here. We have representatives from Euratom from both the inspection and the research and development side, and of the two U.S. government agencies which are responsible for safeguards. I would like to just take a second to define the role of Euratom safeguards to make sure that there is a distinction between that, as I understand it, and the responsibilities in the different countries for physical protection.

Wilhelm Gmelin: As far as safeguards is concerned we are basically implementing Chapter VII of the Euratom Treaty. It does not include responsibilities relating to physical protection, which is the responsibility of the individual Member States. Relating to safeguards under the Treaty, the Member States have transferred sovereignty rights to Euratom. Our situation is fairly difficult to describe in that we are a supra-national body, but on the other hand we have some regulatory responsibilities. So it's neither meat nor fish, and that's a bit of a problem. This is an issue which our friends at the IAEA always realize and recognize in the Annual Safeguards Implementation Report when they mention a group of States or the State System of Accounting for and Control of Nuclear Material (SSAC) of a group of States . . . they have five or six different names for us.

WH: We have a real common thread. Every speech this morning addressed support for the International Atomic Energy Agency (IAEA). What I'd like to ask the people from Euratom and the representatives of the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC) is how the United States cooperates with Euratom in this area.

Glenn A. Hammond: Let me begin by saying that the Department of Energy has as one of its objectives the support of international safeguards. The objective is to facilitate IAEA safeguards not only within the U.S. but within other countries. Part of the program includes research and development. We sponsor a program of about $5 million per year to improve the effectiveness and efficiency of international safeguards. Priorities include existing facilities in the U.S. that are subject to international safeguards and those that are still on the drawing board to determine the most effective and efficient IAEA safeguards that can be applied, particularly for new DOE facilities.

We then in a cooperative manner look at other facilities outside the U.S., those that are increasing the amount of inventories where there are particular technical difficulties in inventory verification. We also manage a Program Of Technical Assistance to IAEA Safeguards called POTAS, which is funded by the Department of State. The program is managed through a technical support coordinating committee, in conjunction with the Department of State as well as the Arms Control and Disarmament Agency (ACDA) and the NRC, based on priorities submitted by the IAEA.

WH: I was looking more to bilateral support, which is basically underneath all of this. Bilateral is something which I don't think gets as much publicity as the general support of various countries for IAEA safeguards.

GH: The area where we certainly have a substantial amount of cooperation is the area of bilateral agreements. Cooperation includes technical exchanges and development of conceptual safeguards designs and technology that will help to facilitate IAEA safeguards.

We have specific bilateral agreements with Euratom, the Federal Republic of Germany, France, the United Kingdom, and we are negotiating one with Japan. Emphasis is on new facilities that are expected to process large amounts of bulk nuclear materials. Most agreements not only cover material control and accountability, but also exchange of information in the area of physical protection; information on new technology to facilitate the physical protection within each of the individual countries.

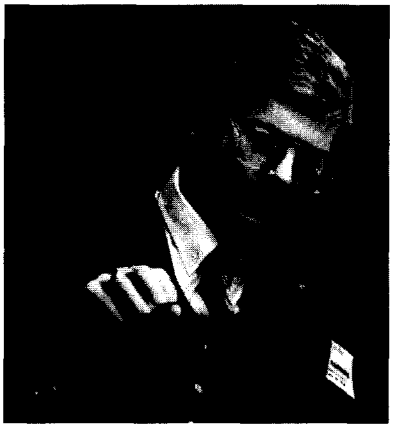
WH: Do you want to add to that, Mr. Burnett?

Robert F. Burnett: I don't know what I can add. The NRC is a participant in the bilateral process. I said participant because DOE is actually a party to the bilaterals where NRC is . . . "consulting" is the way the law is written. So as the bilateral is developed we work with it to assure that NRC can hold up our end of the bargain.

Many of the bilaterals are going into new areas, as Glenn said, which demand increased MC&A systems to be able to perform functions that they cannot now perform, particularly in the bulk handling facilities. There are several new ones under construction, and we need new techniques to be able to satisfy the bilaterals that are being negotiated.

We do also support, monetarily, tasks through the POTAS group. We prioritize a list of items that IAEA wants to pursue. NRC has money to actually take some of these items and do them in-house and turn our product over to the State Department, which then goes to the IAEA. In addition to that both DOE and NRC send people over on multi-year assignments to acquaint themselves with the IAEA, come back, and help us in the interface with the IAEA. But the bilateral renegotiation is the big thing that's going on. As you know the Nuclear Nonproliferation Act mandates that the bilaterals be renegotiated. I think five have been renegotiated and we're working on the latest one, Japan. After Japan is Euratom. It is getting a large profile at the NRC right now.

Eugene V. Weinstock: This question is directed at both Mr. Burnett and Mr. Hammond. In the abstract of [Deputy Assistant Secretary for Security Affairs in Defense Programs, U.S. Department of Energy] Michael Seaton's talk, he referred to balancing the cost of safeguards against the risk. That's difficult to do objectively, even when you're dealing with a relatively straightforward quantifiable risk like accidents, where there's an actuarial history. How do you do it for safeguards, and how does NRC do this in particular, where, in the absence of a history of attacks on nuclear facilities, at least in the U.S., the risk is essentially unknown?

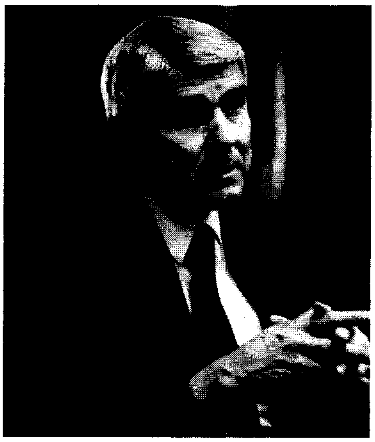


Glenn A. Hammond

GH: It's not only difficult to do it objectively, Gene, it's very difficult to do it subjectively. We would much prefer to look at that question in the inverse. That is: What's the effectiveness of a system using current technology . . . using the best things we could bring to bear today, and how much would that cost? One way we do that is through the use of analytic tools which have been generated by R&D for domestic safeguards, and we are now applying those techniques to Master Safeguards and Security Agreements for DOE facilities.

There are analytical tools that have been computerized, one is called SAVI (Systematic Analysis of Vulnerability to Intrustion) that comes out of the physical protection program systems studies over the last few years, another called ET is an Evaluation Tool developed by Lawrence Livermore Laboratory. These analytical tools use the parameters of detection, delay, assessment, and response and put those into a computerized model and obtain information on the effectiveness. We do a similar evaluation for the insider threat using ET.

The next thing we're working on is bringing those two evaluation methods together so that we can generate information on the effectiveness of an integrated system for a given facility, overall, and a cost model that would be applied against it.



Robert F. Burnett

EW: So in essence, then, what you do is assume a certain level of resources is available and then ask what is the most effective way in which to use those resources.

GH: Basically, yes, cost-effectiveness is the major objective.

RB: Strangely enough you can get to the same requirements by an alternate route. NRC some time ago selected what we call analogous industries. We studied both internal and external incidents. Then we looked at facilities that have a high degree of security associated with them, including those involved with protection of costly commodities. We made a complete study of all the types of incidents, identified the perpetrator where possible, and determined the *modus operandi* used by the adversaries. Using the study as a basis, we put together what would be the most likely picture of a design basis threat to the nuclear community in this country. So we call it just that: the Design Basis Threat. That means that in the absence of any known actual threats to nuclear facilities, or incidents from terrorist activities, we hypothesized a design threat for use in developing security systems.

We did the same thing for the insider threat. What was the *modus operandi* for theft, how were protective systems defeated and how many people were involved? From that we designed a system to counter those types of actions. It's not an absolute system; it does select a limit to the scenarios. From that we've created two Design Basis Threats, one for sabotage and one for theft. We published that in 10/CFR part 73, and then we designed a system that if installed would counter attacks of that nature. Strangely enough, it comes out with a high degree of comparability between the DOE method and ours.

EW: You mention NRC safeguards, DOE safeguards and Department of Defense (DOD) safeguards in your talk. Are the Design Basis Threats for these three agencies the same?

RB: In fact a study was done. The DOD for the most part falls out of the equation because they generally have very little nuclear material. Their nuclear inventory consists primarily of weapons, which are excluded from comparability considerations. So then there is just DOE and NRC.

Their threat statements are, for the most part, very much alike. DOE has a classified threat, whereas ours is a public document. But DOE and NRC have jointly evaluated our threats and articulated differences in protective measures. There are a few right now. The NRC is now addressing those differences to assure that the protective systems remain comparable.

EW: Is there a classified portion to the NRC Design Basis Threat? There are no numbers . . . .

RB: There is. The numbers in particular, of the threat, are classified. We justify this because although security systems do not fail like a pane of glass, there would be some advantage in providing a potential adversary with base numbers. If the design basis was "X," would X + 1 automatically fail? No, it would degrade; X + 2, X + 3 . . . the degradation would be faster. So the numbers are not the important aspect of the threat, but the capability of the adversary. That's what we try to get people to understand in the regulatory world.

EW: I'm glad you brought that up because that's a common misunderstanding. You design for "X," and people say, "What about X + 1, is the system going to collapse?"

It has been suggested by some — and this is prompted by the shipment a few years ago of a large amount of plutonium to Japan — that nuclear materials like plutonium and highly enriched uranium in bulk form ought to be as well protected as nuclear weapons. Do you think that that's a reasonable standard?

RB: Well, the NRC has elected to say no. We believe in graded safeguards. The weapon would get the highest level, or ultimate level of safeguards. Weapons-usable material would get the next highest level; smaller quantities the next; and then non-weapons-grade would get the lowest. We defend that because there is a certain period of time necessary to convert material to a weapon. There are classified studies on this subject and we know the minimum number of people it would take and the disciplines and capabilities of those people. Based on that, we feel that we can grade the level of safeguards in the licensed community. It is a controversial question, and I'm sure that other people could give you well-placed logic to defend their position, too. But at the present time that is NRC's position.

GH: DOE currently has a graded safeguards program, and I am going to use safeguards and security as a cumulative term, meaning all of the protective features that we apply. However, we are also looking at the possibility of a more detailed definition of gradation based on the chemical and physical forms of materials, primarily for materials control and accounting. I would not predict at this time what the impact would be on the physical protection side. The more detailed definition is to take into account the time and complexity that might be required to steal nuclear material, process it, and build a nuclear explosive device.

We believe that good loss detection capability is very important, particularly for materials control and accounting. We need to build additional means into our systems in bulk processing materials facilities to detect protracted diversions. When it comes to the high-level, pure forms of materials, we make very little distinction in physical protection requirements. If it's in a pure form of sufficient quantity, we give the highest amount of safeguards control to that set of materials.

EW: Are you saying then that you actually do give the same amount of physical protection to Category I quantities as to a weapon?

GH: Yes, as of right now. We are, however, reviewing the impact of additional gradation on physical protection systems.

RB: And of course we have no weapons in our jurisdiction, so that is not a problem.

WH: To be fair, as Glenn knows, the question of whether graded safeguards are making sense or not is something which has been and is again being reviewed, because maybe it's not cost-effective the way we're doing things.

Bob, you brought up the subject of physical protection practices in other countries and in the United States, and in particular the document INFCIRC/225 on physical protection. Are we talking about a review of the Omnibus Diplomatic Antiterrorism Act of 1986 to be done by NRC, or a review to be done by NRC in conjunction with DOE and somebody else, or an international review? It was originally an international effort that put that together.

RB: The Act actually requires two separate reviews. One was to be independently formed by each of the five agencies that are involved in the process: Department of State, ACDA, DOE, NRC, and DOD. They were to submit to Congress a report that represented their opinion and not to be a concert document. That was step one. Step two was that the Executive Branch was to put together a conglomerate document that would be delivered to the Director General of the IAEA.

The agencies have completed the first set of reports. The NRC version has been shipped to the Hill. The others, I think, are in the process of being shipped to the Hill. They are classified.

GH: Other than the NRC report, those documents are with OMB (Office of Management and Budget). They are being held for executive branch questions on "Why can't we reach an agreement?"

RB: The second phase, which is a conglomerate report from the President, in effect, to the Director General of the IAEA, has not been started.

WH: What's the purpose of this? Never mind what the Act says. What are we going to accomplish when we get through with it?

Eugene V. Weinstock

William A. Higinbotham

RB: I can only tell you what the stated purpose is that is in the documentation that supports the law: Many congressmen were concerned about worldwide terrorism and the inevitably increasing movement of special nuclear material, globally. There is a lot of debate in all the periodicals on whether the material is being moved in a safe configuration, from a security point of view. This debate did arrive on the doorstep of the Congress of the United States, so to speak.

WH: But the thing is that the INFCIRC/225 is a document which was put together voluntarily by a number of countries. The IAEA issued it only as a convenience. The IAEA has no authority to require or enforce. So, really the important thing is not reviewing 225 so much as it is to discuss in what way can we work together, informally as well as formally. This is extremely important if you're going to have some sort of confidence that you have a decent system; that we are working together and not that "There's no point in breaking my back because he's not doing anything . . . " We don't want to get into that kind of a hole at all.

RB: Basically, I guess we caused this questioning to come to us. In all questions that have been directed to us we call attention to the the fact that foreign countries have agreed and given the United States assurances that they will apply INFCIRC/225. Having done that and looking for that assurance, the very next question is, "What assurance do you have that that level of protection will indeed do what we want done?"

EW: Dr. Kroebel, it's evident from your talk that a tremendous amount of effort has been expended on the development of sophisticated nuclear materials measurement methods, especially nondestructive ones, over the last 20 years. Yet often, these methods don't reach their full potential because facility operators don't provide the conditions that would enable them to do so. For example, we can point to the problem of NDA of spent fuel in reactor pools. It is greatly hampered by the almost universal objection of operators to the movement of the fuel, posing an almost impossible task for the inspectors, even though the operators themselves often move the assemblies for their own purposes.

What good is all this development, accomplished at great cost, if in practice its products can't be used effectively? And what can organizations like ESARDA and Euratom do to alleviate the situation?

Reinhard Kroebel: I think I can only answer half the question because most of it should be addressed by Mr. Gmelin. I should first clarify what ESARDA is. ESARDA is an association which is not financed by any one agency, but the financial support for all the R&D efforts comes from the associates. They might have help from their own countries because usually it is not a governmental organization that takes part. Our organizations, which were of course borne by the government, have no governmental functions . . . Kernforschungszentrum in Karlsruhe and all the others. That means that we are only an association which wants to keep contact between different laboratories and different persons and enhance and promote R&D results in cooperation with the utility owners or with industry.

We as the researchers try to support implementation of our products in these facilities. The requirement of use of such instruments for safeguards application however is a matter to be negotiated by States and safeguards authorities.

By the way, the example you mentioned — NDA techniques on spent fuel — has not been a subject considered by the ESARDA NDA Working Group.

There is no intention to get industry to do something except by convincing them through the quality of our work. It is certainly difficult — and this is up to Mr. Gmelin to answer — to get industry to accept even only on a basis of certain implementing of research results to the things which you mentioned.

WH: I think I would like to follow that. I attended the ESARDA meeting in 1974 where you brought in the operators of the facilities. I was the only American so everybody blamed me for all of these operations . . . Anyway, I know that what you have done since then is to try to involve the facility people. I think you ought to say a little more about that and then maybe Mr. Gmelin would like to add to that. In the United States we don't very often ask a licensee what he'd like to have. What we do is tell them what they ought to do. I'd like to understand how you work it in your part of the world.

RK: I think that there is progress insofar as operators are now participating in almost all ESARDA bodies. They then have the opportunity to initiate R&D activities of interest from their point of view. For example, the Working Group on Low Enriched Fabrication Plants in recent years was very successful in achieving results that are of practical interest for all plant operators.

Wilhelm Gmelin: First of all I'm glad for this question because it gives me the opportunity to thank the United States for collaboration regarding instrumentation, and for the direct, uncomplicated support to Euratom safeguards, which has developed very nicely over the last four years. This is a substantial contribution to safeguards. It is very good — running so well — especially between Los Alamos National Laboratory, Sandia National Laboratories and us. If we have a problem we just pick up the phone and we get it fixed.

WH: Well, that works both ways.

WG: As far as NDA is concerned, the last four or five years have seen a very rapid introduction of NDA in the European community. I know of course of the worldwide difficulties that our colleagues in the IAEA have. They don't have that so much in the European community. We have introduced these methods and we are using them. I will give you just one example, because you mentioned this, Mr. Weinstock, and I have to be careful because most of the information is classified.

We have performed, with the Ion Fork, more than 200 fuel assembly measurements, a considerable number of them following anomalies. As far as the other instrumentation is concerned, we are moving forward. The Fork is one thing every operator in the community gets very emotional and very excited about. But when there are anomalies, the follow-up has to be conclusive. And, from time to time there are anomalies; switching lights off or things like that. We have defined anomalies as being restricted events which are to be attributed to the operator. It is an important operation in which we have to follow two principles: one is "The other party has to be heard," and secondly "If in doubt you must lean in favor of the accused."

Our thanks to the United States that we received instruments on loan. It was accomplished, I should emphasize, to a large degree due to the personal engagement of U.S. Ambassador-at-Large Richard Kennedy. Subsequently we purchased such instruments. I think we now have something like five neutron collars in routine use in the facilities.


Reinhard Kroebel

WH: Good. You're in a position to enforce it, you know. The IAEA has more trouble.

WG: The IAEA is in, I would think, at least 50 percent of these facilities together with us. But there are places as you know, that we are alone.

RK: Well, that's fine.

WG: The other instrumentation, in addition to the neutron equipment, is progressing satisfactorily. In gamma applications — permit me to make this simplification — we have enough instruments now: Silenas, Davidsons . . . a whole slew of equipment, and it is being used. We also are using our Mobile Mass Spectrometers. That's an interesting thing, perhaps I should elaborate.

WH: I wish you would.

WG: The problem is a classical one: timeliness. The problem is that if you draw samples — which is first of all, a complicated process — you have to pay for packing, shipment, then it has to be shipped to one of our Commission Laboratories for the analysis. If you are lucky and you are able to solve the beaurocratic red tape of transport, then you may be able to obtain your results in usual response times of, say, six to eight weeks. But this is not a highly satisfactory solution, especially for plutonium samples.

So the idea was quite clear, and thanks to ISPRA we have used a first prototype of a Mobile Quadrupole Mass Spectrometer starting with a very tough exercise at RBU in 1983. The safeguards family was not very happy when we did that. They said, "Well, its only 0.5 percent in accuracy. Why did you do this? It costs about 250,000 ECU ($250,000 U.S.). We calculated that with all the transportation costs the break even point would be about 40 to 60 samples a year.

WH: Wow.

WG: Yes, because the transport costs of samples are tremendous. I don't know how it is in this country, but in Europe it is very, very expensive to transport nuclear materials.

WH: There's also red tape.

WG: The red tape is colossal. And it doesn't really matter whether you transport one ton or one gram. So the Mobile Mass Spectrometer started with UF_6, and at that point the Hexapartite Safeguards Project (HSP) came to a conclusion and we had to implement the HSP conclusions in our encrichment facilities. What we did was this: We told the inspectors, "On the input and product end you just take samples and you drop them in a sealed box. At intervals of about three months the Mobile Mass Spectrometer comes by and makes an analysis." That's what we do.

WH: Oh, I see.

WG: We stay well within the detection time, which we define as between six months and one year. We are now down to an accuracy of about 0.2 percent. And that works, and the results are instantaneous.

The results are such that we have now decided to buy a second one — and we already have it. The first is for UF_6 samples, as I have mentioned, and operates as follows: The Mobile Mass Spec is based in Luxembourg. We have a special van which travels to the site and analyzes there. It becomes contaminated. After the measurement it goes back to ISPRA where it undergoes preventative maintenance, cleaning and decontamination, and then it returns to Luxembourg. This is a rather crammed tour. Still, we are doing about 80 samples a year, so we are operating at a profit on the last 30 or so.

Based on this we have now bought — again, a project successfully completed by ISPRA — the second Mobile Mass Spec for UO_2 samples. It not only incorporates improvements resulting from the experience with the UF_6 head, but it also has a charging magazine in which you load 10 samples during your inventory campaign, press a button and go home. The next morning you have your results and you load another 10 samples. A complete measurement cycle with 16-20 samples takes about 20-24 hours including preparation and dissolution of the samples.

So I think on-site DA is going forward, and I think it has to, since, as previously mentioned, the transport of radioactive samples, especially after Chernobyl, is getting more and more difficult in the community.

WH: Yes it is, everywhere. It's a problem in the United States, too.

GH: Incidentally, it looks like there is going to be another substantial benefit from the quadrupole mass spectrometer to safeguards and security, and that is for the detection of explosives. Using two in tandem, mass spectrometry is becoming a prime candidate for detection of high explosives.

WG: The cost question looks really good. The new Mass Spec we have cost us 300,000 ECU, which is about $300,000 (U.S.) and the break-even is still about 60 samples per year.

WH: Now on plutonium you can use gamma rays . . . .

WG: We are now planning to obtain and use a further Mobile Mass Spec for plutonium. With plutonium it is more difficult due to contamination problems, but we are not giving up because we are convinced by the speed we get results. The simple fact that you get results and can look at it, go to the operator and say, "Hey, what's that?" And he can clarify the point immediately.

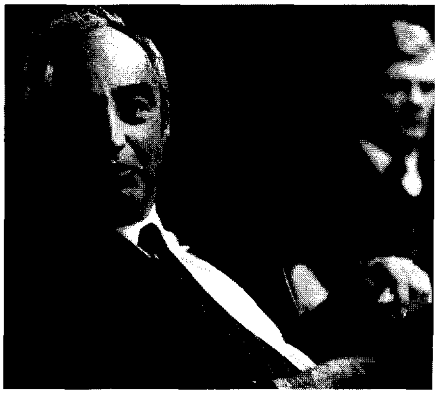
WH: Now we get to something in your paper which I couldn't digest as fast as you presented it. You were talking essentially about isotopic tracking . . . .

WG: The isotopic tracking is something that we still have great hopes for; that it will come to something. The problem is well known: Large throughputs of NM in bulk handling facilities. The operators don't like to take a physical inventory every month because then they would do only physical inventories, right? However, we have detection times of one month.

The idea was pursued — not a very new idea — that we would subdivide the flow through fabrication units into portions, which however must be clearly distinguishable. The distinguishability may be by gamma spectrum, related to isotopic differences. You make an independent balance of each individual portion which may vary between, say, two and 15 kilos of material. We have developed the approach and we have negotiated it with the Agency and the operator, and implemented it. The results, as always in safeguards when new approaches are implemented, are neither a smashing success nor a total failure. The costs are very high. We had all the access to all the process data, but the mere fact that the inspectors have the opportunity to see all the data occupies them. They see a lot of trees but not necessarily the forest, and that's the trouble.

EW: Like process monitoring.

WG: It is practically like that. It is this independent balancing that we are still after, since you get a MUF or inventory difference for as many portions as you balance independently.



Wilhelm Gmelin

WH: It's a great idea . . .

WG: We hope that it will come through. We think up to now that effectiveness-wise, it's a great success, but efficiency-wise it's not a great success. That's the best way to characterize it.

EW: Dr. Till, you pointed out that during the routine operations of the IFR there will be no need to have shipments of Pu, but what about the start-up?

Charles E. Till: What we're talking about is starting it up with U-235. The conversion ratio is such that we will have an effective breeding ratio slightly larger than one using U-235.

EW: That will be highly enriched uranium.

CT: Well, that depends on the size of the reactor, but for the smaller reactor sizes used in modular design the enrichment will probably be around 30 percent.

EW: Has anyone undertaken a careful safeguards analysis of the IFR?

CT: We did that at the time that we were doing a conceptual study of a commercial version of the fuel cycle facility and there is an Argonne report on it. It's about a year old and there have been one or two changes to the process flow sheet since then.

EW: Was this study done internally at Argonne or was it an outside study?

CT: It was an internal study. We also have had IEAL (International Energy Associates, Ltd.), do a study for us on the anti-proliferation and national and international diversion features.

Nancy Trahey: Dr. Till, you mentioned that both General Electric and Rockwell are looking at the IFR concept as a commercial design concept. But all of the things that seem to make the IFR attractive in terms of proliferation and such, nonetheless would run into difficulties in terms of present NRC regulations controlling commercial power reactors. How have GE and Rockwell tackled that problem and is Argonne involved in that?

CT: In terms of proliferation as such, I'm not claiming any particular advantages for the IFR. That's for others to decide. Again, however, even the process itself is still in the process of development. I made the point this morning that the decontamination factor appears to be above five, so the fuel stays very radioactive. But the precise number changes as the chemists find out more things about the chemistry. As far as the situation with respect to commercial reactors, the thing I have to stress is that this process is in the R&D stage. The General Electric and Rockwell versions of the reactor — the General Electric version is called Prism, the Rockwell version is called SAFR — use the IFR fuel cycle process but there's a lot of work that Argonne has to do in the development before any conceivable deployment can take place.

Charles E. Till

I don't know what they're doing specifically about safeguards, but both Rockwell and General Electric are having ongoing interaction, briefings, and feedback from the NRC on the safety aspects of the reactor, and we help in that. I think the real answer to your question is that the entire reactor system, including the fuel cycle, in my view, is years away.

NT: It's using very well-developed technology. I guess I'm trying to anticipate safeguards if at all possible at the design stage so that at least there is a sensitivity to it and a recognition that someone, someday, is going to have to deal with it.

CT: Very much so.

WH: Well there are several kinds of safeguards. International and domestic.

RK: Would your new reactor design degrade the plutonium to a large degree, because I understand you have high burn-ups. But it is basically degraded, so you would have a fairly high concentration of Pu-240 and perhaps Pu-242.

CT: Yes, in the core, but the blanket Pu disposition will depend on the flow sheets. The flow sheets that we're using mix the blanket in with the core right at the start, so clean Pu-239 never emerges.

RK: But it would be only through the process.

CT: It would be only through the process because with the fast spectrum in a blanket produces very clean Pu-239 even at fairly high exposures.

WG: I have had the chance to visit the facility twice, so this isn't the first time I have heard about it. But no one has ever told me how much plutonium or fissile material is lost in that process, and no one could tell me what they were going to do with the waste.

CT: I don't know the answer to this question of overall recovery. The development work will settle the question. What we are looking for is 99 percent recovery. Development is also underway on the waste.

EW: How is the IAEA ever going to verify the inventory at this reactor? If it's changing from 30 percent U-235 to plutonium and they can't get at it they have got to change their basic philosophy of safeguarding.

I would like to ask Mr. Burnett a question that arose in my mind when I was reading a book on nuclear terrorism that has just come out in the past year, edited by Paul Leventhal and Yonah Alexander *(See books, this issue)*. In one of the articles in the book Professor Daniel Hirsch from the University of California/Santa Cruz strongly criticizes NRC for suspending consideration of a rule to protect power reactors against truck bombs. He claims that this was done despite the findings of an NRC-sponsored study by Sandia National Laboratories that "unacceptable damage to vital reactor components" could result even from a truck bomb of large, but reasonable size, detonated off-site.

RB: The study that Dan Hirsch is referring to is confidential. Licensed nuclear facilities in America are not protected against a truck bomb of the size and magnitude that was used in Lebanon. The NRC has that point under deliberation right now, working with intelligence agencies and other agencies of the government, trying to determine if that should be part of the Design Basis Threat. It has not yet been decided.

EW: Does NRC require any protection against truck bombs?

RB: No. We are working on a rule for Category I facilities where theft of material is the primary consideration that would require vehicle denial systems. Don't confuse that with truck bombs. The agency has not yet made a decision on the truck bomb threat.

EW: Does the DOE require protection against the truck bomb threat to its reactors?

GH: DOE requires protection against a wide spectrum of threats including protection against certain capabilities of terrorist groups.

Discussion participants were given the opportunity to edit their remarks.

INMM Safeguards Roundtable Participants' Presented Paper Abstracts

The complete text of papers presented at the 28th Annual Meeting of the Institute of Nuclear Materials Management is available in the INMM Annual Meeting Proceedings.

Members of the Institute and meeting attendees receive a copy of the proceedings as a part of their membership or registration fee.

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Safeguards — An Evolving Policy

Robert F. Burnett

The responsibilities of the Nuclear Regulatory Commission (NRC) related to the safeguarding of nuclear material derive from a number of legislative enactments which include The Energy Reorganization Act, The Nuclear Non-Proliferation Act and the Omnibus Diplomatic Security and Anti-terrorism Act. The development of NRC material control and accounting requirements over the years has resulted in a number of refinements in system capabilities. A recent rule amendment will provide for more timely analysis of accounting data to enhance anomaly detection and resolution and thus provide for earlier detection of possible theft or diversion. This, along with present initiatives in physical protection program areas, will combine to provide increased assurance in capabilities to adequately protect special nuclear materials. Among the physical protection measures now under consideration are revised requirements for security force training and the establishment of a formal requirement for tactical response exercises to evaluate security system effectiveness. In the international arena, full cooperation with the IAEA continues to be regarded as an important function. A primary recommendation in this area is to reconvene an international committee to review IAEA programs for physical protection (INFCIRC 225). All countries have an overriding interest in attaining nonproliferation objectives. NRC activities in support of these goals include improving safeguards capabilities, requiring the reduction of enrichments used in nonpower reactor fuels, the reduction of inventories of highly enriched uranium to levels actually needed for nonpower reactor operations, the maintenance of comparable levels of protection for weapons usable materials under Department of Energy and NRC programs, and continued support of IAEA initiatives and objectives.

Robert F. Burnett graduated from the University of Virginia in 1965 with a degree in Electronic Engineering. He began his career in security at the U.S. Secret Service in 1969 as chief engineer responsible for the development of security equipment to support facility and personnel protection as well as criminal investigations. Mr. Burnett joined the Nuclear Regulatory Commission in 1977 and since that time has been the Director of the Division of Safeguards, Office of Nuclear Material Safety and Safeguards.

Challenges and Future Trends in Safeguards in the European Community

Wilhelm Gmelin

Following a short description of the scope and tasks of Euratom safeguards, the paper presents the requirements from the increase of the European fuel cycle and the consequences arising to Euratom safeguards. It addresses the technical challenges to safeguards and certain issues in need of resolution. The paper also describes the role of Euratom safeguards with regard to the provisions of the Euratom Treaty, including the requirements of IAEA safeguards pursuant to the three Verification Agreements and the external obligations of the Community, and with regard to the growing attention from the public domain.

Wilhelm Gmelin was named Director of Euratom Safeguards in 1982. Previous to that appointment he served for 12 years in the Department of Safeguards at the International Atomic Energy Agency in Vienna. His work there included safeguards system studies, and the development and implementation of data processing in safeguards. From 1965-1970 he conducted work in system studies and NPT-safeguards at the Nuclear Research Center, in Karlsruhe, Federal Republic of Germany.

Where Have We Been . . . Where SHOULD We Be Going?

Michael B. Seaton

presented by Glenn A. Hammond

Where have we been in the recent past? Operation Cerberus emphasized the need to continue to improve the effectiveness and efficiency of safeguards and security systems at key Department of Energy (DOE) facilities. We have recognized the need to manage our improvement strategy to ensure an even more integrated *approach in balancing risk and cost. Substantial improvements have been and are continuing to be made in physical protection systems, guard force capabilities, training and in reducing inventory differences. More needs to be done in material control and accounting (MC&A). We have tasked the National Academy of Sciences to review the MC&A process. Vulnerability analyses, considering the spectrum of threats, are being conducted at key DOE facilities as part of the Master Safeguards and Security Agreement process to provide consistent planning for site-specific needs. Where are we going? Given the threat history for DOE facilities, we will place increased emphasis on insider threat concerns, including selective use of a human reliability program and improved materials control and accounting. Balanced and flexible systems will be emphasized so that there are no "weak links" that would allow an adversary to target a more vulnerable area. International Safeguards will need to deal with large reprocessing plants now being built in other countries, large quantities of plutonium, new isotopic enrichment technologies, and long-term storage of plutonium-bearing spent fuel in the U.S.*

Glenn Hammond received a degree in Chemistry from East Tennessee State in 1956. Since then he has been employed by the AEC at the Oak Ridge Operations Office in production operations, and by AEC, ERDA, and DOE since 1961 at Headquarters in Washington in the areas of safeguards policy and R&D for both domestic and international applications. He assumed the position of Director of the Division of Safeguards in early 1987.

The Role of ESARDA and Its Current R&D Efforts

R. Kroebel, W. Bahm and M. Cuypers

The peaceful use of nuclear energy substantially has increased worldwide during the last decade. At present about 400 power stations are connected to the grid providing a total capacity of 280 GWe. According to present day projections a further increase is to be expected.

The generation of electricity by nuclear energy is inherently linked to the production of plutonium, presently about 75 t per year. Some countries already have or are going to recycle plutonium commercially in thermal and fast reactors. The related reprocessing capacity in countries of the European Community will increase from presently 300 t heavy metal per year to more than 3000 t within the next decade.

This situation will result in a challenge for safeguards mainly by two reasons: Firstly its resources are not likely to be increased accordingly, therefore more emphasis has to be put on cost/effectiveness. Secondly, new techniques such as long term storage and remote handling are supposed to be applied requiring adequate safeguards measures. Therefore the present day status of safeguards does not appear to be mature.

In this connection ESARDA plays the role of an important platform for exchange of technical information and initiation as well as coordination of international R&D efforts. The ESARDA Symposium at London through 12-14 May 1987 proved to be very successful in that sense.

The activities of the ESARDA Working Groups are mainly focussed on specific questions arising from safeguards practice such as estimation of measurement errors to be expected, comparison exercises etc.

The outline of current R&D efforts in the Working Groups as well as a report on the London Symposium are presented in this paper.

Dr. Reinhard Kroebel studied inorganic chemistry at Kiel University from 1955 to 1963, then served as scientific staff member for Euratom at the Belgian research centre in actinide chemistry, Mol. From 1965 to 1970 he was with Eurochemic reprocessing company at Mol, as section head for applied radio chemistry (head-end and extraction unit operations). During the following three years he was a research chemist with Bayer AG, Leverkusen, in the field of uranium chemistry. In 1974 he joined the Kernforschungszentrum Karlsruhe and became head of the newly created research and development project for reprocessing and waste management.

Next-Generation Nuclear Power: The Integral Fast Reactor

C. E. Till

Just a little over a year ago, in the same month, April 1986, two nuclear power reactors, one in the Soviet Union and one in the United States, were subjected to very severe equipment and operator malfunctions, similar in each reactor but very different in their consequences. The Soviet reactor was Unit 4 at Chernobyl. The U.S. reactor was EBR-II at Idaho Falls. Chernobyl is now an indelible part of world history. At EBR-II the world remained unaware that anything historic had taken place, for there were absolutely no consequences. But the events at EBR-II may have just as much impact as the tragic events at Chernobyl in shaping the future of nuclear power, for these were remarkably successful tests of a new inherently-safe reactor being developed at Argonne National Laboratory. Called the Integral Fast Reactor, the basic thrust of the concept is to develop everything needed for the complete nuclear power system — reactor, closed fuel cycle, and waste processing — as a single optimized entity. Radical improvements in safety characteristics, in reprocessing, and in waste are possible from this concept.

The paper describes the IFR concept, the inherent nature of the reactor properties, the safety tests, and the status of IFR development today.

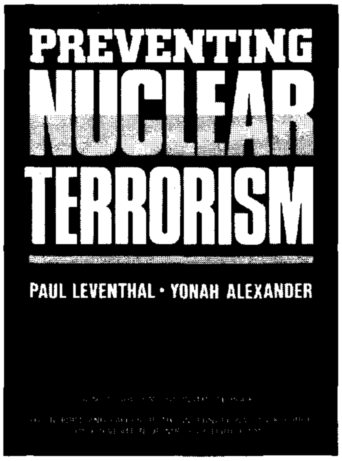
Dr. Charles E. Till directs all engineering research at Argonne National Laboratory. As Associate Laboratory Director, his areas of involvement include all fission reactor work, fusion, nonnuclear energy supply R&D, chemical engineering and applied materials technology. Most recently, he has led the development of the Integral Fast Reactor. Dr. Till earned a Nuclear Engineering Ph.D. from the University of London. Over the years he has held every position in the R&D line at Argonne, assuming his present position in 1980.

Preventing Nuclear Terrorism:
The Report and Papers of
the International Task
Force on Prevention of
Nuclear Terrorism
Edited by Paul Leventhal and Yonah Alexander
Lexington Books, D.C. Heath and Company
Lexington, Mass., 1987
(cloth, $56.00; paper, $22.95).

In 1985, the Nuclear Control Institute, a non-profit organization concerned with the issue of nuclear proliferation (on which it generally reflects the views of the Carter Administration), in cooperation with the Institute for Studies in International Terrorism of the State University of New York, convened an international "Task Force" (aren't there any plain old committees any more?) to assess the problem of nuclear terrorism and recommend ways to deal with it. Membership in the Task Force, consisting of people prominent in the nuclear and related policy fields, covered a wide spectrum of opinion and background, no doubt in the hope that its recommendations would enlist equally wide support. To help it with its task, a large number of background papers on various aspects of the subject were commissioned. This book contains both the report of the Task Force and the background papers on which it is largely based.

A major problem for any effort such as this is the difficulty of studying a virtually non-existent phenomenon. If nuclear terrorism is defined as involving such acts as stealing nuclear material with the intent of using it in a bomb, dispersing it to threaten public health and safety, or of sabotaging an operating reactor in order to cause widespread radioactive contamination, there have simply been no such incidents so far, although lesser ones have occurred. These include hoaxes, sabotage of fuel assemblies, thefts of natural and low-enriched uranium, bombings of non-operational reactors, and even assassinations of nuclear plant managers. It is therefore difficult, if not impossible, to come up with objective estimates of the magnitude of the risk or of the amount of effort that should be spent on avoiding it.

That doesn't faze the U.S. Department of Energy, which, prodded by Congress, has spent several billion dollars in the last few years improving the security of its nuclear facilities against terrorist attack. Since in all of 1986 (as an example) not a single person in the U.S. has been killed by a terrorist bomb and there has never been an attack against a U.S. nuclear facility, in an actuarial sense this must rank as one of the most expensive insurance policies of all time.


PREVENTING
NUCLEAR
TERRORISM
PAUL LEVENTHAL · YONAH ALEXANDER

The paucity of evidence for the existence of the phenomenon about whose dangers it was trying to arouse the public was obviously a source of some discomfort to the Task Force. To surmount the difficulty it advanced two arguments: first, that although the likelihood of nuclear terrorism is small, it is increasing, and second, even if the probability is very small the consequences could be horrendous. There is little convincing evidence for the first proposition, but since there is no limit to what nuclear terrorists — if they existed — *might* do it is hard to argue with the second.

Having settled that issue to its satisfaction, the Task Force brought forth its recommendations. I counted 30, but with sub-recommendations the total is closer to 50. They range from the short term to the long term and touch just about every base: protecting nuclear weapons, materials, and facilities; the role of intelligence; civil liberties issues; controlling nuclear transfers; U.S.-Soviet cooperation; arms control measures; emergency management; international institutions; and emerging nuclear technologies.

Many of the recommendations are difficult to quarrel with: for example, using access denial to protect nuclear facilities against sabotage, converting reactors using high-enriched fuel to low-enriched, making greater use of intelligence, quick ratification of the international Convention on Physical Protection of Nuclear Material (although in this case events overtook the publication of the book: the Convention came into force this year), and improved cooperation at all levels of government in providing for adequate response to nuclear emergencies. Some are a rehash of the Carter Administration non-proliferation policies, and the adoption of others, notably the arms control recommendations, is likely to hinge on much weightier factors than the threat of nuclear terrorism. Still others rest on questionable logic. One is the recommendation that explosive nuclear materials such as plutonium be given the same level of protection as nuclear weapons. This has a logical ring to it until one states the corollary, that fully assembled nuclear weapons should be no better protected than the raw materials out of which they are made. One suspects that the criterion originated with people trying to block the peaceful uses of plutonium by proposing a standard they believe impossible or at least impractical to achieve.

As a consensus document, the Task Force report is written in a rather bland style, replete with generalities and hedging, and designed not to offend anyone. This reader found the background papers, reflecting the peculiar style and prejudices of the individual authors, much more interesting, although of very uneven quality.

A paper entitled "Can Terrorists Build Nuclear Weapons?", by a group of weapons experts including J. Carson Mark and Theodore Taylor, is the best treatment of the subject I have ever seen. It should go far towards dispelling the myth that making a nuclear weapon is easy, within the reach of any small group of terrorists that puts its mind to it. An interesting and unusual sidelight is that one of the authors, Ted Taylor, is forced to eat crow. In the past he has claimed that it would be feasible for a terrorist group to make a bomb with a container of plutonium oxide seized from a fuel fabrication plant — that is, without converting the material first into cast and machined metal shapes. This is usually referred to as the "coffee-can bomb." The paper points out that tens of kilograms and possibly more of the oxide would be needed, and that predicting the behavior, particularly with respect to density, of such a porous material under the shock-wave conditions of the explosion would be a formidable theoretical and experimental problem.

An important question that almost always arises in discussions of nuclear terrorism is the minimum number of people that would be required to build a crude weapon. The authors conclude that it "could scarcely be fewer than three or four *and might well have to be more*" (emphasis added). The Task Force report leaves out the important underlined qualification, declaring only that "building a crude bomb, . . . is within reach of . . . three or four technically qualified specialists." Obviously, this conveys quite a different impression than the authors of the background paper intended, and strengthens the position of the Task Force.

Five papers address the question, "What Factors Influence Whether Terrorists Go Nuclear?" the title of one of the six chapters into which the background papers are divided. The results, as might be expected, since we are now in the realm of pure speculation, are inconclusive. Some encouragement is offered by Konrad Kellen's observation that "Some terrorists already have the capability to do some forms of nuclear damage but have chosen to do very little of it and at the periphery only." In what must be one of the silliest papers on the subject ever to appear, Louis Beres, a professor of political science and international law at Purdue, argues that the major cause of terrorism in the world today is the U.S.'s (and especially the Reagan Administration's) "obsessive anti-Sovietism," which leads us to support oppressive regimes, thus arousing the intense popular resentment out of which terrorism grows. The journalist Claire Sterling, in the article immediately following, demolishes Beres's thesis by citing case after case of terrorist movements aimed at democratic and even Socialist governments, and examples of appeasement of terrorists being followed by increased terrorist demands.

It seems that in any subject connected with nuclear power the writer's predilections tend to leak through even the most scholarly fabric. A case in point is one of the better papers, a careful analysis of the current and projected flows of plutonium and highly-enriched uranium worldwide by David Albright, a frequent contributor to the Bulletin of Atomic Scientists. He has done an impressive job of collecting data from original sources and the available literature and deducing from these the expected flows, but then at the end he comes to a wholly unwarranted and unsupported conclusion that "... the demands of reprocessing and plutonium recycle on physical security will be staggering." A simple calculation based on his data shows that this is a gross exaggeration. According to Albright's projections, the total number of road shipments (the most vulnerable transportation mode) of separated plutonium could be as high as 400 per year, or, on average, roughly 8 per week, in the late 1990s. Allowing 12 armed guards per shipment, we can estimate there would be no more than 100 armed guards on the road at any given time throughout the world, a number that could be supported by a guard force of only a few hundred persons. Sea shipments would require far fewer guards (altogether) because there would be many fewer of them, and the guard-force requirements of air shipments, the inherently most secure mode of transport, would be even less. Assuming four major reprocessing plants (one each in France, the Federal Republic of Germany, Japan, and the United Kingdom), and allowing 30 guards on duty at each site at all times, with similar assumptions for the mixed-oxide fuel fabrication plants, we can estimate a total fixed-site guard-force requirement of 1200 persons in all four countries. The total number of armed guards required to protect a "plutonium economy" (to use a favorite expression of those opposed to plutonium use) of the magnitude projected by Albright for the late 1990s would then come to no more than 2000, or, if one were to increase the number of guards per road shipment to 24, to roughly 2500. This works out to a mere 500-600 armed guards per major supplier or user country, by no stretch of the imagination a "staggering" number.

Albright also invokes, without justifying it, the nuclear-weapon criterion for the protection of raw nuclear materials referred to earlier. I should hasten to add that, despite these criticisms, I think Albright's paper is one of the best in the book.

There are other good papers as well. One, on "Civil Liberties and Nuclear Terrorism," by Stephen Goldberg, a past member of the staff of the Office of the General Counsel of the U.S. Nuclear Regulatory Commission and now at the Georgetown University Law Center, takes a reasoned and temperate approach to a subject that often arouses overheated fears. While pointing out that "virtually every legal doctrine this study addresses involves a recognition that individual rights must be balanced against social needs," he suggests that the greatest potential threat to civil liberties may be in the detention and treatment of suspects in a crisis atmosphere. The solution is to exercise "executive self-restraint."

Another good paper is contributed by Bertram Wolfe and Burton F. Judson, both of the General Electric Company, who discuss the economics of the back end of the nuclear fuel cycle. They recommend against reprocessing now, preferring retrievable long-term storage of spent fuel until the economics of plutonium recovery and use improves. They also support a U.S. spent-fuel take-back policy to discourage reprocessing abroad, and favor continued research and development of the breeder.

There are also some very poor papers, the worst of which has already been mentioned. Only occasionally does one encounter the shrill voice of the doctrinaire anti-nuke, the most blatant of whom is Daniel Hirsch, writing on the truck bomb and insider threats. He concludes that the only reason the NRC won't accept his judgement in preference to its own on the seriousness of these threats and the measures needed to protect against them is that it is in the pocket of the nuclear industry. One might have greater confidence in Mr. Hirsch's judgement if he didn't trot out that hoary old Brookhaven report on worst-case nuclear accidents, the notorious WASH-740.

Still, the selection of papers is not a bad one, and there is much useful and interesting information and analysis here for anyone interested in the subject, despite the fact that the basic premise of the book is, as I have stated, pure speculation. A reasonable balance of views has also been maintained. Considering that the Nuclear Control Institute has allied itself in the past with the most strident anti-nuclear groups, and no doubt will continue to do so when it suits its purposes, that's not a bad achievement.

Reviewed by
Eugene V. Weinstock
Brookhaven National Laboratory
Upton, New York U.S.A.

Leak Testing Is Automatic

Nuclear Sources and Services, Inc. offers an automatic leak testing service utilizing a kit developed for testing all types of sealed radioactive sources.

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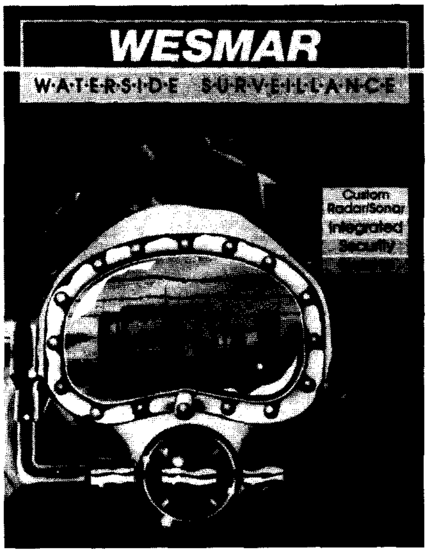
Waterside Security Brochure

Wesmar has a new brochure available that details their Waterside Intrusion Surveillance System, the ISS.

The brochure explains how Wesmar's combined radar and sonar technology provide an impenetrable blanket of highly sophisticated surveillance for security sensitive facilities with waterside access. The sophisticated technology in the ISS system represents new breakthroughs in radar.



Contact Wesmar Security Systems (206) 481-2296, or write at P.O. Box C3001, Bothell, Wash. 98041-3001.

Use of Crystals to Measure Radiation

Teledyne Isotopes makes available new literature on NaI (T1) Scintillation Detectors. The 24-page brochure explains the use of scintillation crystals to measure the spectrum and intensity of radiation. A series of photographs shows how crystals are grown and annealed for best transmission and resolution.

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For more information and a copy of the brochure, contact Teledyne Isotopes, 50 Van Buren Avenue, Westwood, N.J. 07675 (201) 664-7070.

Waste Management and Facilities Cleanup Literature

A new brochure, "Clearing the Way for American Business," describes the waste management and facilities cleanup services offered by Hampton-Clarke, Inc., Hackensack, N.J.

The brochure details the role of professional waste management in day-to-day business and the issues that must be addressed by manafacturers and handlers of hazardous materials, including regulatory complexity, selection of methods, government reporting and technical resources.

Also described are the company's two areas of service — waste stream management and compliance cleanup services.

For a copy, contact Hampton-Clarke, Inc., 171-173 Main Street, Hackensack, N.J. 07601 (201) 487-1133 or Sullivan & Fuchs International, Inc., authorized representatives, P.O. Box 255, Kenvil, N.J. 07847 (201) 584-4047.

CALENDAR

November 8-13, 1987
Joint Meeting of the American Nuclear Society and the Atomic Industrial Forum, San Francisco, Calif., U.S.A. *Sponsors*: American Nuclear Society, Atomic Industrial Forum *Contact*: Meetings Dept., American Nuclear Society, 555 N. Kensington Ave., La Grange Park, Ill. 60525, U.S.A.

November 11-14, 1987
California Radioactive Materials Management Forum's Fifth Annual Conference: The Future of Low-Level Waste Management and Disposal in California, and Working Together to Promote the Development of New LLW Disposal Facilities, Radisson Plaza Hotel, Manhattan Beach, Calif. *Sponsor:* Cal Rad *Contact:* Jean Parker, Cal Rad, P.O. Box 40279, San Francisco, Calif. 94140 U.S.A. Telephone (415) 647-3353.

November 3-6, 1987
INMM Technical Workshop, "Integrating the Elements of Delay, Intrusion Detection, and Entry Control into Physical Protection Systems," Y-O Ranch Hilton, Kerrville, Texas. *Sponsor:* Institute of Nuclear Materials Mangement *Contact:* Beth Perry, INMM, 60 Revere Dr., Suite 500, Northbrook, Ill. 60062 U.S.A. Telephone (312) 480-9573.

November 15-19, 1987
Joint meeting of the American Nuclear Society and the Atomic Industrial Forum, Los Angeles, Calif. U.S.A. *Sponsors*: ANS/AIF *Contact*: Meetings Dept., ANS, 555 North Kensington Ave., LaGrange Park, Ill. 60525 U.S.A.

November 29-December 4, 1987
3rd International Conference on Facility Operations — Safeguards Interface, San Diego, Calif. U.S.A. *Sponsor*: American Nuclear Society *Contact*: Dr. D. C. Camp, L-232, Safeguards Technology Prog., Lawrence Livermore National Laboratory, Livermore, Calif. 94550 U.S.A., Telephone (415) 422-6680.

November 30-December 5, 1987
International Conference on Waste Management, Hong Kong *Sponsors*: Nuclear Engineering Division, American Society of Mechanical Engineers, Fuel Cycle and Waste Management Division, American Nuclear Society, Atomic Energy Society of Japan, Canadian Nuclear Society, Chinese Nuclear Society, *et al.* *Contact*: Mr. Larry C. Oyen, Conference General Chairman, Sargent & Lundy, 55 E. Monroe St., Chicago, Ill. 60603 U.S.A. Telephone (312) 269-6750.

December 8-9, 1987
Fourth Annual Low-Level Radioactive Waste Conference, Ambassador West Hotel, Chicago, Ill. *Sponsor:* Illinois Department of Nuclear Safety *Contact:* Merry Carol Splan, IDNS 1035 Outer Park Dr., Springfield, Ill. 62074 U.S.A. Telephone (217) 785-9954.

January 20-22, 1988
INMM Spent Fuel Storage Seminar V, Loew's L'Enfant Plaza Hotel, Washington, D.C. *Sponsor*: Institute of Nuclear Materials Management *Contact*: Beth Perry, INMM, 60 Revere Drive, Suite 500, Northbrook, Ill. 60062 U.S.A., Telephone (312) 480-9573.

March 2-4, 1988
INMM Technical Workshop on Process Hold-up of Special Nuclear Materials, Ramada Hotel Rockville, Rockville, Md. U.S.A. *Sponsor*: Institute of Nuclear Materials Management *Contact:* Beth Perry, INMM, 60 Revere Drive, Suite 500, Northbrook, Ill. 60062 U.S.A., Telephone (312) 480-9573.

March 21-25, 1988
General Meeting of the American Physical Society, New Orleans, La. *Sponsor:* American Physial Society *Contact:* The American Physical Society, 335 East 45th St., New York, N.Y. 10017 U.S.A.

April 11-14, 1988
INMM Technical Workshop, "Security Personnel Training," Marriott Hotel, Albuquerque, N.M. *Sponsor:* Institute of Nuclear Materials Management *Contact:* Beth Perry, INMM, 60 Revere Dr., Suite 500, Northbrook, Ill. 60062 U.S.A. Telephone (312) 480-9573

May 23-25, 1988
International Conference on Transportation for the Nuclear Industry, Stratford-on-Avon, Warwickshire, U.K. *Sponsor:* Institution of Nuclear Engineers *Contact:* Mrs. S.M. Blackburn, Institution of Nuclear Engineers, Allen House, 1 Penerley Rd., London SE6 2LQ U.K. Telephone 01-698-1500.

June 12-17, 1988
Annual Meeting of the American Nuclear Society, San Diego, Calif. *Sponsor:* American Nuclear Society *Contact:* Meetings Dept, American Nuclear Society, 555 N. Kensington Ave., LaGrange Park, Ill. 60525 U.S.A.

July 26-29, 1988
INMM 29th Annual Meeting, Bally's Hotel, Las Vegas, Nev. U.S.A. *Sponsor:* Institute of Nuclear Materials Management *Contact:* Beth Perry, INMM, 60 Revere Dr., Suite 500, Northbrook, Ill. 60062 U.S.A. Telephone (312) 480-9573.

The events listed in this calendar were provided by Institute members or taken from widely available public listings. We urge INMM members, especially those from countries outside the United States, to send notices of other meetings, workshops or courses to INMM headquarters.

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